Implementation of a Weather Responsive Traffic Estimation and Prediction System (TrEPS) for Signal Timing at Utah DOT

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Final Report — July 2014
FHWA-JPO-14-140

U.S. Department of Transportation

Produced under Contract: DTFH61-12-D-00045 by Northwestern University and SAIC
U.S. Department of Transportation
Federal Highway Administration

Notice

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Technical Report Documentation Page

1. Report No.
FHWA-JPO-14-140

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Implementation of a Weather Responsive Traffic Estimation and Prediction System (TrEPS) for Signal Timing at Utah DOT

5. Report Date
July 2014

6. Performing Organization Code

7. Authors
Hani S. Mahmassani, Tian Hou, Jiwon Kim, Ying Chen, Zihan Hong, Hooram Halat, and Robert Haas

8. Performing Organization Report No.

9. Performing Organization Name and Address
SAIC
11251 Roger Bacon Drive
Reston, VA 20190

Northwestern University
633 Clark Street
Evanston, IL 60208

10. Work

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Federal Highway Administration
1200 New Jersey Ave., SE
Washington, DC 20590

13. Type of Report and Period Covered

14. Sponsoring Agency Code

15. Supplementary Notes
Roemer Alfelor, COTM

16. Abstract

The overall goal of this project is to integrate and operationalize weather-sensitive TrEPS models calibrated for the Salt Lake City region to support weather-responsive traffic signal timing implementation and evaluation in the Riverdale corridor in Ogden, UT. The TrEPS model selected for this study is DYNASMART-X, a real-time system that interacts continuously with loop detectors, roadside sensors and vehicle probes, providing real-time estimates of traffic conditions, network flow patterns and routing information. The results confirm the ability of the calibrated TrEPS to replicate observed traffic patterns in a large corridor network. With the current detectors and roadside sensors coverage, DYNASMART-X is able to use available real-time measurements to improve the quality of its estimation and future prediction, and thus provide a reliable basis for improved traffic management decisions that anticipate future conditions. This study successfully demonstrates a working TrEPS system installed at the UDOT Traffic Management Center and leverages the existing traffic detection installation to extract real-time traffic state variables as a real-time input to the system.

17. Key Words
weather-responsive traffic signal timing, real-time traffic estimation and prediction, Riverdale Corridor, DYNASMART

18. Distribution Statement
No restrictions.

19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No of Pages** 138	**22. Price** N/A

Acknowledgments

The study team would like to acknowledge the many individuals who have enthusiastically supported this study with their time, effort, and comments, and substantially contributed to its success. We are especially grateful to Roemer Alfelor of the US Dept. of Transportation for his leadership in defining and guiding the study, and facilitating many contacts with local and state agencies. Robert Haas of Leidos, Inc. provided helpful comments and support throughout the study.

From the Utah Department of Transportation (UDOT), we would like to particularly thank Robert Clayton, UDOT Traffic Operations Center Director, for supporting this project; and Mark Taylor, Traffic Signal Operations Engineer, for making this study possible, and for his continuing support and help in facilitating access to UDOT Traffic Operations Center facilities and data. His expert advice and generous insight throughout the duration of the study on all aspects related to signal operation were invaluable. We are also grateful to the other staff members of UDOT's Traffic Operations Center for all their help throughout the project, especially Jamie Mackey, Matt Luker, Shane Johnson, Derek Lowe, Peter Jager, Eric Rasband, Adam Lough and Carrie Jacobson.

Several students and research staff at the Northwestern University Transportation Center contributed to various aspects of the network development and modeling activities, especially Lan Jiang, Omer Verbas, and Ali Zockaie.

The authors remain solely responsible for all work, findings, conclusions and recommendations presented in this report.

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Executive Summary

The disruptive effect of inclement weather on the operation of traffic systems is well documented, including congestion, delay, diminished reliability of travel, and greater risk of crash involvement. The Federal Highway Administration (FHWA) Road Weather Management Program (RWMP) promotes research, development and deployment of weather responsive traffic management (WRTM) strategies and tools. Integrating weather information with traffic estimation and prediction tools has enabled the development and deployment of predictive weather-responsive traffic system management decision support capabilities. A core component to provide such capabilities is a weather-sensitive Traffic Estimation and Prediction System (TrEPS).

The overall goal of this project is to integrate and operationalize weather-sensitive TrEPS models calibrated for the Salt Lake City region to support weather-responsive traffic signal timing implementation and evaluation in the Riverdale corridor in Ogden, UT. It is the result of a collaborative effort between the US Department of Transportation, the Utah Department of Transportation (UDOT), Northwestern University Transportation Center, and Leidos, Inc. The TrEPS model selected for this study is DYNASMART-X, a real-time system that interacts continuously with loop detectors, roadside sensors and vehicle probes, providing real-time estimates of traffic conditions, network flow patterns and routing information.

The results confirm the ability of the calibrated TrEPS to replicate observed traffic patterns in a large corridor network. With the current detectors and roadside sensors coverage, DYNASMART-X is able to use available real-time measurements to improve the quality of its estimation and future prediction, and thus provide a reliable basis for improved traffic management decisions that anticipate future conditions. Both off-line and on-line tests conducted with the installation have showed and helped quantify the impacts of weather-responsive predictive signal control strategies in terms of improved service levels for users, through reduced congestion, lower waiting times, and smoother progression through the signalized intersections.

This study has successfully demonstrated a working TrEPS system installed at the UDOT Traffic Management Center. It has leveraged the existing traffic detection installation to extract real-time traffic state variables as a real-time input to the system. It has also demonstrated a Scenario Manager to simplify and facilitate the human operator’s interaction with the predictive system. As such, capabilities provided by the Scenario Manager can go a long way towards enhancing the acceptability, usability and effectiveness of weather-related traffic management approaches. Together, the TrEPS and Scenario Manager define the basic blocks of a decision support system for managing network operations.

While considerable progress has been accomplished to date on the successful deployment of weather responsive TrEPS in Utah, there remain several aspects that could be improved towards (1) enhancing the present functionalities as deployed, and (2) adding functionalities to address a wider range of management strategies. Accordingly, *our highest priority recommendation is to conduct an “assisted in-situ deployment” that would cover a period of 12 to 18 months*, to include several actual instances of inclement weather intervention. Several improvements to the present functionalities include (1) development of a base demand library, through application of clustering techniques, to provide a better starting point for greater accuracy of estimation and prediction application; (2) development of more complete libraries of signal timing plans for varying conditions (to include weather, demand levels as well as other special events); (3) testing a range of adaptive short-term correction mechanisms (STCC) to provides more accurate speed prediction; (4) consideration of additional real-time data sources (e.g. mobile data and social media) in the estimation and prediction process; (5) conducting a behavior tracking study that would allow observation of actual user responses to WRTM strategies, with particular focus on demand management strategies; and (6) development of a template for adoption by operating agencies of WRTM-sensitive TrEPS tools.

Examples of additional functionalities that could greatly benefit the realm of weather-related traffic management include (1) Integration of accident response functionality with WRTM in the real-time TrEPS platform; (2) enhancing the ability of the TrEPS simulation tools to assess the impact on relative safety of inclement weather, and correspondingly the impact of WRTM measures on that important system performance; (3) incorporating transit-related and multimodal capabilities in the interest of greater metropolitan mobility; (4) integration of fleet routing functionality, e.g. for snow removal equipment, preventive sanding and freeze-melting agent spreading, and other logistical processes; and (5) expanding the behavioral content of the WRTM capabilities to consider a range of interventions that target user behavior.

The study provides an important milestone in the development and application of methodologies to support WRTM. It brings WRTM applications into the mainstream of network modeling and simulation tools, and demonstrates the potential of WRTM for urban areas and states, as well as of TrEPS tools to evaluate and develop strategies on an ongoing basis, as part of the routine functions of planning and operating agencies.

Chapter 1. Introduction

1.1 Motivation and Objectives

The disruptive effect of inclement weather on traffic results in considerable congestion and delay, due to reduced service capacity, diminished reliability of travel, and greater risk of accident involvement. To mitigate the impacts of adverse weather on highway travel, the Federal Highway Administration (FHWA) Road Weather Management Program (RWMP) has been involved in research, development and deployment of weather responsive traffic management (WRTM) strategies and tools. Recognizing the importance of tying weather and traffic management together in areas exposed to adverse weather situations, many traffic management centers (TMC) have integrated weather information into their operations to support decisions regarding various WRTM strategies (Cluett et al., 2011). There are active efforts in states around the country to develop and implement a wide range of advisory, control and treatment strategies under the WRTM framework. A comprehensive overview of WRTM practices and a collection of case studies from municipal and state transportation agencies can be found in Gopalakrishna et al. (2011) and Murphy et al. (2012), respectively. There have also been efforts to integrate the weather effects into decision support tools allowing improved traffic state prediction and estimation (Mahmassani et al., 2009; Billot et al., 2010).

In order to reduce the impacts of inclement weather events and prevent congestion before it occurs, weather-related advisory and control measures could be determined for predicted traffic conditions consistent with the forecast weather, that is, anticipatory road weather information. A recent study (Cluett et al., 2011) identified levels of weather information integration in TMC operations and found many TMCs viewed the desirable level of decision support strategies as using “response scenarios through software supply potential solutions with projected outcomes” while the current levels were evaluated as “ad-hoc implementation of weather management strategies.” This calls for integrated real-time WRTM with a Traffic Estimation and Prediction System (TrEPS). Because the dynamics of traffic systems are complex, many situations necessitate strategies that anticipate unfolding conditions instead of adopting a purely reactive approach. Real-time simulation of the traffic network forms the basis of a state prediction capability that fuses historical data with sensor information, and uses a description of how traffic behaves in networks to predict future conditions, and accordingly develop control measures (Jayakrishnan et al. 1994; Mahmassani 1998, 2001). The estimated state of the network and predicted future states are given in terms of flows, travel times, and other time-varying performance characteristics on the various components of the network. These are used in the on-line generation and real-time evaluation of a wide range of measures, including information supply to users, VMS displays, coordinated signal timing for diversion paths, as well as weather-related interventions (through variable speed limits, advisory information, signal timing adjustments and so on).

In a previous FHWA-funded project, the research team developed and tested a methodology for incorporating weather impacts in Traffic Estimation and Prediction Systems (TrEPS) (Mahmassani et al., 2009). The project addressed both supply and demand aspects of the traffic response to adverse weather, including user responses to various weather-specific interventions such as advisory information and control actions. The methodology was incorporated and tested in connection with the DYNASMART-P simulation-based DTA system, thereby providing a tool for modeling the effect of adverse weather on traffic system properties and performance, and for supporting the analysis and design of traffic management strategies targeted at such conditions.

A recently completed follow-on study advanced the work towards actual implementation, through calibration, implementation and evaluation of weather-responsive traffic estimation and prediction systems, focusing on: (1) actual implementation and evaluation in the context of a regional planning and/or traffic operations agency to establish the model and calibrate it for application under a variety of local conditions and traffic patterns; and (2) development of weather-related traffic management and control measures, and interfacing their actual deployment and evaluation with the decision-support tools (Mahmassani et al. 2012). In that project, the team calibrated and tested weather-sensitive TrEPS models using the networks of four cities in the U.S., and connected the system to the real-time traffic data feeds for the Salt Lake City network. Through that effort, the team also established a real-time WRTM decision-support system, which integrates a new prototype Scenario Manager into the real-time TrEPS model. The Scenario Manager is a tool and interface for generating, preparing and managing various operational scenarios. For the proposed project, this system can be further extended and developed to help monitor, analyze and evaluate the effectiveness of the optimized signal timing parameters, including adverse weather signal timing plans.

The primary objectives of this project are to integrate and operationalize the weather-sensitive TrEPS models calibrated for Salt Lake City to support weather-responsive traffic signal timing implementation and evaluation in the Riverdale corridor. This entails working with the Utah Department of Transportation (UDOT) in deploying and utilizing the calibrated TrEPS models as a decision support tool for evaluating different possible signal timing strategies under weather-related scenarios, as well as for determining when to deploy such weather responsive signal timing plans in the corridor.

1.2 Background

It is shown that weather events could reduce the effectiveness of traffic signal timing plans designed for use in clear, dry pavement conditions, and a weather-responsive signal timing plan is desired when adverse weather events occur. Al-Kaisy and Freedman (2006) provide a review of previous studies that reported empirical observations on the effect of adverse and extreme weather conditions on signal timing input parameters. For instance, Agbolosu-Amison et al. (2005) investigated the effect of inclement weather on start-up lost time and saturation headway at a study site in northern New England. Maki (1999) reported a 40% reduction in average speed, 11% reduction in saturation flow rate, and 50% increase in start-up lost time due to adverse weather conditions at an arterial corridor in the Minneapolis–St. Paul Twin Cities metropolitan area of Minnesota. Perrin et al. (2001) investigated the change in traffic flow parameters under various weather severity levels at two intersections in Salt Lake City throughout the winter of 1999–2000.

Integration of Weather in TrEPS

A real-time traffic estimation and prediction system (TrEPS) is an essential methodology to enable implementation and evaluation of on-line traffic management, as it can incorporate field observations and traffic measures, as well as estimate and predict network states. DYNASMART-X (Mahmassani et al., 1998; Mahmassani and Zhou, 2005) and DynaMIT-R (Ben-Akiva et al., 2002), both developed largely under FHWA support, use a simulation-based dynamic traffic assignment (DTA) approach for real-time traffic estimation and prediction. As a deployable real-time system, a TrEPS recognizes that OD demand information and network conditions can typically only be reliably available for a short period of time in the future. One way to account for the uncertainty of future information is the rolling horizon (RH) approach (Peeta and Mahmassani, 1995). In a RH framework, new OD desires are being continuously estimated and corrected using the incoming stream of actual observations from different data sources. Based on the updated OD demand, a new network state is predicted for the next stage or prediction horizon. With every roll, the newly estimated variables overwrite the ones obtained from the previous stage, i.e. only the most up-to-date information is used.

As a state-of-the-art real-time TrEPS, DYNASMART-X is designed to continuously interact with multiple sources of real-time information, such as loop detectors, roadside sensors, and vehicle probes, which it integrates with its own model-based representation of the network traffic state. The system combines advanced network algorithms and models of trip-maker behavior in response to information in an assignment-simulation-based framework to provide, in real-time: (1) estimates of network traffic conditions, (2) predictions of network flow patterns and travel times over the near and medium terms in response to various contemplated traffic control measures and information dissemination strategies, and (3) anticipatory traveler and routing information to guide trip-makers in their travel (Dong, Mahmassani, and Lu, 2006). The system includes several functional modules (e.g. OD estimation, OD prediction, real-time network state simulation, consistency checking, updating and resetting functions, and network state prediction), integrated through a flexible distributed design that uses CORBA (Common Object Request Broker Architecture) standards, for real-time operation in a rolling horizon framework with multiple asynchronous horizons for the various modules (Mahmassani et al., 2004). The functionality of DYNASMART-X is achieved through judicious selection of modeling features that achieve a balance between representational detail, computational efficiency and input data requirements. Further detail on the structure and components of a TrEPS such as DYNASMART-X is available in the appropriate manuals.

In a previous FHWA project (Mahmassani et al., 2009), the principal supply-side and demand-side elements affected by adverse weather were systematically identified and modeled in the TrEPS framework. The models and relations developed were calibrated using available observations of traffic and user behavior in conjunction with prevailing weather events. The proposed weather-related features have been implemented in DYNASMART, and demonstrated through successful application to a real world network, focusing on two aspects: (1) assessing the impacts of adverse weather on transportation networks; and (2) evaluating effectiveness of weather-related advisory/control strategies in alleviating traffic congestion due to adverse weather conditions. The procedures implemented provide immediately applicable tools that capture knowledge accumulated to date regarding weather effects on traffic. The application to a real world network shows that the proposed model can be used to evaluate weather impacts on transportation networks and the effectiveness of weather-related variable message signs and other strategies (Dong et al., 2010).

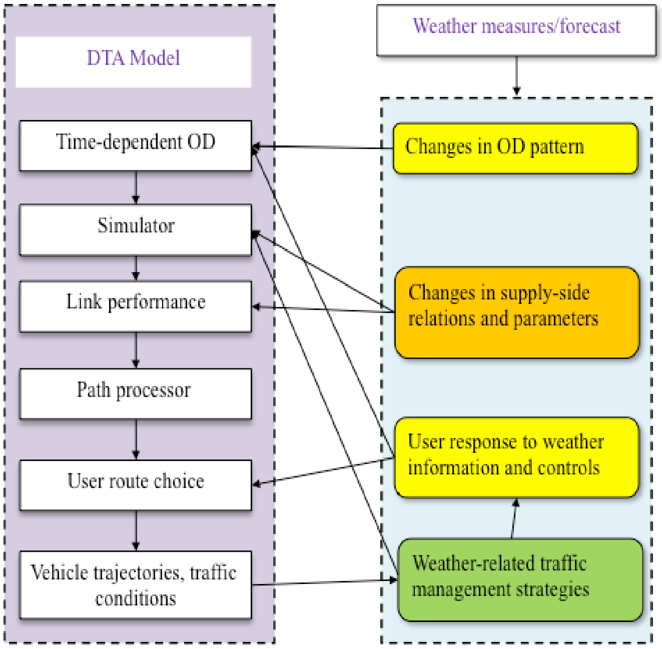
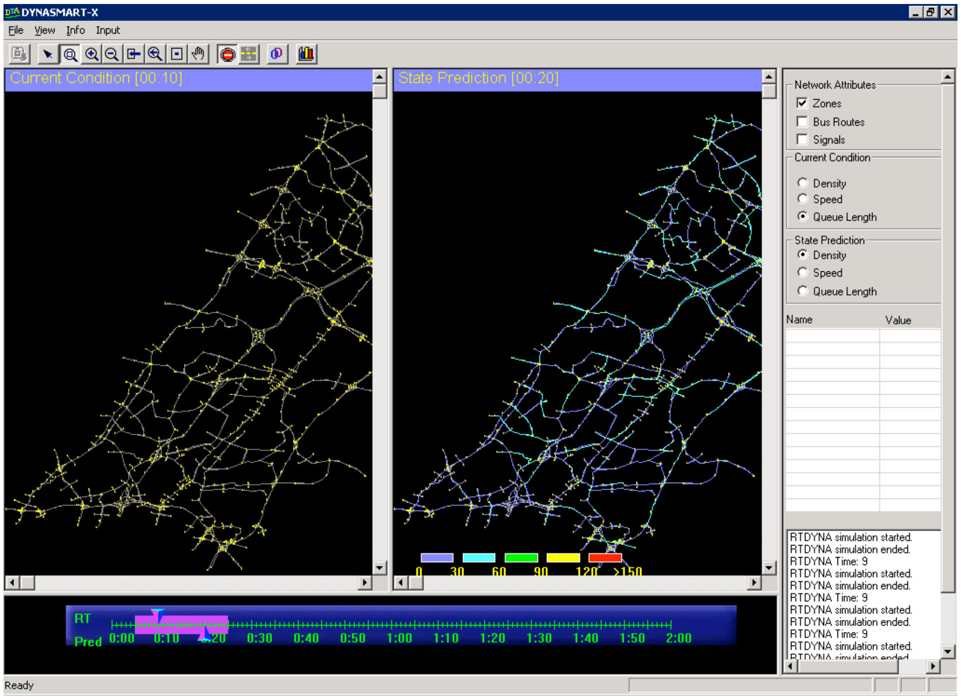


Figure 1-1. Incorporating Weather in DTA Model

(Source: Mahmassani et al., 2009)

In addition, the modular structure of the system enables consideration of multiple future scenarios simultaneously, as illustrated in the GUI snapshot in Figure 1-2 , for the Maryland CHART network (along I-95 between Washington, D.C. and Baltimore). In the left pane, the estimated traffic conditions are shown, in a manner that is completely synchronized with real time; i.e. it displays currently prevailing conditions, as seen by the model. In the right panes are displayed prediction results, using P-DYNA. For example, say that adverse weather has been anticipated, and this has been communicated to the TrEPS. A prediction is then generated for the traffic under that scenario, which would be viewed as the base case (using P-DYNA0). To evaluate the effectiveness of an intervention, say the display of various advisory messages, and dissemination of information through the internet and mass media, another scenario can be run in parallel, using another copy of P-DYNA (say P-DYNA1), to predict conditions with the intervention. Comparing the results of P-DYNA0 vs. P-DYNA1 would then allow the traffic manager to decide accordingly. This feature of DYNASMART-X, developed for the Maryland CHART network (Mahmassani et al., 2005), enables parallel execution of several alternative intervention scenarios in the context of real-time decision support for traffic management. Of course, various comparative statistics can also be displayed through the GUI.



Network Attributes
☑ Zones
☐ Bus Routes
☐ Signals

Current Condition
○ Density
○ Speed
● Queue Length

State Prediction
● Density
○ Speed
○ Queue Length

```
RTDYNA simulation started.
RTDYNA simulation ended.
RTDYNA Time: 9
RTDYNA simulation started.
RTDYNA simulation ended.
RTDYNA Time: 9
RTDYNA simulation started.
RTDYNA simulation ended.
RTDYNA Time: 9
RTDYNA simulation started.
RTDYNA simulation ended.
```

Figure 1-2. Graphic Windows for Current and Predicted Conditions

(Source: Mahmassani et al., 2005)

Weather-responsive Traffic Signal Control

Since weather events could reduce the effectiveness of traffic signal timing plans designed for use in clear, dry pavement conditions, a weather-responsive signal timing plan is desired when adverse weather events occur. Al-Kaisy and Freedman (2006) provide a review of previous studies that reported empirical observations on the effect of adverse and extreme weather conditions on signal timing input parameters. For instance, Agbolosu-Amison et al. (2004) investigated the effect of inclement weather on start-up lost time and saturation headway at a study site in northern New England. The study reveals that inclement weather has a significant impact on saturation headways (the highest increases in average saturation headway of 21%), particularly once slushy conditions are encountered. Maki (1999) reported a 40% reduction in average speed, 11% reduction in saturation flow rate, and 50% increase in start-up lost time due to adverse weather conditions at an arterial corridor in the Minneapolis–St. Paul Twin Cities metropolitan area of Minnesota. Perrin et al. (2001) investigated the change in traffic flow parameters under various weather severity levels at two intersections in Salt Lake City throughout the winter of 1999–2000. According to that study, the largest decrease in vehicle performance occurs when snow and slush begin to accumulate on the road surface. Saturation flows decrease by 20%, speeds decrease by 30%, and start-up lost times increase by 23%.

Along with studies that document observed effects of weather on signal timing parameters, empirical and simulation studies have been conducted to determine optimal signal plans during inclement weather. In a simulation study of a hypothetical arterial corridor with four successive intersections, Lieu and Lin (2004) assessed the benefits of retiming signal control under adverse weather conditions, and found that such benefits accrued primarily when traffic flows are moderately high. Maki (1999) performed field tests in an arterial corridor in the Minneapolis–St. Paul Twin Cities metropolitan area to evaluate the feasibility of implementing a coordinated traffic signal timing plan under adverse weather. Using field data on weather impacts and the Synchro signal optimization software, the study concluded that the "corridor operation was not radically affected by the adverse weather"; this is mainly "due to the fact that there are fewer vehicles to cause delay to during bad weather." Agbolosu-amison et el. (2005) designed and conducted several simulation experiments to understand the impact of different factors affecting the magnitude of the operational benefits of special timing plans for inclement weather. Two signalized arterial corridors were selected as case studies, and optimal signal plans were developed for six different weather and road surface conditions for each corridor by using four different simulation models (TRANSYT-7F, Synchro, CORSIM, and SimTraffic). To develop the weather-specific models, the saturation flow rate and free flow speed corresponding to each weather and road surface condition were coded by using reduction factors, which gave the percent reduction relative to the dry condition rate. The results show that signal retiming during inclement weather can result in significant operational benefits (as high as a 20% reduction in control delay in some cases). Al-Kaisy and Freedman (2006) present a set of recommended guidelines that relate weather conditions to operational impacts and potential benefits of weather-responsive signal timing through a systematic investigation considering isolated and coordinated signalized intersections in urban and suburban areas under various traffic conditions. Both operational and safety analyses were conducted in that investigation. Traffic signal optimization and microscopic traffic simulation were used to perform the operational analysis with average travel time as a performance measure. The adequacy of change and clearance intervals and the presence of dilemma zones were used as safety indicators at signalized intersections.

In practice, Goodwin (2003) and Goodwin et al. (2004) presented two case studies of weather-responsive signal control operations, which are intended to issue traffic signal preemption (e.g., to clear traffic from a beach or drawbridges) or to slow the overall intersection progression speed in response to poor road weather conditions. By selecting signal timing plans based upon prevailing weather conditions traffic managers can improve roadway mobility and safety. A description of weather-related parameters in simulation models and the benefits of weather-responsive signal timing are also discussed.

The above discussion of prior work reveals that efforts to devise weather-related traffic management systems have remained limited to a few countries and locales, though recognition for the need for such intervention continues to increase. Furthermore, the need for and potential usefulness of a weather-enabled TrEPS presents a significant though challenging opportunity for advancing the state of practice.

1.3 Conceptual Framework for Real-time Implementation

Traffic signal operations involve a large number of control parameters, where key parameters include cycle length, split and offset. In defining traffic signal timing for a particular time-of-day interval, these parameters are optimized and selected based on the expected traffic condition (e.g., historical average link speed) for the given interval. During inclement weather events, however, the actual traffic condition may largely deviate from the assumed condition and the control parameters must be adjusted to account for such changes in traffic characteristics. The real-time TrEPS can be effectively used in this regard as it provides the prediction of traffic conditions under an anticipated weather and the environment to test various alternative timing plans to mitigate its impact based on the most up-to-date network information. This project develops a framework and methods for integrating the TrEPS model into the UDOT's decision support system for determining traffic signal timing strategies during inclement weather events.

Figure 1-3 illustrates the overall architecture of the proposed decision support system. The system supports TMC signal systems operators' decision making in deploying alternative signal timing plans during a weather event by integrating three components into the TMC's signal operations, namely TrEPS, Scenario Manager and Scenario Library. The functionality and role of each component will be described iin greater detail in Chapter 5.

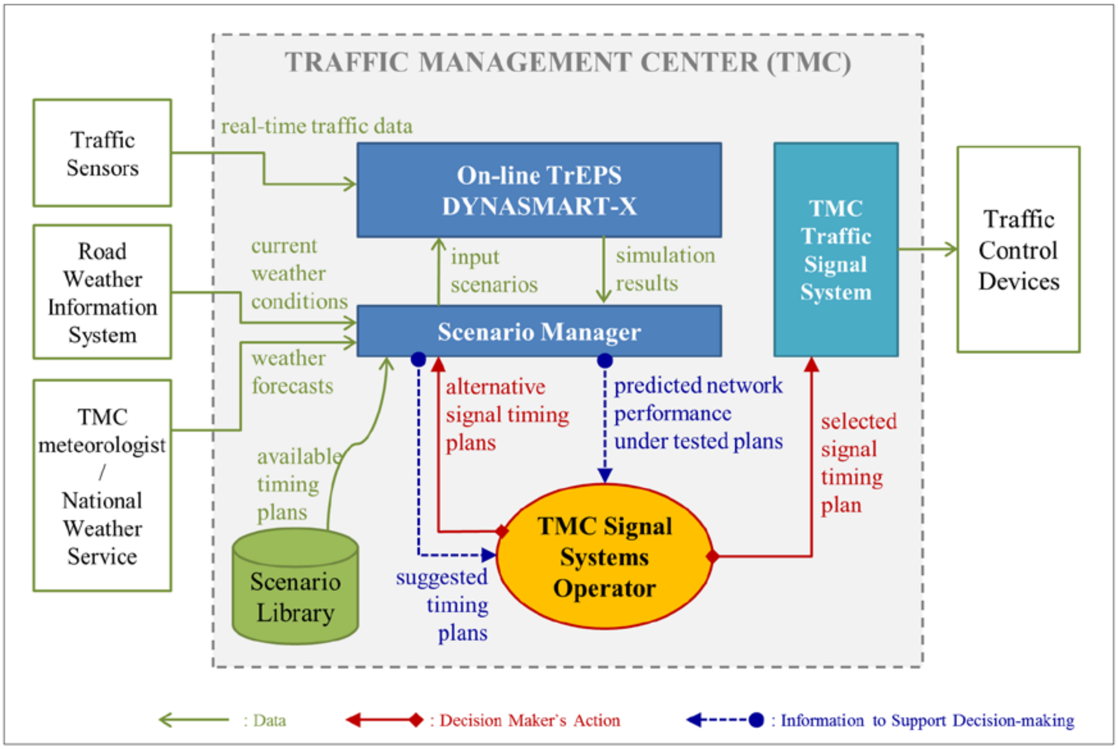


Figure 1-3. Framework of TrEPS-based Decision Support System for Weather-Responsive Traffic Signal Operations

1.4 Structure of Final Report

This report consists of six chapters. Following the introduction and objectives presented in this Chapter, Chapter 2 describes the Ogden-Salt Lake City test network and the available data, such as weather data, traffic data and signal timing data for the application and tests of interest to this project. Chapter 3 provides results of calibration and validation of Weather-responsive TrEPS model, especially focusing on (1) the speed-density relationship calibration, (2) the calibration of Weather Adjustment Factor (WAF) coefficients and (3) the estimation and prediction of time-dependent O-D trips in a procedure that combines detector link flow data with a prior static O-D matrix available for planning applications. Chapter 4 validates the calibrated off-line models and tests the effectiveness of various signal timing plans by conducting traffic simulation experiments with selected severe weather events. Chapter 5 describes the methodology about online Weather-Responsive TrEPS implementation and evaluates the estimation and prediction capabilities of weather responsive signal plan. Chapter 6 provides summary of findings and specific recommendations for further development and deployment.

Chapter 2. Study Network

2.1 Network Preparation

A full size Salt Lake City network, consisting of Ogden-Salt Lake City-Provo area, is available from a previous FHWA funded project (Implementation and Evaluation of Weather Responsive Traffic Estimation and Prediction System) (Mahmassani, et. al. 2012). To enhance the estimation and prediction performance of TrEPS during the implementation procedure, two smaller sub-networks are extracted from the original large Salt Lake City network, respectively for off-line and on-line testing purpose. Both two sub-networks cover the Ogden downtown area and Riverdale corridor, while the on-line version is chosen to be smaller than the off-line version in order to save computational power and at the same time maintain model accuracy. Figure 2-1 shows the relations between three different sizes of networks. We use Figure 2-1(b) as the sub-network for off-line calibration and implementation and Figure 2-1(c) as the sub-network for on-line tests.

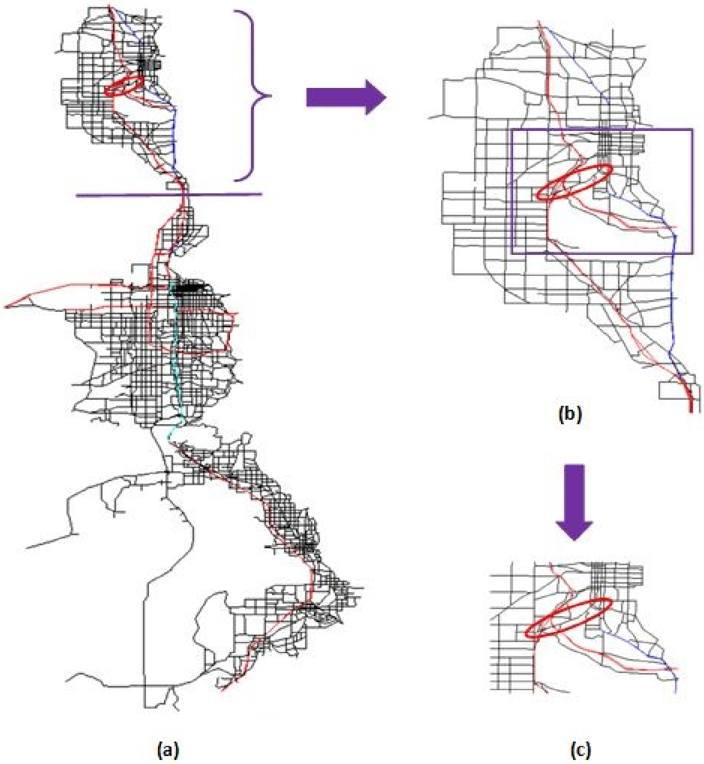


Figure 2-1. Study Networks: (a) Original Full Salt Lake City Network; (b) Extracted Sub-network for Off-line Tests; (c) Extracted Sub-network for On-line Tests

The main tool used for extracting network nodes, links and zones is DSPEd (DYNASMART-p Editor), which is a graphical user interface to facilitate the preparation of DYNASMART-p datasets. The procedures for network demand extraction are as follows:

Step 1. The new sub-network is defined by the sets of nodes *N*, links *A* and zones *Z* according to the new boundaries. This sub-network is designated as the internal network, whereas the remaining sections of the full network is designated as the external network.

Step 2. The original (external and internal) full Salt Lake City network is simulated in a dynamic simulation and assignment platform (DYNASMART-p) to obtain the following traffic flows:
  a. External to internal,
  b. Internal to external,
  c. Internal to internal,
  d. External to external (using the internal network),
  e. External to external (not using the internal network).

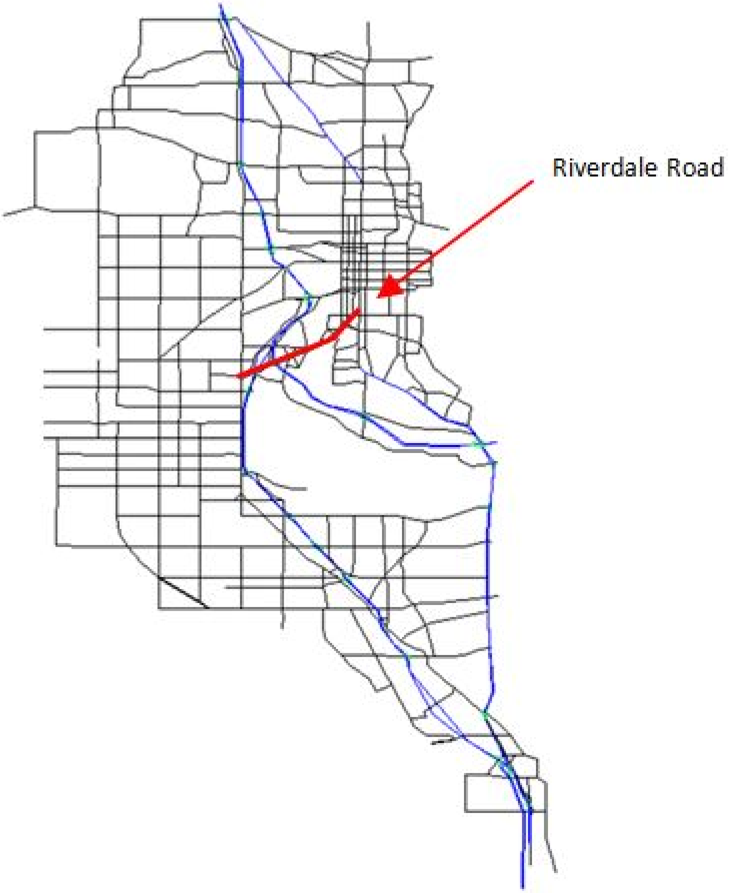
The sum of above five types of traffic flows define the time-dependent origin-destination (TDOD) matrix of the original network, whereas the sum of the first four types of flows define the TDOD matrix of the sub-network of interest. The outcome of this step is the TDOD matrix of the sub-network. Table 2-1 summarizes the characteristics of the original network and two extracted sub-networks.

Table 2-1. Comparison of full Salt Lake City Network and Extracted Sub-networks

Network	Original Salt Lake City Network	Off-line (Ogden) Network	On-line (Riverdale) Network
Description	▪ 17,947 links 791 freeways 136 highways 151 HOV facilities 576 ramps 16,293 arterials ▪ 8,309 nodes ▪ 2250 zones ▪ Demand period 6am -9pm	▪ 3,003 links 164 freeways 82 highways 102 ramps 2,655 arterials ▪ 1,289 nodes ▪ 423 zones ▪ Demand period 6am -9pm	▪ 1,168 links 80 freeways 31 highways 45 ramps 1,012 arterials ▪ 510 nodes ▪ 147 zones ▪ Demand period 24 hours

2.1.1 Off-line Network

The off-line sub-network includes the north part of the original Salt Lake City network, which is north to Centerville area. When the rough boundary of the sub-network is determined, the corresponding sub-network input files are prepared based on the new configuration, including a new OD matrix which reflect zones and travel demand only for the sub-network area. Figure 2-2 shows the configurations of the extracted Ogden network.



Network Description

- 3,003 links
    - 164 freeways,
    - 82 highways,
    - 102 ramps,
    - 2,655 arterials,
- 1,289 nodes,
- 423 zones,
- Demand period
    - 6 am - 9 pm

Figure 2-2. Network Configuration and Description for Extracted Ogden Network

2.1.2 On-line Network

The on-line sub-network includes the central part of the Ogden area, a rectangular shape network with the Riverdale corridor as the central part. The corresponding sub-network input files are prepared with the same extraction procedure as off-line subnetwork. A new OD matrix which reflects daily zones and travel demand only for the sub-network area is also prepared as a shiftable 24 hours OD matrix. Figure 2-3 shows the configuration of the extracted Riverdale sub-network.

Figure 2-3. Network Configuration and Description for Extracted Riverdale Network

2.2 Data Description

This section describes the weather and traffic data collection procedure for calibrating supply-side and demand-side parameters of weather-responsive TrEPS model.

2.2.1 Weather Data

Two sources of weather data are available in the study area: (a) Automated Surface Observing System (ASOS) stations located at local airport and (b) Road Weather Information System (RWIS) Stations installed along roadsides. Figure 2-4 presents the spatial distribution of these two types of weather stations within Ogden area.

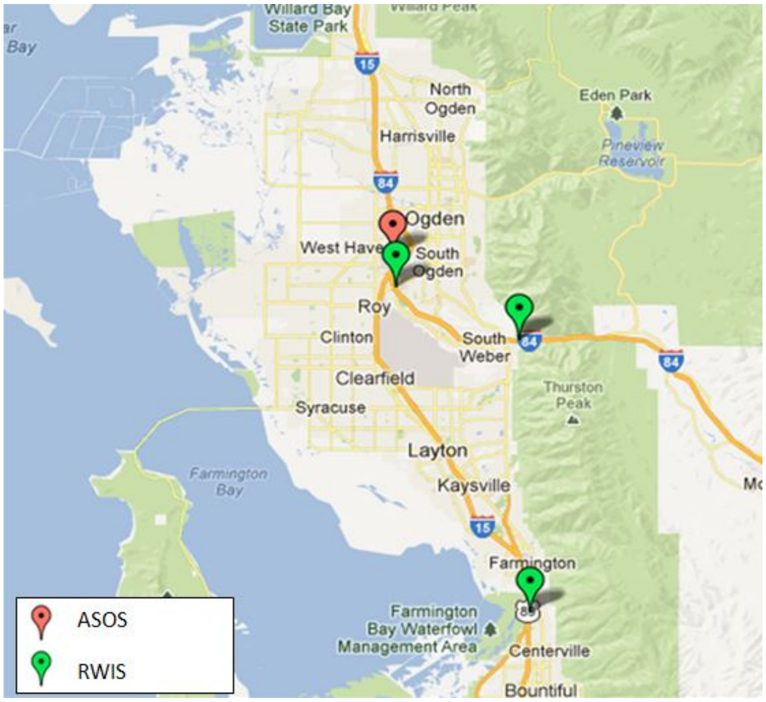


Figure 2-4. Spatial Distribution of Weather Stations in Ogden

(Map Source: Google)

The characteristics of the two different weather data sources are summarized here.

ASOS:

- Station located at Ogden-Hinckley Airport;
- 5-minute resolution;
- Data available from 2005;
- Data contains visibility, precipitation type, and precipitation intensity.

RWIS:

- Three stations in the network, one in South Weber, one in Centerville, and one at Riverdale Road;
- 10-minute resolution;
- Data at South Weber and Centerville stations are available from 2010; data at Riverdale station is available from 2013.
- Data at South Weber and Centerville stations contain precipitation intensity information only; data at Riverdale station contains visibility and precipitation. No station has precipitation type information.

A total number of seven weather categories are identified based on their precipitation type and the intensity. With a normal weather as the base case, in which no precipitation is observed, three levels of precipitation intensities (light, moderate and heavy) are used for both rain and snow.

Specifically, the seven different weather categories are: normal (no precipitation), light rain (intensity less than 0.01 in./hr), moderate rain (0.01 to 0.25 in./hr), heavy rain (greater than 0.25 in./hr), light snow (less than 0.05 in./hr), moderate snow (0.05 to 0.1 in./hr), and heavy snow (greater than 0.1 in./hr). The definitions for the intensity range are consistent with the literature (Hranac et al., 2006; Maze et al., 2006).

2.2.2 Traffic Data

The primary sources of traffic data for off-line supply and demand calibration are: (a) loop detectors installed on freeway lanes; and (b) radar detectors installed at arterial intersections. Freeway traffic data are obtained from Utah Freeway Performance Measurement System (PeMS) through website http://udot.bt-systems.com/. Five-minute aggregated data, from 2009 to present are available to download, which contain flow, speed, and occupancy information. In addition to freeway data, arterial traffic data are available to download from UDOT's Signal Performance Metrics website http://udottraffic.utah.gov/signalperformancemetrics/. Five-minute aggregated volume and speed data are mostly available starting from January 2013 to present. No density or occupancy data is available for arterial streets. For calibration purpose, stationary traffic flow assumption is made, to obtain density information using the following fundamental equation.

$$q = k \cdot v$$

where q = traffic flow (veh/hr);
k = traffic density (veh/mile);
v = space mean speed (mile/hr).

The characteristics of the two traffic data sources are summarized in Table 2-2. The geographic distribution of traffic detectors are shown in Figure 2-5 (maps were accessed in May 2013; additional arterial traffic data may became available as UDOT kept updating their database and signal performance metrics website). In selecting appropriate detector locations for model calibration, following criteria are mainly considered.

1. Choose detectors as close as possible to weather stations; no farther than 10 miles from ASOS or RWIS stations.
2. Remove the influence of other external events such as incidents/accidents, work zones and special planned events.
3. Include various facility/lane types and calibrate separately for each type. For instance, types can be classified into mainlines, on-ramps, off-ramps and HOV; and the number of lanes could be further distinguished.
4. Match traffic data with weather date to ensure sufficient amount of traffic data for every weather category, i.e., clear, light rain, moderate rain, heavy rain, light snow, median snow and heavy snow.

Table 2-2. Characteristics of Traffic Data Sources

Facility Type	freeway (I-15)	arterial
Data Source	PeMS	UDOT Signal Performance Metrics website
Resolution	5 minute	5 minute
Data Contents	flow, speed, occupancy	Flow, speed
Coverage Period	2009 - present	Jan, 2013 - present

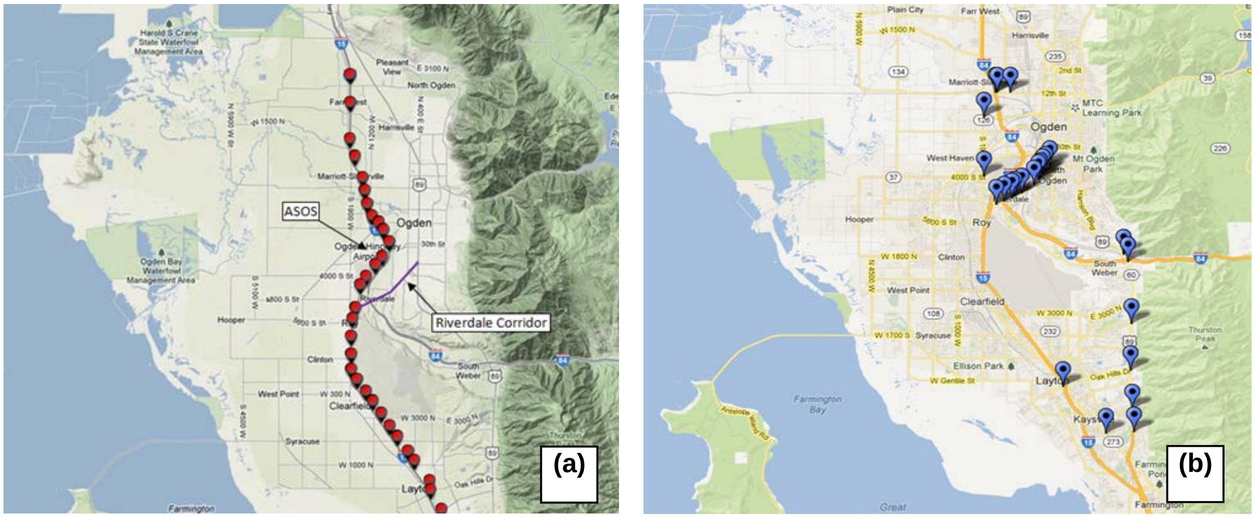


Figure 2-5. Locations of Traffic Detectors: (a) Freeways; (b) Arterials (accessed in May 2013)

(Map Source: Google)

2.2.3 Signal Timing Plans

A total number of 13 signalized intersections are identified along the Riverdale corridor in the study network. Their locations and ID's are presented in Figure 2-6. Based on the signal data obtained from UDOT, the signal plans implemented on Riverdale Road have both day-of-week and time-of-day variations. Table 2-3 to Table 2-5 summarize the 24-hour signal plans during weekdays, Saturdays, and Sundays, respectively. During the weekdays, traffic signals along this corridor are programmed to operate in an isolated (actuated control) mode during the night hours

(9:00 p.m. – 6:30 a.m.) and in a coordinated way in the day time. The isolated mode works very well with low volumes of traffic flow, as signal changes are driven by the vehicle loop detectors at the intersection. When there is major flow of traffic in one direction, the coordinated mode usually works better to allow the progression of traffic along the road. The coordination asks for two requirements: (i) a common cycle time among all coordinated signals; (ii) an offset between the start times of one intersection's main green movement and the next intersection’s main green movement, so that vehicles travelling at the designated speed leave the first intersection on the green will also reach the second intersection on green. The mechanism of coordinated signal plan is illustrated in Figure 2-7.

The actual timing plans of these 13 signals are provided by UDOT. The information are then converted into DYNASMART required simulation input format, which includes control type, number of phases, cycle length, maximum green, minimum green, offset, amber time, etc.

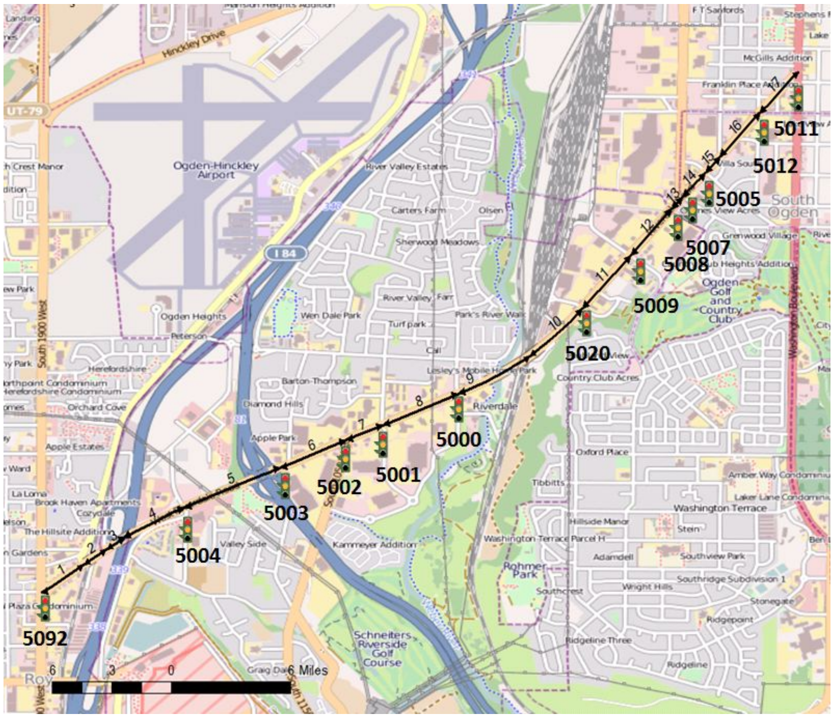


Figure 2-6. Signalized Intersections along Riverdale Road

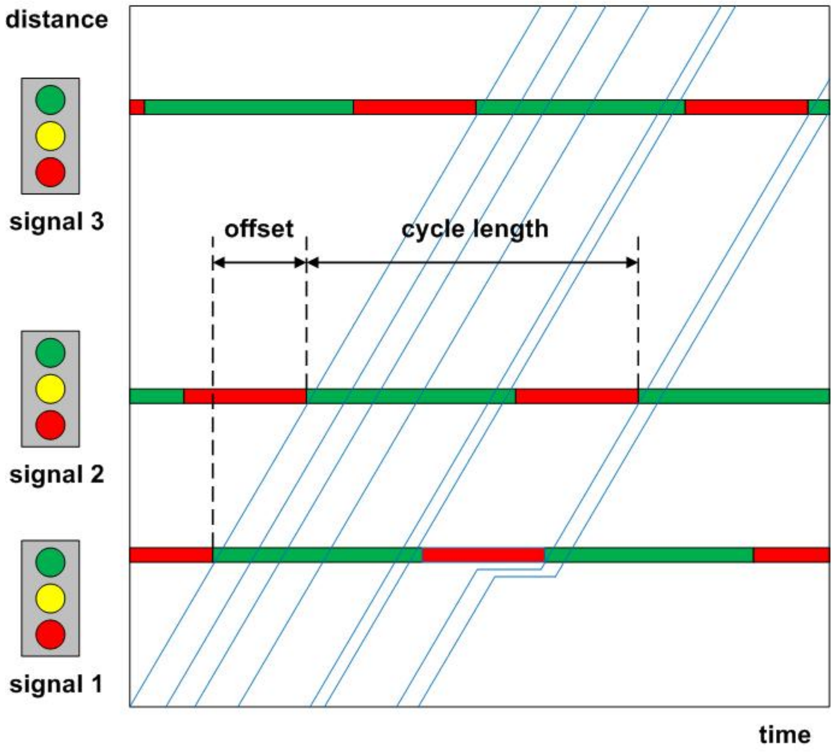


Figure 2-7. Coordinated Signal Plan with Offsets

Table 2-3. Riverdale Road Signal Plans during Weekdays

UDOT signal ID	Weekday Signal Timing Plan ID								
	6:00 - 6:30	6:30 - 7:00	7:00 - 9:00	9:00 - 11:00	11:00 - 13:00	13:00 - 15:00	15:00 - 18:30	18:30 - 21:00	21:00 - 24:00
5092	actuated	actuated	1	4	7	7	13	4	actuated
5004	actuated	1	1	4	4	13	13	19	actuated
5003	actuated	1	1	4	4	13	13	19	actuated
5002	actuated	1	1	4	4	13	13	19	actuated
5001	actuated	1	1	4	4	13	13	19	actuated
5000	actuated	1	1	4	4	13	13	19	actuated
5020	actuated	1	1	4	4	13	13	19	actuated
5009	actuated	1	1	4	4	13	13	19	actuated
5008	actuated	1	1	4	4	13	13	19	actuated
5007	actuated	1	1	4	4	13	13	19	actuated
5005	actuated	1	1	4	4	13	13	19	actuated
5012	actuated	1	1	4	4	13	13	19	actuated
5011	actuated	actuated	1	4	7	7	13	4	actuated

Source: Utah DOT

Table 2-4. Riverdale Road Signal Plans during Saturdays

UDOT signal ID	Saturday Signal Timing Plan ID					
	0:00 - 8:00	8: 00 - 10:00	10:00 - 18:30	18:30 - 21:00	21:00 - 22:00	22:00 - 24:00
5092	actuated	4	4	4	4	actuated
5004	actuated	1	13	19	actuated	actuated
5003	actuated	1	13	19	actuated	actuated
5002	actuated	1	13	19	actuated	actuated
5001	actuated	1	13	19	actuated	actuated
5000	actuated	1	13	19	actuated	actuated
5020	actuated	1	13	19	actuated	actuated
5009	actuated	1	13	19	actuated	actuated
5008	actuated	1	13	19	actuated	actuated
5007	actuated	1	13	19	actuated	actuated
5005	actuated	1	13	19	actuated	actuated
5012	actuated	1	13	19	actuated	actuated
5011	actuated	4	4	4	4	actuated

Source: Utah DOT

Table 2-5. Riverdale Road Signal Plans during Sundays

UDOT signal ID	Sunday Signal Timing Plan ID		
	0:00 - 10:00	10:00 - 21:00	21:00 - 14:00
5092	actuated	4	actuated
5004	actuated	4	actuated
5003	actuated	4	actuated
5002	actuated	4	actuated
5001	actuated	4	actuated
5000	actuated	4	actuated
5020	actuated	4	actuated
5009	actuated	4	actuated
5008	actuated	4	actuated
5007	actuated	4	actuated
5005	actuated	4	actuated
5012	actuated	4	actuated
5011	actuated	4	actuated

Source: Utah DOT

The timing plans listed in the above tables are called based signal plans, which are used during clear weather conditions when there is no rain or snow precipitation. The offsets of based signal plans are designed based on the assumption that the prevailing speed along the Riverdale corridor is the same as the posted speed limit, i.e., 45 mph between signal 5092 and signal 5020, and 35 mph between signal 5020 and signal 5011.

In addition to base signal plans, several sets of weather-responsive coordinated timing plans are also designed by UDOT to accommodate adverse weather scenarios. Similar to base plan, weather-responsive plans are also designed for different combinations of day-of-week and time-of-day. For instance, the day-of-week variable can have three states: weekday, Saturday and Sunday. For a given weekday and time-of-day, three different adverse weather conditions are considered in terms of their impacts on link speeds: 5 mph, 10 mph and 15 mph reductions in normal link speeds, i.e., the posted speed limits, and the associated signal timing plan is specified (e.g. plan ID 58, 57 and 56, respectively). For a given weekday, four different time-of-day states are defined: AM peak (6:30 - 9:00), AM off-peak (9:00 - 13:00), PM off-peak (13:00 - 18:60) and PM peak (18:30 - 21:00). Figure 2-8 shows a tree structure defining a list of plans for each case. It is noted that weather-responsive plans follow the same parameters (e.g., cycle length and splits) specified in the base plan (i.e., plan 1 for normal weather condition), and only offsets are adjusted to reflect the assumed speed reductions due to weather. The figure only shows the Weekday AM peak as an example; the plans for other days and times are listed in the previous tables.

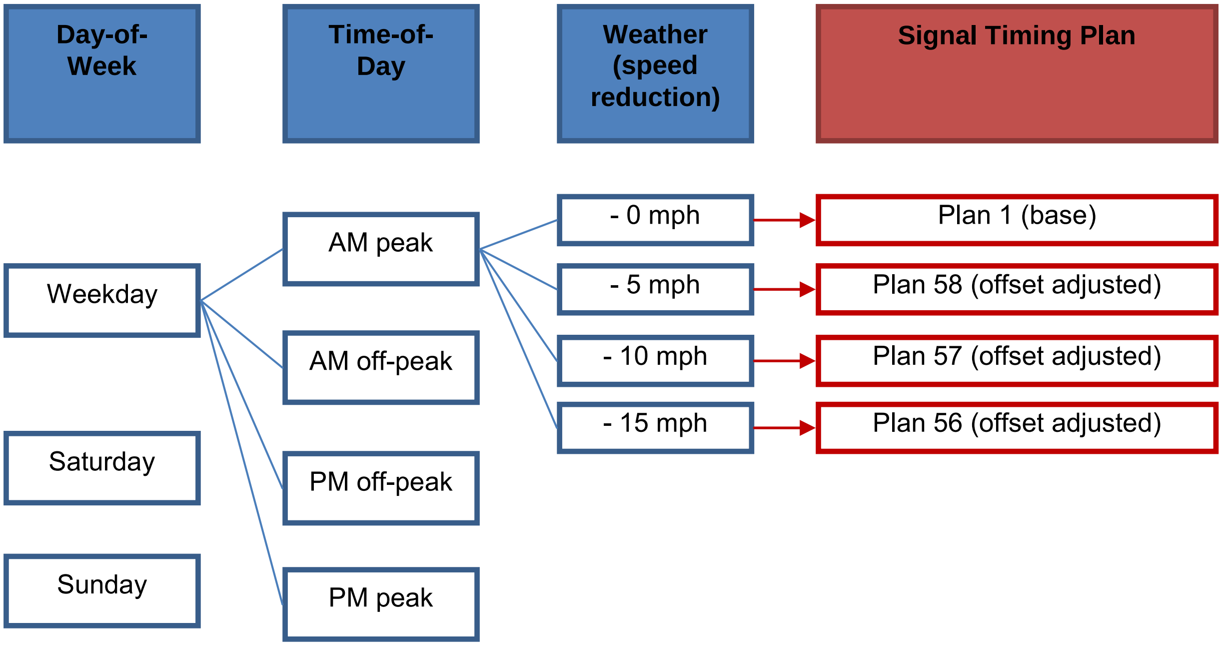


Figure 2-8. Structure of Signal Timing Plan Action Set

Chapter 3. Calibration and Validation of Weather-Responsive TrEPS Model

The supply-side parameter calibration for this study includes two parts: calibrating parameters in the traffic flow model (i.e., modified Greenshields models) and estimating the weather adjustment factor (WAF). First, the traffic flow model is calibrated under different weather conditions based on pre-defined weather categories. The calibrated parameters for the normal weather are supplied to DYNASMART as the base case traffic flow model. The parameters under different weather conditions are used to obtain the weather adjustment factor (WAF), which is a reduction factor that reflects the weather impact on each traffic flow parameter. The detailed calibration procedure and the results are discussed in the following sections.

3.1 Calibration of Traffic Flow Model Parameters

3.1.1 Calibration Procedure

Two types of modified Greenshields models are used in DYNASMART for traffic propagation (Mahmassani and Sbayti, 2009). Type 1 is a dual-regime model in which constant free-flow speed is specified for the free-flow conditions (1st regime) and a modified Greenshield model is specified for congested-flow conditions (2nd regime) as shown in Figure 3-1.

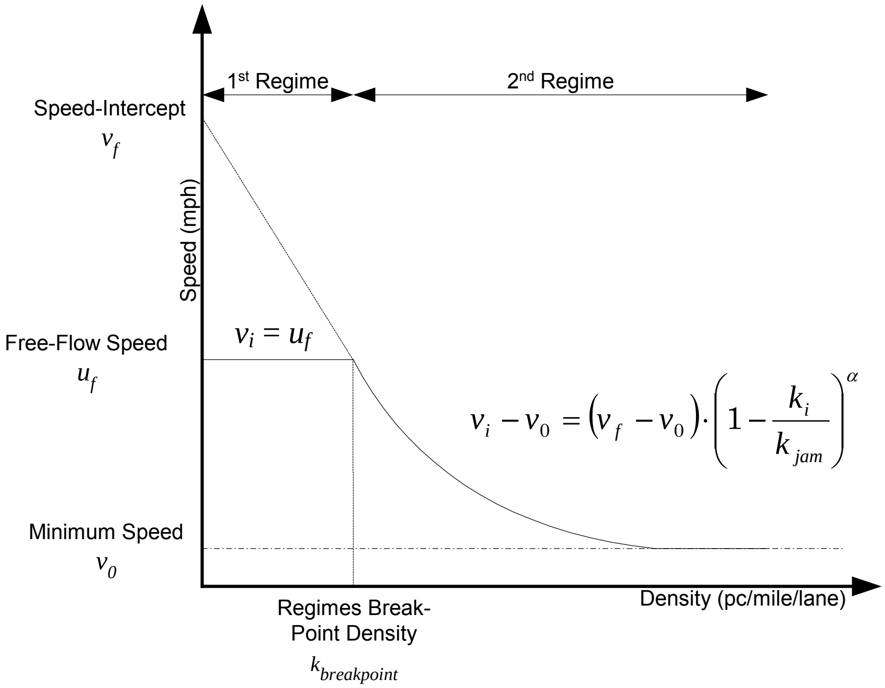


Figure 3-1. Type 1 Modified Greenshield Model (dual-regime model)

In mathematical terms, the Type 1 modified Greenshields is expressed as follows:

$$v_i = \begin{cases} u_f & 0 < k_i < k_{breakpoint} \\ v_0 + (v_f - v_0)\left(1-\frac{k_i}{k_{jam}}\right)^{\alpha} & k_{breakpoint} < k_i < k_{jam} \end{cases}$$

where v_i = speed on link *i*

v_f = speed-intercept

u_f = free-flow speed on link *i*

v_0 = minimum speed on link *i*

k_i = density on link *i*

k_{jam} = jam density on link *i*

α = power term

$k_{breakpoint}$ = breakpoint density

Type 2 uses a single-regime to model traffic relations for both free- and congested-flow conditions as shown in Figure 3-2.

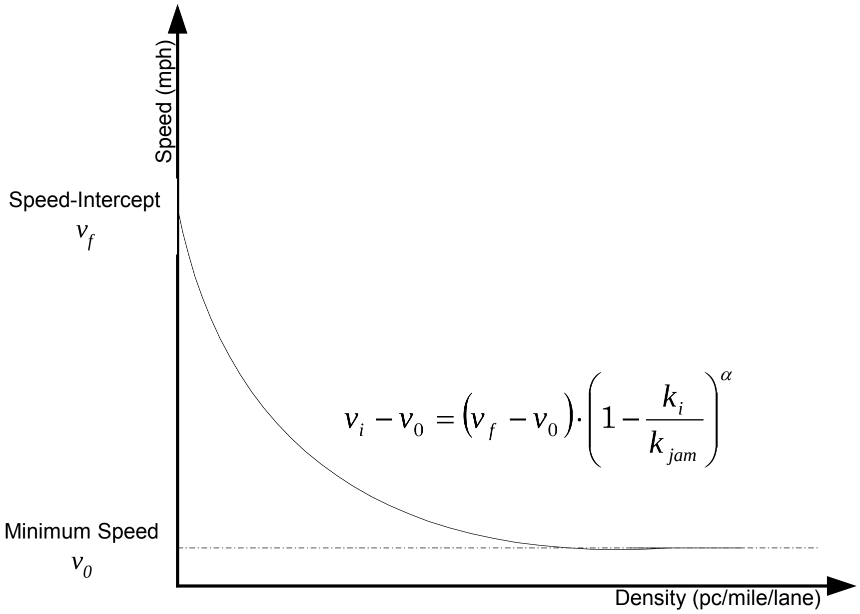


Figure 3-2. Type 2 Modified Greenshield Model (single-regime model)

In mathematical terms, the type 2 modified Greenshield is expressed as follows:

$$v_i - v_0 = (v_f - v_0)\cdot\left(1-\frac{k_i}{k_{jam}}\right)^{\alpha}$$

Dual-regime models are generally applicable to freeways, whereas single-regime models apply to arterials. The reason why a two-regime model is applicable for freeways in particular is that freeways have typically more capacity than arterials, and can accommodate dense traffic (up to 2300 pc/hr/ln) at near free-flow speeds. On the other hand, arterials have signalized intersections, meaning that such a phenomenon may be short-lived, if present at all. Hence, a slight increase in traffic would elicit more deterioration in prevailing speeds than in the case of freeways. Therefore, arterial traffic relations are better explained using a single-regime model. All the traffic data used in this study come from loop detectors installed on highways. Therefore the dual-regime model is chosen to fit the collected historical data. For the dual regime model, the total six parameters are calibrated, namely, breakpoint density (k_{bp}), free flow speed (u_f), speed-intercept (v_f), minimum speed (v_0), jam density (k_{jam}), and the shape parameter (α). For the single regime model, only three parameters including speed-intercept (v_f), minimum speed (v_0), and the shape parameter (α) are used.

After traffic data are categorized based on weather, parameters in the modified Greenshields model are calibrated for each weather condition using a nonlinear regression approach. The following steps describe the procedures for calibrating the dual-regime model, which is used in cases when traffic data are collected from freeways.

Step 1. Plot the speed vs. density graph, and set initial values for all the parameters, i.e. breakpoint density (k_{bp}), speed-intercept (v_f), minimum speed (v_0), jam density (k_{jam}), and the shape parameter (α), based on observations.

Step 2. For each observed density (k_i), calculate the predicted speed value ($\hat{v}_i$) using Eq. (2) and the parameters initialized in Step 1.

Step 3. Compute the squared difference between observed speed value (v_i) and predicted speed value ($\hat{v}_i$), for each data point, and sum the squared error over the entire data set.

Step 4. Minimize the sum of squared error obtained in Step 3, by changing the values of model parameters.

3.1.2 Calibration Results

To fully utilize the all the available weather and traffic data sources, ASOS weather data is used in conjunction with PeMS traffic data to calibrate models on highways, while RWIS weather data is used in conjunction with arterial traffic data to calibrate models for arterial streets. Although the RWIS weather data does not provide precipitation type information, but only precipitation intensity; it is used with the assistance of ASOS weather data to identify the precipitation type, i.e., rain and snow. As mentioned before, seven different weather conditions are identified in year 2011 and 2012 using weather data, namely, clear (no precipitation), light rain, moderate rain, heavy rain, light snow, moderate snow, and heavy snow. Following the procedures described in the previous section, modified Greenshields models under different weather conditions are calibrated for several selected detector locations.

Figure 3-3 presents the calibration results of freeway traffic flow models on I-15. Two detector locations (I-15@Park Ln, and I-15@Glover Ln) are selected for calibration. At each location, traffic data from north- and south-bound directions are obtained. These two locations are chosen because they have sufficient traffic data to cover different level of densities under all seven different weather conditions. The results are consistent with findings in previous studies (Mahmassani, et. al. 2012). The calibrated models will be used directly for the two major highways in Ogden area, i.e., I-15 and I-84.

Figure 3-4 shows the calibration results of arterial traffic flow models using volume and speed data obtained from UDOT. Four locations (intersection 5000, 5002, 5008, and 5020) are chosen along the Riverdale Road for arterial traffic model calibration, subject to the availability and quality of data. Same as freeway models, seven different weather conditions are identified.

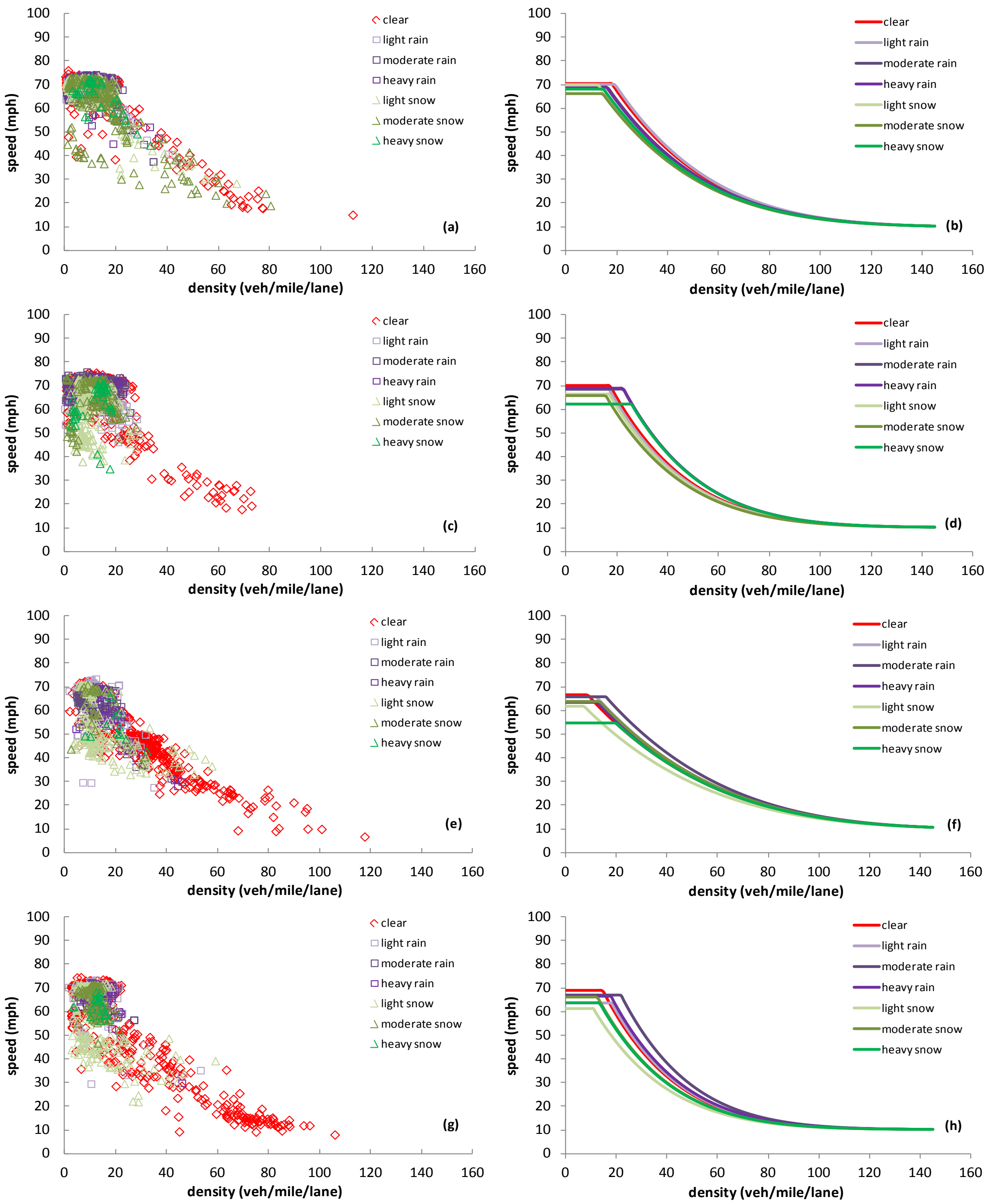


Figure 3-3. Raw Traffic Data and calibrated speed-density curves under Different Weather Conditions using PeMS Freeway Data: (a,b) I-15 NB @ Park Ln; (c,d) I-15 SB @ Park Ln; (e,f) I-15 NB @ Glover Ln; (g,h) I-15 SB @ Glover Ln;

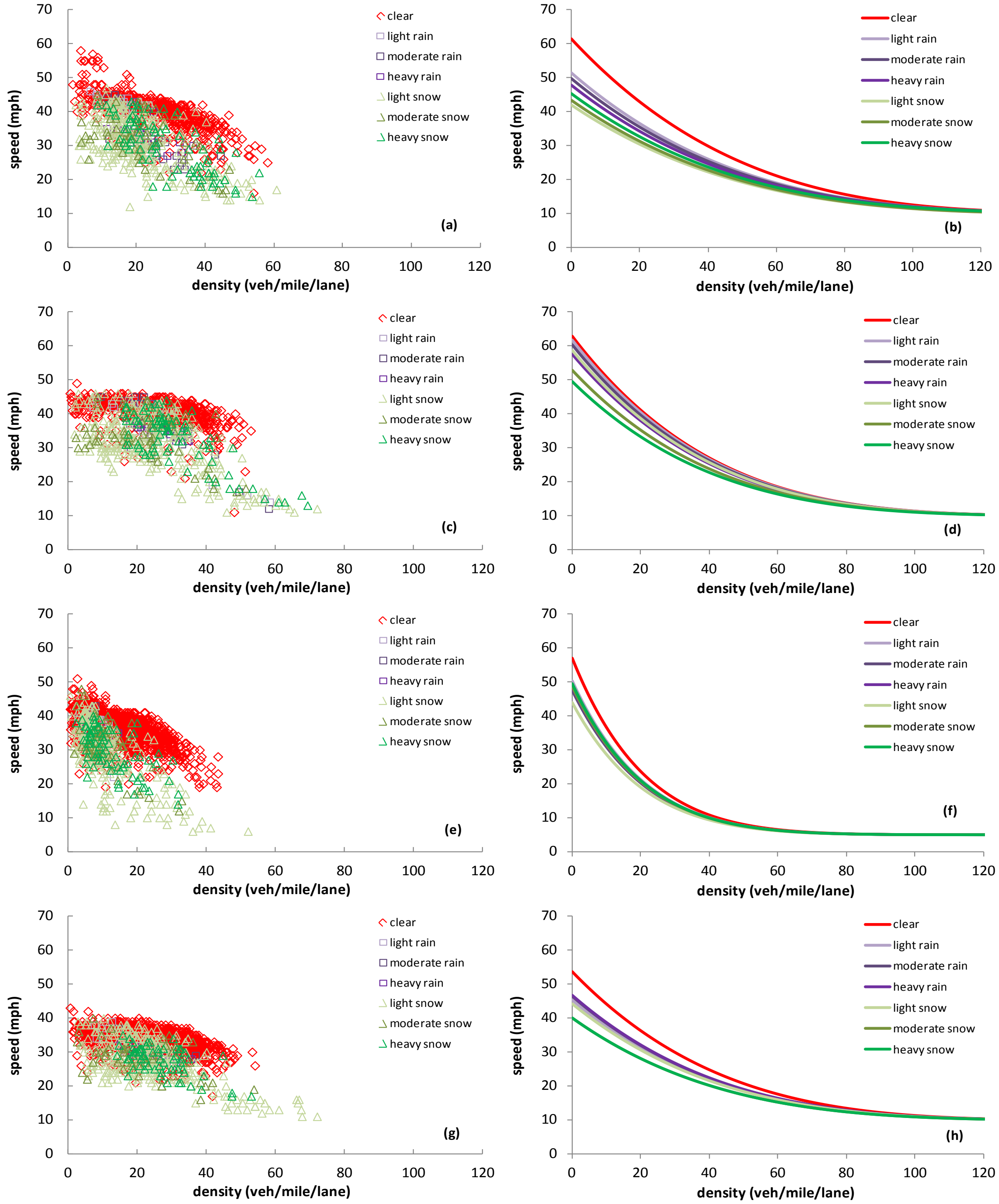


Figure 3-4. Raw Traffic Data and Calibrated Speed-Density Curves under Different Weather Conditions using UDOT Arterial Traffic Data: (a,b) Riverdale Road signalized intersection 5000 WB; (c,d) Riverdale Road signalized intersection 5020 EB; (e,f) Riverdale Road signalized intersection 5002 WB; (g,h) Riverdale Road signalized intersection 5008 WB;

3.2 Weather Adjustment Factor (WAF)

3.2.1 Calibration Procedure

In DYNASMART, supply-side parameters that are expected to be affected by the weather condition are identified as presented in Table 3-1. The inclement weather impact on each of these parameters is represented by a corresponding weather adjustment factor (WAF) such that

$$f_i^{Weather\ Event} = F_i \cdot f_i^{Normal}$$

where $f_i^{Weather\ Event}$ denotes the value of parameter *i* under a certain weather event, f_i^{Normal} denotes the value of parameter *i* under the normal condition and F_i is the WAF for parameter *i*.

Table 3-1. Supply Side Properties related with Weather Impact in DYNASMART

Category	*i*	Parameter Description
Traffic flow model[1]	1 2 3 4 5	Speed-intercept (mph)[1] Minimal speed (mph) Density break point (pcpmpl)[1] Jam density (pcpmpl) Shape term alpha
Link performance	6 7 8	Maximum service flow rate (pcphpl or vphpl) Saturation flow rate (vphpl) Posted speed limit adjustment margin (mph)
Left-turn capacity	9	g/c ratio
2-way stop sign capacity	10 11 12	Saturation flow rate for left-turn vehicles (vphpl) Saturation flow rate for through vehicles (vphpl) Saturation flow rate for right-turn vehicles (vphpl)
4-way stop sign capacity	13 14 15	Discharge rate for left-turn vehicles (vphpl) Discharge rate for through vehicles (vphpl) Discharge rate for right-turn vehicles (vphpl)
Yield sign capacity	16 17 18	Saturation flow rate for left-turn vehicles (vphpl) Saturation flow rate for through vehicles (vphpl) Saturation flow rate for right-turn vehicles (vphpl)

[1] Only available in dual-regime model.

Source: Dynasmart User Guide, 2005

The WAF is assumed to be a linear function of weather conditions, and is expressed in the following form:

$$F_i = \beta_{i0} + \beta_{i1} \cdot v + \beta_{i2} \cdot r + \beta_{i3} \cdot s + \beta_{i4} \cdot v \cdot r + \beta_{i5} \cdot v \cdot s$$

where

F_i = weather adjustment factor for parameter *i*,
v = visibility (mile),
r = precipitation intensity of rain (inch/hr),
s = precipitation intensity of snow (inch/hr), and
$\beta_{i0}, \beta_{i1}, \beta_{i2}, \beta_{i3}, \beta_{i4}, \beta_{i5}$ = coefficients to be estimated.

Thus, once the speed-density functions for different weather conditions (i.e., normal, light rain, moderate rain, etc) are obtained for each network, a multiple linear regression analysis is performed to obtain the WAF for each parameter based on observed rain intensities, snow intensities and visibility levels. A detailed description of the calibration procedure is provided below.

The calibration of WAF coefficients includes the following steps.

Step 1. For each weather condition c, calculate the WAF for each parameter i such that $F_i = f_i^c / f_i^{Base} \quad \forall c$, where Base denotes the normal (no precipitation) weather.

Step 2. Assign F_i to corresponding traffic-weather data such that each observation has a structure similar to the following:
{time, traffic data (volume, speed, density), weather data(v, r, s), WAF(F_1,⋯,F_i)}.

Step 3. For each parameter *i*, estimate coefficients $\beta_{i0}, \beta_{i1}, \beta_{i2}, \beta_{i3}, \beta_{i4}, \beta_{i5}$ by conducting the regression analysis, given F_i as a dependent variable and weather data (v, r, s) for all observations as independent variables.

Note that not all of the parameters listed in Table 3-1 can be calibrated using the available traffic data. Some parameters could be inferred from other calibrated parameters. For example, link characteristics such as posted speed limit adjustment are inferred from the calibrated traffic flow model parameters, while left turn, stop sign, and yield sign capacities are inferred from maximum observed flow rate as a surrogate of capacity.

3.2.2 Calibration Results

Based on the calibrated traffic model of the network, it is found that the maximum service flow rate (q_{max}), shape parameter (α), and free flow speed (u_f), are sensitive to both rain and snow intensities. However, as minimum speed and jam density turn out to be insensitive to weather conditions from the calibration results, WAF for those parameters are assumed as 1, which indicates these are not affected by weather conditions. In addition, the shape parameter alpha is also fixed as 1 based on the observations that the both speed-intercept (v_f) and alpha(α) govern the shape of the curve and controlling for one variable results in a more consistent and meaningful pattern on the other allowing a better interpretation.

As the rain or snow intensity increases, maximum flow rate, speed intercept and free flow speed are reduced. It is also found that increasing snow intensity reduces breakpoint density; however, the effect of rain on it is opposite with that of snow, i.e., when rain intensity increases, the breakpoint density also increases. Similar findings are present in the literature (Ibrahim and Hall, 1994; Rakha et al., 2008; Mahmassani, et. al. 2012; Hou et al., 2013). The calibration results of WAF coefficients are provided in Table 3-2. As a summary, the effects of the rain intensity and the snow intensity on different traffic flow model parameters are presented in Figure 3-5 and Figure 3-6, respectively.

Table 3-2. Calibration Results of WAF

Parameter	β_0	β_1	β_2	β_3	β_4	β_5	R^2
q_{max}	0.9540	0.0040	-0.2884	-2.8399	-0.0952	-0.1350	0.8956
v_f	0.8859	0.0106	0.2616	-1.3015	-0.1247	-0.3831	0.7656
k_b	0.9031	0.0097	0.9664	-1.1047	-0.1273	-0.4347	0.7550
u_f	0.9246	0.0066	0.0016	-1.0522	-0.0814	-0.2168	0.8272

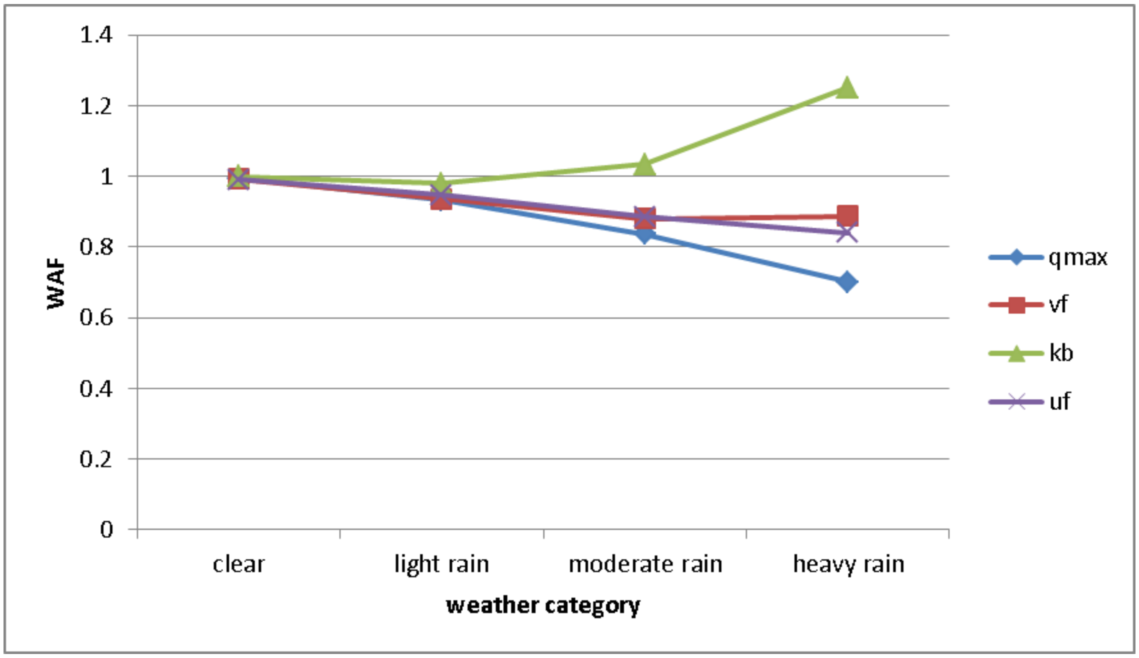


Figure 3-5. Effect of Rain Intensity on Weather Adjustment Factors for: maximum flow rate (q_{max}); speed intercept (v_f); breakpoint density (k_{bp}); and free flow speed (u_f)

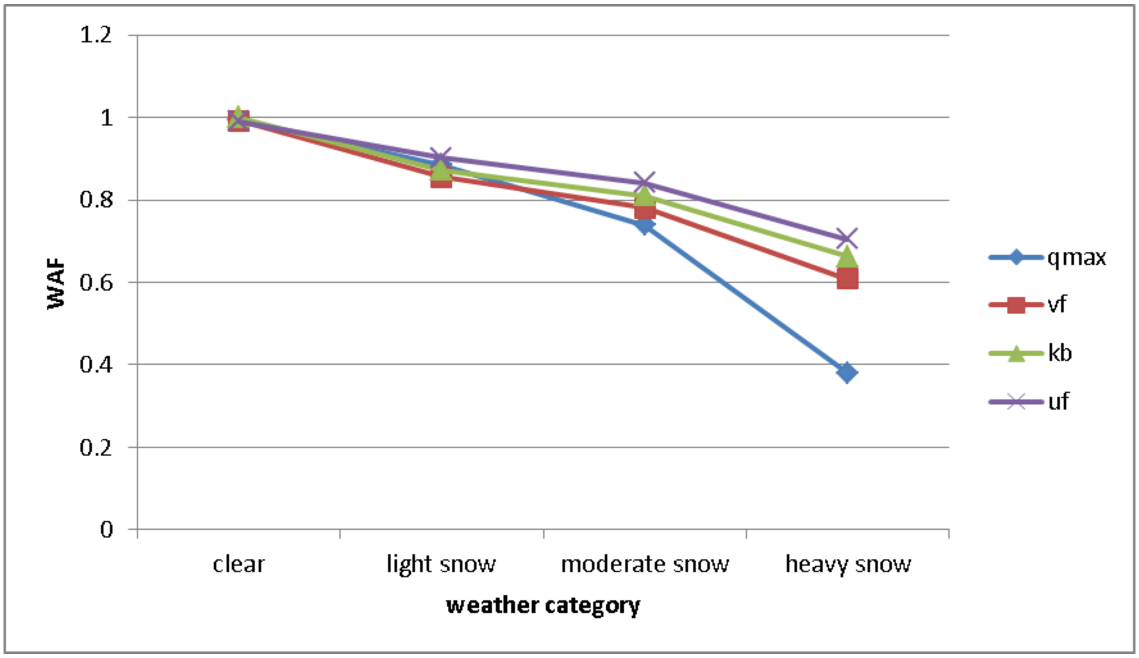


Figure 3-6. Effect of Snow Intensity on Weather Adjustment Factors for: maximum flow rate (qmax); speed intercept (vf); breakpoint density (kbp); and free flow speed (uf)

3.3 Estimation of Time-dependent OD Matrix

3.3.1 Estimation Procedure

Time-dependent (or dynamic) origin-destination (TDOD) matrices are of crucial importance as an input for dynamic traffic assignment (DTA) models. Determining the scale and resolution of the network model is an essential step in planning applications, with important implications for specifying the associated time-dependent demand patterns. In order to capture the time-dependent pattern, a bi-level optimization method is used (Verbas et al., 2011). In the upper level of the bi-level framework, the sum of squared deviations of the simulated link flows from the corresponding observed values is minimized; in the lower level a dynamic traffic assignment problem is solved. The process is iterated until convergence in the reduction of root mean square errors (RMSE) of the estimated link-flows is achieved.

The upper-level problem is a weighted multi-objective optimization problem. The objective function of the optimization problem is presented below.

$$\min_{d_{i,j,h}} (1-w)\left(\sum_{l=1}^{L}\sum_{t=1}^{T}[M_{l,t}-O_{l,t}]^2\right)+(w)\left(\sum_{i=1}^{I}\sum_{j=1}^{J}\left[\left\{\sum_{h=1}^{H}d_{i,j,h}\right\}-\delta_{i,j}\right]^2\right)$$

$$subject\ to\ \ d_{i,j,h}\geq 0, \qquad \forall i, j, h$$

where

L : The set of observation links,
l : The index for observation links; $l \in L$,
T : The set of simulation time intervals,
t : The index for simulation time intervals; $t \in T$,
h : The set of departure time intervals,
H : The index for departure time intervals; $h \in H$,
I : The set of origins,
i : The index for origins; $i \in I$,
J : The set of destinations,
j : The index for destinations; $j \in J$,
$d_{i,j,h}$: Time-dependent OD flow from origin $i \in I$ to destination at the time interval $h \in H$
$\delta_{i,j}$: The static OD flow from origin $i \in I$ to destination $j \in J$
$p_{i,j,h,l,t}$: The proportion of demand for origin i, destination j, at departure time h, observed on link l, at simulation/observation time t.

The first objective is to minimize the squared deviations between the simulated flows $M_{l,t}$ and the observed flows $O_{l,t}$ for all observation links $l \in L$ and simulation time intervals $t \in T$; while the second objective is to minimize the squared deviations between the sums of the time-dependent OD flows $d_{i,j,h}$ over the departure time intervals $h \in H$ and static OD flows $\delta_{i,j}$ for all OD pairs $i \in I$ and $j \in J$.

The simulated flows $M_{l,t}$ are solved by the lower-level problem and are a function of the decision variables $d_{i,j,h}$ such that $M_{l,t} = \sum_{i,j,h} p_{i,j,h,l,t} d_{i,j,h}$. $p_{i,j,h,l,t}$ is the so-called link proportion, which describes the fraction of OD flow $d_{i,j,h}$ on the link flow $M_{l,t}$. The two stopping criteria used in this methodology are the root mean squared errors for demand and observations, as described below.

$$RMSE_{Demand} = \sqrt{\frac{\sum_{i=1}^{I} \sum_{j=1}^{J} \left[\left\{ \sum_{h=1}^{H} d_{i,j,h} \right\} - \delta_{i,j} \right]^2}{IJH - 1}}$$

$RMSE_{Demand}$ is the measure of error for the deviation between the new time-dependent demand matrix and the original static demand matrix.

$$RMSE_{Flows} = \sqrt{\frac{\sum_{l=1}^{L} \sum_{t=1}^{T} [M_{l,t} - O_{l,t}]^2}{LT - 1}}$$

$RMSE_{Flows}$ is the measure of error for the deviation between the simulated and the observed link flows.

Figure 3-7 illustrates the conceptual relationship between two criteria used in the optimization process. Since the original static OD matrix (left circle in Figure 3-7) typically does not agree well with the actual observations (right circle), our goal is to find a new time-dependent matrix (middle circle) whose resulting traffic flows are well matched with the observed traffic flows, but at the same time not deviating too much from the original static matrix, which was used as a seed for the new matrix. The final new time-dependent OD matrix is therefore obtained by minimizing both $\text{RMSE}_{\text{Flows}}$ and $\text{RMSE}_{\text{Demand}}$.

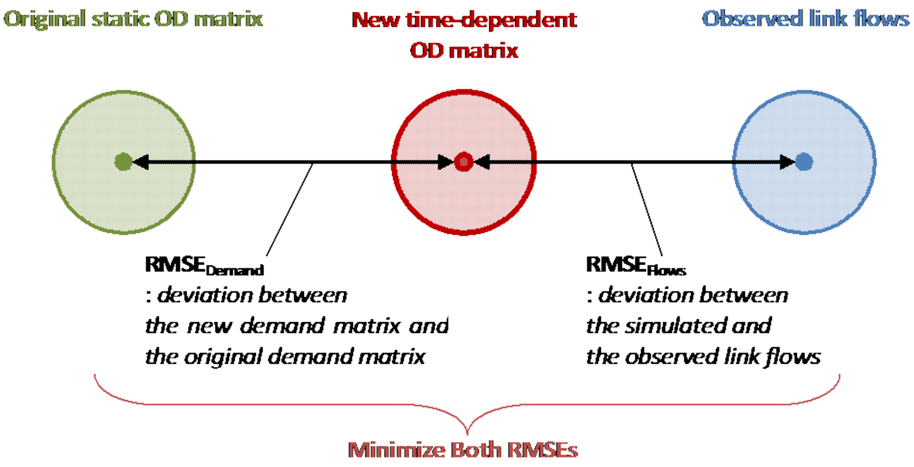


Figure 3-7. Two Stopping Criteria in Optimization Process

3.3.2 Data Source

The required inputs to the OD estimation framework are: (a) static or historical OD matrix for the planning time horizon; and (b) time-dependent traffic counts on selected observation links.

To estimate the travel demand for the sub-network, we run dynamic traffic simulation on the full network first, and then extracted the trips that traversed within and through the sub-network based on vehicle trajectories. The data source we used to construct the demand profile was 3-hr (6am – 9am) demand obtained from Wasatch Front Regional Council (WFRC). We then extended the 3-hr demand to 15-hr demand for the off-line sub-network and 24-hr demand for the on-line sub-network, by applying multiplication factors to other time periods based on link counts observations. After running the full network, the time-dependent profiles of travel demand for the two sub-networks are extracted following the procedures described in Section 2.

Besides the static historical OD matrix extracted from full network, time-dependent link counts on selected observation links within the sub-network are used with dynamic traffic assignment models for calibrating time-dependent OD matrix. The characteristics of traffic counts data used in this project are summarized in Table 2-2, which consists of both freeway and arterial traffic counts.

3.3.3 Estimation Results

This section discusses the estimation results for the time-dependent OD matrix under normal weather condition for the off-line Ogden network. In the multi-objective formulation described before, two objectives are weighted so that the sum of the two weights is equal to one. The weight for demand w varied from 0.1 to 0.9, with increments of 0.1. The number of links that have observations is 78, whereas the total number of links within the network is 3001. These observation links represent 2.5% of the entire network. Heavy weights are put onto Riverdale Road link counts observations. After some initial trials, it is found that even with a weight of 0.9, the total number of trips in the network is increased from 1.08 million 1.4 million, which could cause heavy congestion and network gridlocks. Some more weight choices (0.99, 0.999, and 0.9999) have been tried. In the end, a weight factor of 0.99 is chosen, which would provide a valid compromise between the two deviations for static target demand and link observations.

After the weight is decided, the rest of OD estimation work is carried out in an iterative manner. As discussed before, the two statistics that we used to evaluate OD estimation performance and terminate the iteration procedure are $\mathrm{RMSE}_{\mathrm{Demand}}$ and $\mathrm{RMSE}_{\mathrm{Flows}}$. Table 3-3 provides the estimation results for the Ogden network. The first column shows the number of vehicle trips after each iteration. The next two columns show the RMSE values. The RMSE for demand has increased initially; however, it has stabilized after more iterations. RMSE for flows has been decreasing since the first iteration, and stays around 80 for further iterations. The rate of deviation is decreasing, which implies convergence. This means that the real-world link count observations are matched better with the simulation results produced by the new time-dependent OD matrix than with the historical OD matrix.

Table 3-3. RMSE Values for the Ogden Network

	Number of Trips	RMSE Values	
		Demand	Flows
Original	1084979	0.000	104.098
Iteration 1	1225418	0.376	81.185
Iteration 2	1265325	0.448	85.192
Iteration 3	1249252	0.365	84.162
Iteration 4	1232539	0.303	89.888
Iteration 5	1230092	0.287	84.612
Iteration 6	1227657	0.270	88.837
Iteration 7	1235370	0.281	89.168
Iteration 8	1231815	0.270	89.123

3.3.4 Validation

As a link-level validation, the simulated and observed link counts are compared for several selected links. Simulated results based on the estimated time-dependent OD matrix are compared with the actual observations, which are collected during peak hours (7 am – 10 am). Figure 3-8 and Figure 3-9 show the 5-minute aggregated vehicle counts and the cumulative number of vehicle counts for two selected link (intersection 5004 eastbound and intersection 5009 eastbound). Overall, link-level comparisons show good agreements between simulated and observed flows.

As a network-wide validation, the overall OD demand pattern is also compared. Figure 3-10 present the temporal distributions of number of trips of the historical OD matrix before and after the OD estimation.

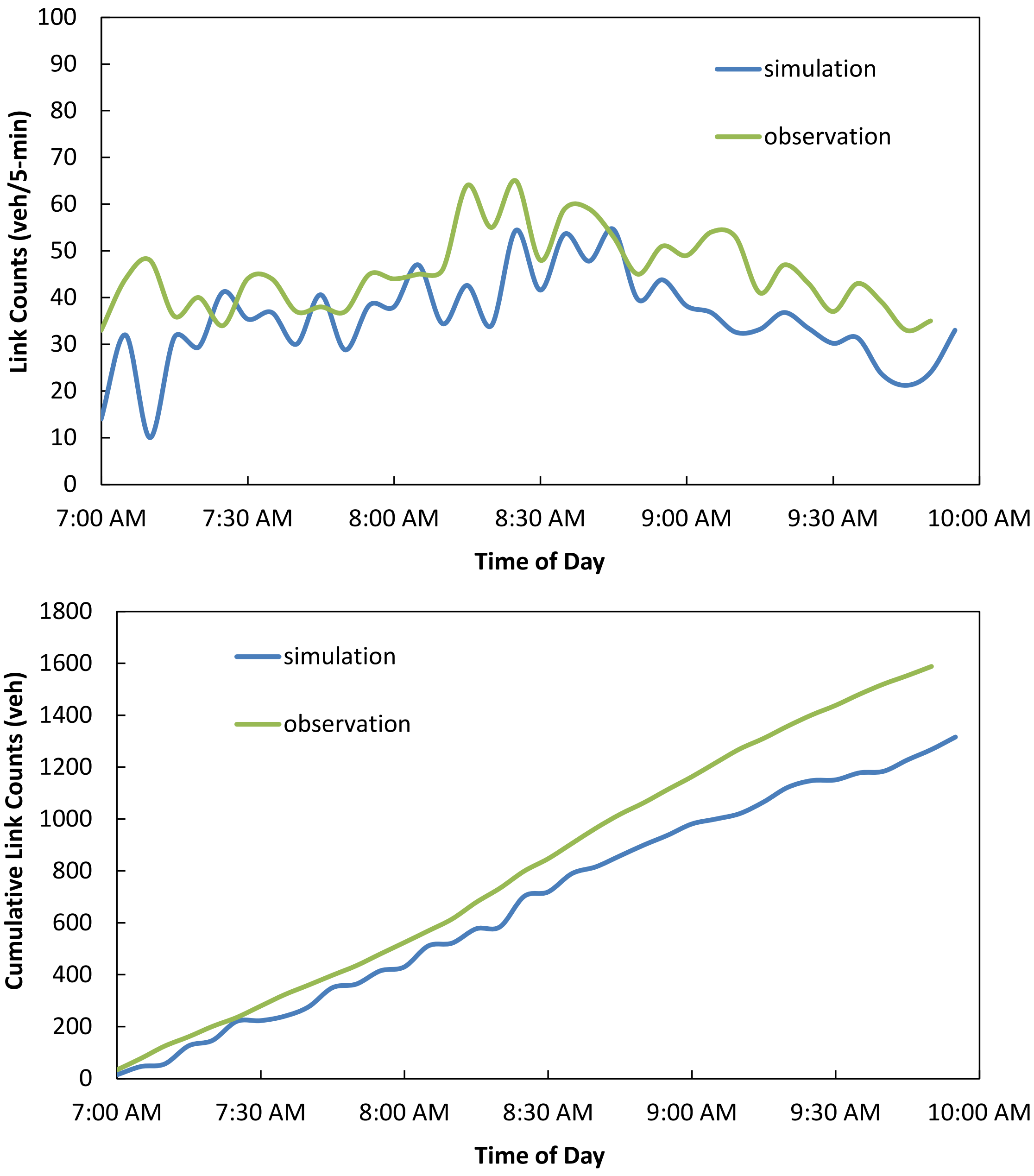
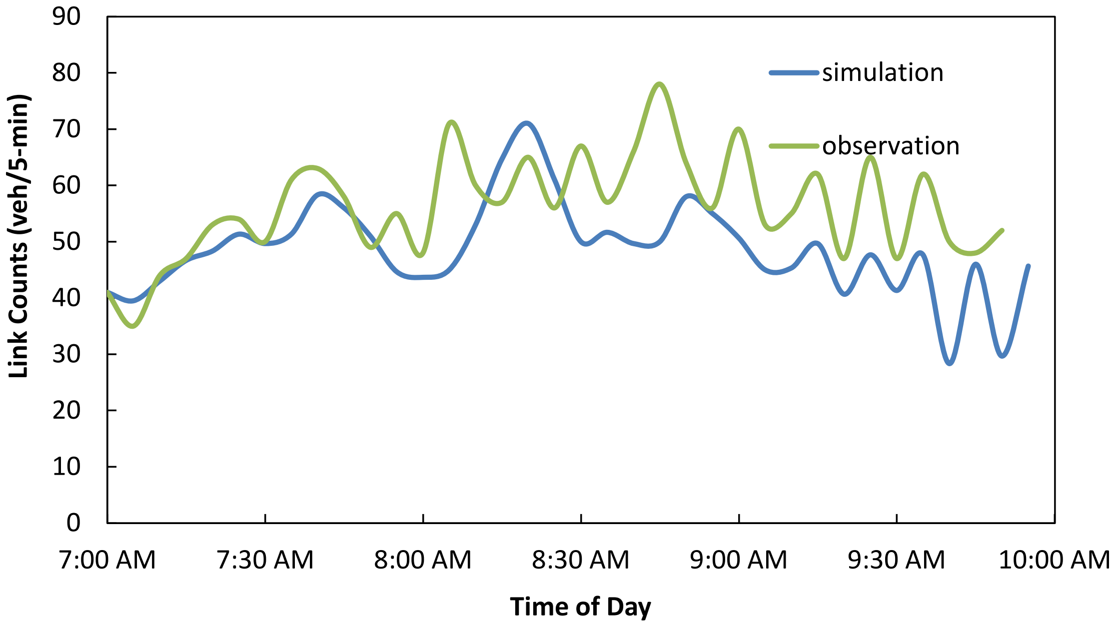


Figure 3-8. Observed and Simulated Counts on Link 5004 Eastbound



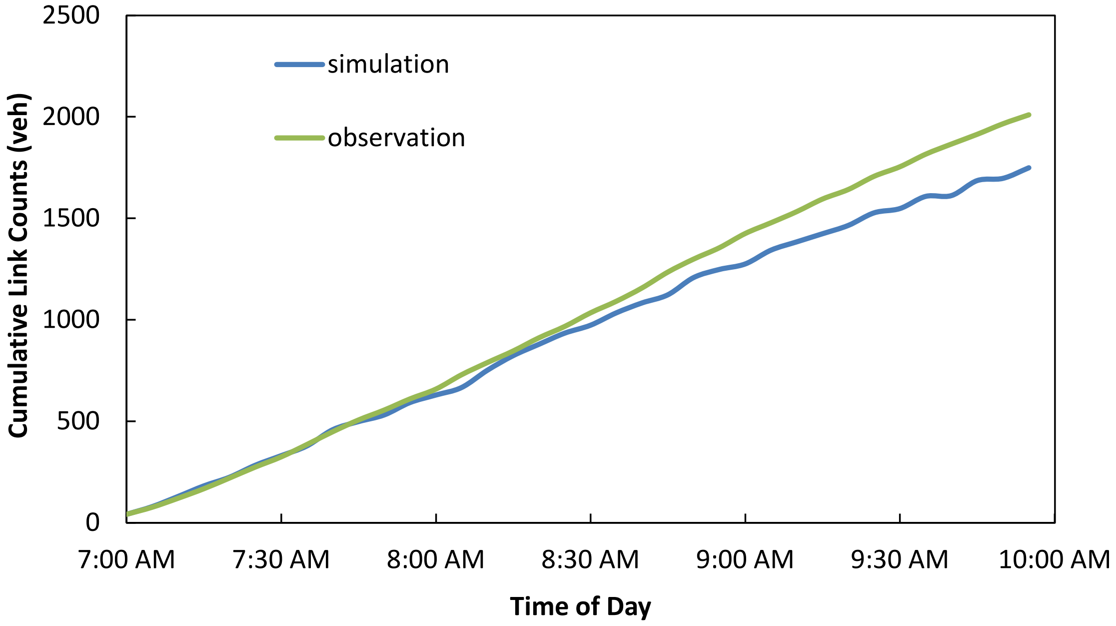


Figure 3-9. Observed and Simulated Counts on Link 5009 Eastbound

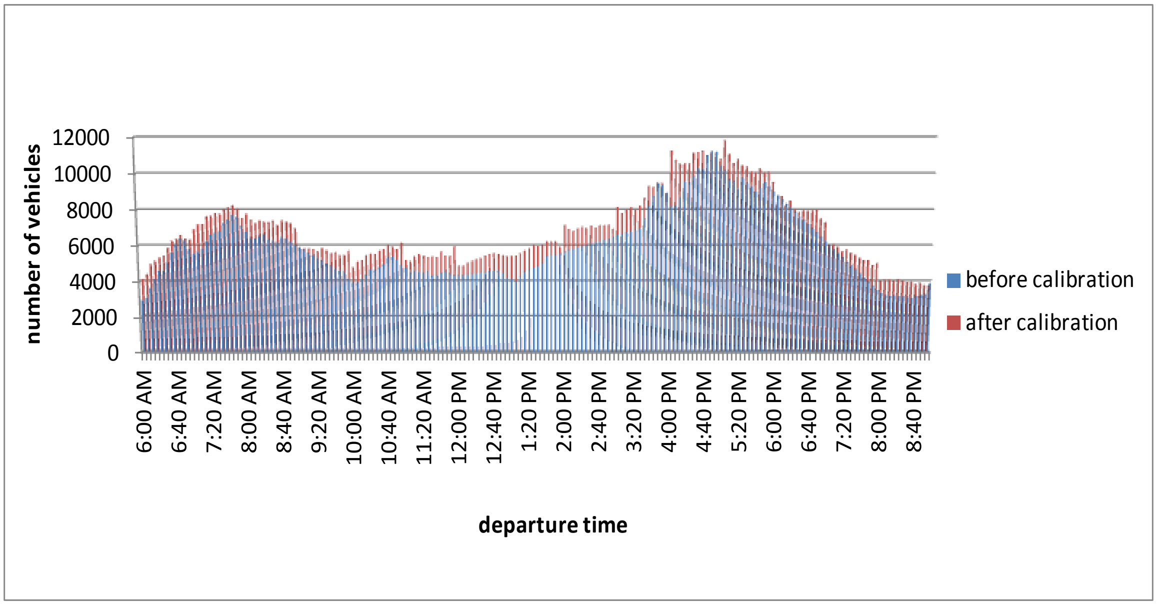


Figure 3-10. Comparison of Demand Profiles Before and After OD Estimation

Chapter 4. Off-line Signal Performance Evaluation

4.1 Snow Scenario

To validate the calibrated off-line models and test the effectiveness of various signal timing plans, traffic simulation experiments are conducted with selected severe weather events. Five days with significant amount of snowfall in early 2013 are selected; these are January 10th-12th, January 29th, and March 21st. Figure 4-1 shows how the snow intensity and visibility vary between 6 a.m. and 9 p.m. on January 29th. It is observed that light snow precipitation started early in the morning; it continued and became moderate snow at close to noontime. After 12 p.m., the intensity reduced to light snow and then stopped. The specific signal timing plans implemented during this snow event are obtained from UDOT (Table 4-1), and they have been converted into DYNASMART required input formats for the simulation.

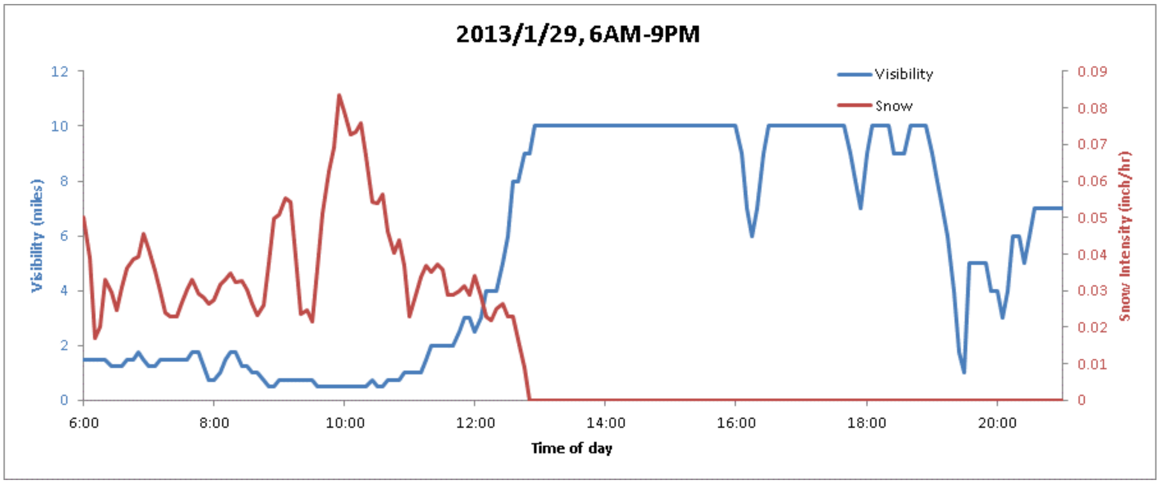


Figure 4-1. Snow Intensity and Visibility during the January 29th Snow Event

Three sets of traffic simulation experiments are conducted under the same traffic demand. These are:

1) **Normal Weather**: dynamic traffic simulation under normal (no snow) weather condition;
2) **Snow with Normal Plan**: dynamic traffic simulation under January 29th snow event without weather-responsive signal plan; and
3) **Snow with Weather-responsive Plan**: dynamic traffic simulation under January 29th snow event with weather-responsive signal plan.

The simulation results are analyzed and several signal performance measures are derived to compare the effectiveness of different signal timing plans under severe weather condition.

Table 4-1. UDOT's Signal Plan ID's under Different Weather Scenarios

Time-of-Day	Normal Plan	Weather-responsive Plan
6:00 - 6:30	fully actuated	fully actuated
6:30 - 9:00	1	58
9:00 - 11:00	4	67
11:00 - 13:00	4	69
13:00 - 18:30	13	57
18:30 - 21:00	19	19

Source: Utah DOT

The next section introduces the performance measure that can be extracted from the TrEPS output, at both the intersection and corridor levels, in addition to overall aggregate statistics. Simulation results for the January 29th 2013 snow scenario are presented in Section 4.3.

4.2 Performance Measures

One standard simulation output of DYNASMART-P consists of vehicle trajectory data, which contain departure time, origin and destination, path node sequence, node exit times, link travel time, and stop time for all the vehicles that have been circulating within the network (Kim et al., 2013). Using detailed vehicle trajectories, we can construct any desired aggregated MOE's, as well as examine signal performance at both corridor-level and intersection-level using the following measures:

Aggregate-level

- Total travel time and total stopped time savings for all vehicles (1) traversing, and/or (2) crossing the corridor.
- Fraction of vehicles stopped.

Corridor-level

- Travel Time (minutes): the time-of-day variation of total travel time for traversing the entire corridor; distributions of the travel times spent passing several successive intersections along the study corridor.
- Stopped Time (seconds): the average total times spent waiting at intersections when a vehicle is traversing from the first intersection to the last intersection along the corridor.

Intersection-level

- Throughput (number of vehicles/5-min): number of vehicles passing the intersection through major approaches within certain time interval.
- Stopped Time (seconds): the average time that the vehicle spends stopped at each individual intersection.

In addition, various travel time reliability measures can be extracted from trajectories to evaluate the effectiveness of a given signal strategy in reducing travel time variability and improving reliability. The travel time reliability related MOE's used in this study include:

- Buffer Index ((95th percentile travel time – mean travel time) / mean travel time)
- Travel Time Index(mean travel time / free flow travel time)
- Planning Time Index (95th percentile travel time / free flow travel time)
- Misery Index (mean of the highest 5% of travel times / free flow travel time)

4.3 Results for the January 29, 2013, Snow Event

The results presented in this section are based on simulation outputs for normal weather, January 29^{th} snow with normal plan, and January 29^{th} snow with weather-responsive signal plan scenarios. Section 4.3.1 first presents the aggregate level analysis for the entire corridor and some pre-defined sub-corridors, followed by results on corridor level performance measures in Section 4.3.2, specifically total travel time, and total stopped time. Section 4.3.3 presents intersection level performance measures, which are throughput and stopped time at each individual signalized intersection. In the end, Section 4.3.4 shows travel time reliability measures for selected path segments.

4.3.1 Aggregate Level Analysis

In aggregate level analysis, we compute the total travel time, total stopped time, and total fraction of stopped vehicles for all the vehicles traversing the mainline of the study corridor, as well as those coming from cross-streets. The total travel time is the sum of travel times experienced while traversing and/or crossing the corridor; the total stopped time is the sum of stopped time at those intersections under study. The analysis is conducted using vehicle trajectory data for all three simulation scenarios. Two different cases are studied, namely traversing vehicles only, and all impacted vehicles that include both traversing and cross-street vehicles. The total travel time and total stopped time savings due to weather-responsive signal plans are quantified by comparing the results between snow under the normal plan and snow under the weather-responsive plan scenarios. To study the effectiveness of individual weather-responsive timing plans, we break down the analysis into several time periods when individual timing plans are active according to Table 4-1. Detailed analysis results are presented in the next two sub-sections. Section 4.3.1.1 presents the results based on analysis conducted on the entire corridor; Section 4.3.1.2 presents the results for two selected sub-corridors.

4.3.1.1 Entire Corridor

Traversing Vehicles Only

Here we first consider vehicles that travel along the mainline of the corridor only. In addition to breaking down into individual time-of-day signal plans, the analysis is also broken down by direction along the Riverdale corridor, i.e., eastbound and westbound. Figure 4-2 shows the bar charts for total travel time, total stopped time, and total fraction of stopped vehicles under the three simulation scenarios.

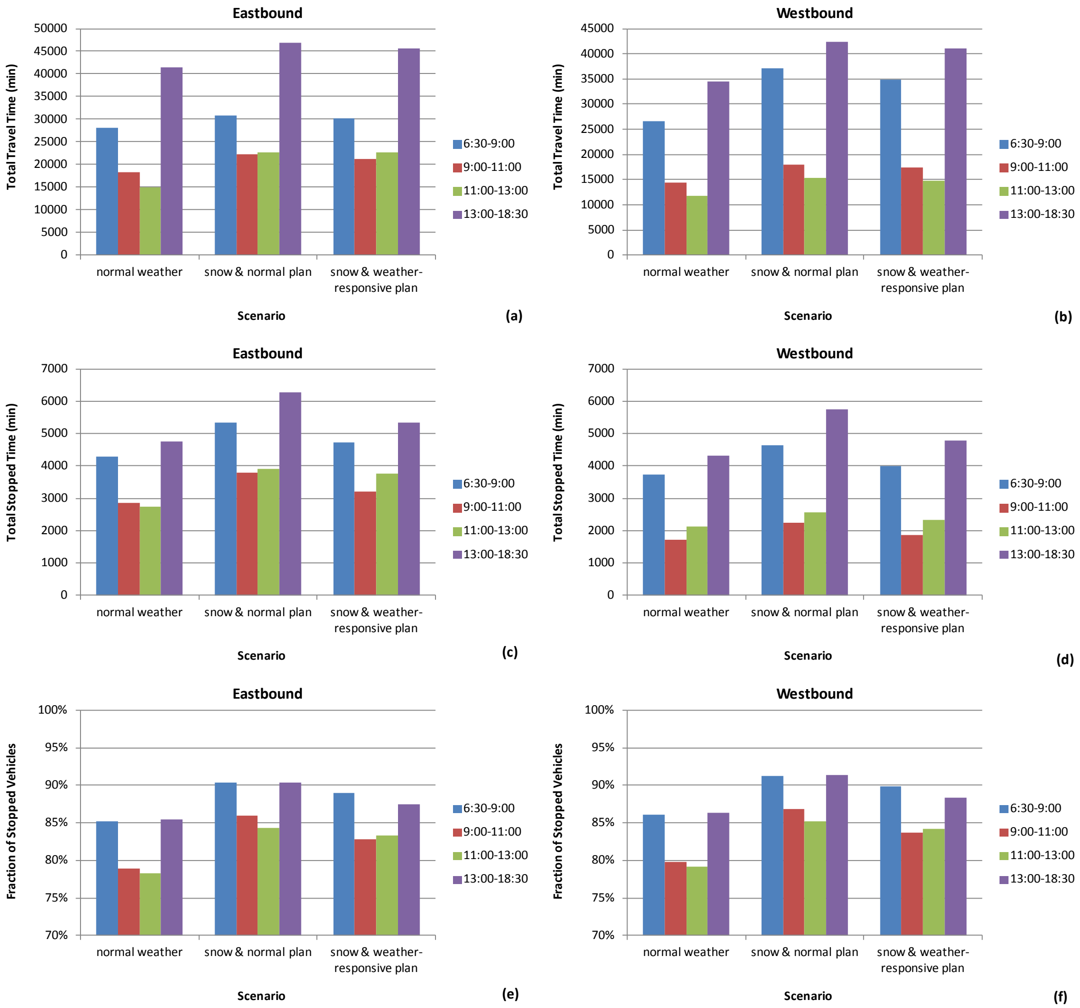


Figure 4-2. Aggregated (a,b) Total Travel Time (c,d) Total Stopped Time (e,f) Total Fraction of Stopped Vehicles for Vehicles Traversing the Entire Corridor

It is observed that snow precipitation can cause adverse effects on traffic progression along the study corridor. UDOT's weather-responsive plans help mitigate the effects of adverse weather by reducing total travel time, total stopped time, and the fraction of stopped vehicles. In general, the westbound direction is performing relatively better than the eastbound direction. The savings due to weather-responsive signal plans, in terms of total travel time, total stopped time, and fraction of stopped vehicles, are listed in Table 4-2. The savings are computed by comparing the results between snow under the normal plan and snow under the weather-responsive plan scenarios.

Table 4-2. Total Savings Due to Weather-Responsive Signal Plans for Vehicles Traversing the Entire Corridor

Time-of-Day	Eastbound			Westbound		
	Total Travel Time	Total Stopped Time	Fraction of Stopped Vehicles	Total Travel Time	Total Stopped Time	Fraction of Stopped Vehicles
6:30-9:00	2.20%	11.65%	1.50%	5.84%	13.44%	1.49%
9:00-11:00	4.42%	15.49%	3.63%	2.80%	16.14%	3.62%
11:00-13:00	-0.32%	3.82%	1.18%	4.74%	9.53%	1.17%
13:00-18:30	2.66%	14.90%	3.22%	3.36%	16.71%	3.21%
Overall	2.32%	11.87%	2.47%	4.28%	14.41%	2.41%

All Impacted Vehicles

Impacted vehicles are defined as not only vehicles traversing the corridor in eastbound or westbound directions, but also those vehicles coming from cross-streets that passed some of the intersections along Riverdale Road, regardless of direction. By considering all impacted vehicles, one obtains an overall picture of how well a particular signal timing plan is performing in terms of total travel time savings for all the vehicles that utilize the corridor.

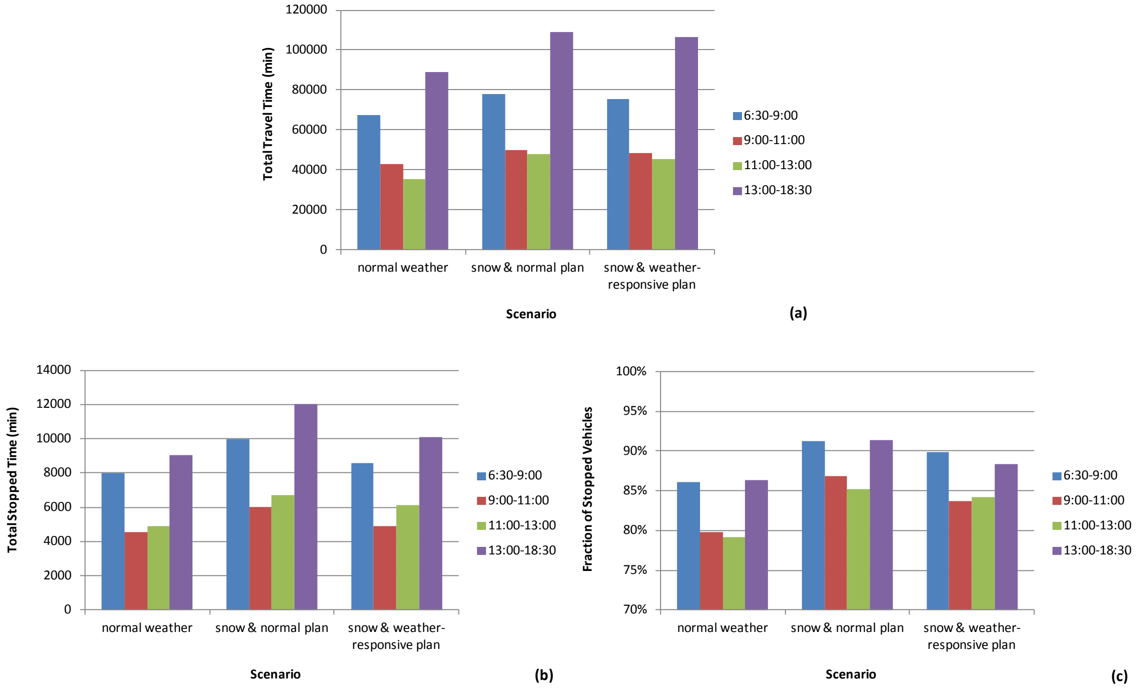


Figure 4-3. Aggregated (a,b) Total Travel Time (c,d) Total Stopped Time (e,f) Total Fraction of Stopped Vehicles for All Impacted Vehicles on the Entire Corridor

Same as for the traversing vehicles only, Figure 4-3 shows the bar charts for total travel time, total stopped time, and fraction of stopped vehicles for all impacted vehicles on the entire corridor under three simulation scenarios. The results suggest that the weather-responsive signal plans help not only those vehicles traveling along the corridor but also the cross-street traffic, by reducing total travel time, total stopped time, and the fraction of stopped vehicles. Table 4-3 lists the savings due to the weather-responsive signal plans.

Table 4-3. Total Savings Due to Weather-Responsive Signal Plans for All Impacted Vehicles in the Entire Corridor

Time-of-Day	Total Travel Time	Total Stopped Time	Fraction of Stopped Vehicles
6:30-9:00	3.29%	14.21%	1.49%
9:00-11:00	2.67%	18.59%	3.62%
11:00-13:00	4.94%	8.70%	1.17%
13:00-18:30	2.14%	15.76%	3.21%
Overall	3.02%	14.45%	2.46%

4.3.1.2 Sub-Corridors

The aggregate level analyses are performed not only for the entire corridor, but also for two selected sub-corridors, as illustrated in Figure 4-4. These two segments are considered as the most utilized portions by travelers along the corridor. Segment 1 is between intersection 5092 (Riverdale and SR-126) and intersection 5002 (Riverdale and 1050 West). Segment 2 is between intersection 5001 (Riverdale and 900 West) and intersection 5007 (Riverdale and Wall Ave).

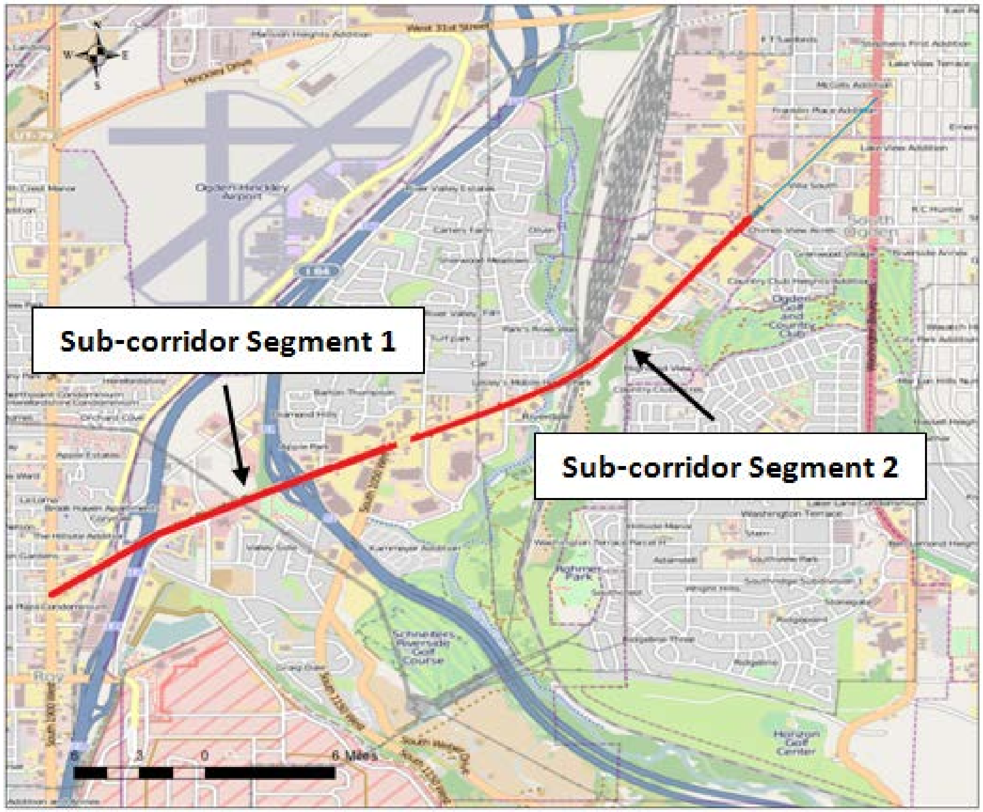


Figure 4-4. Selected Sub-Corridor Segments

Traversing Vehicles Only

Figure 4-5 and Figure 4-6 show the total travel time, total stopped time, and the fraction of stopped vehicles under different signal timing plans and simulation scenarios on both eastbound and westbound directions, for sub-corridor segment 1 and 2, respectively.

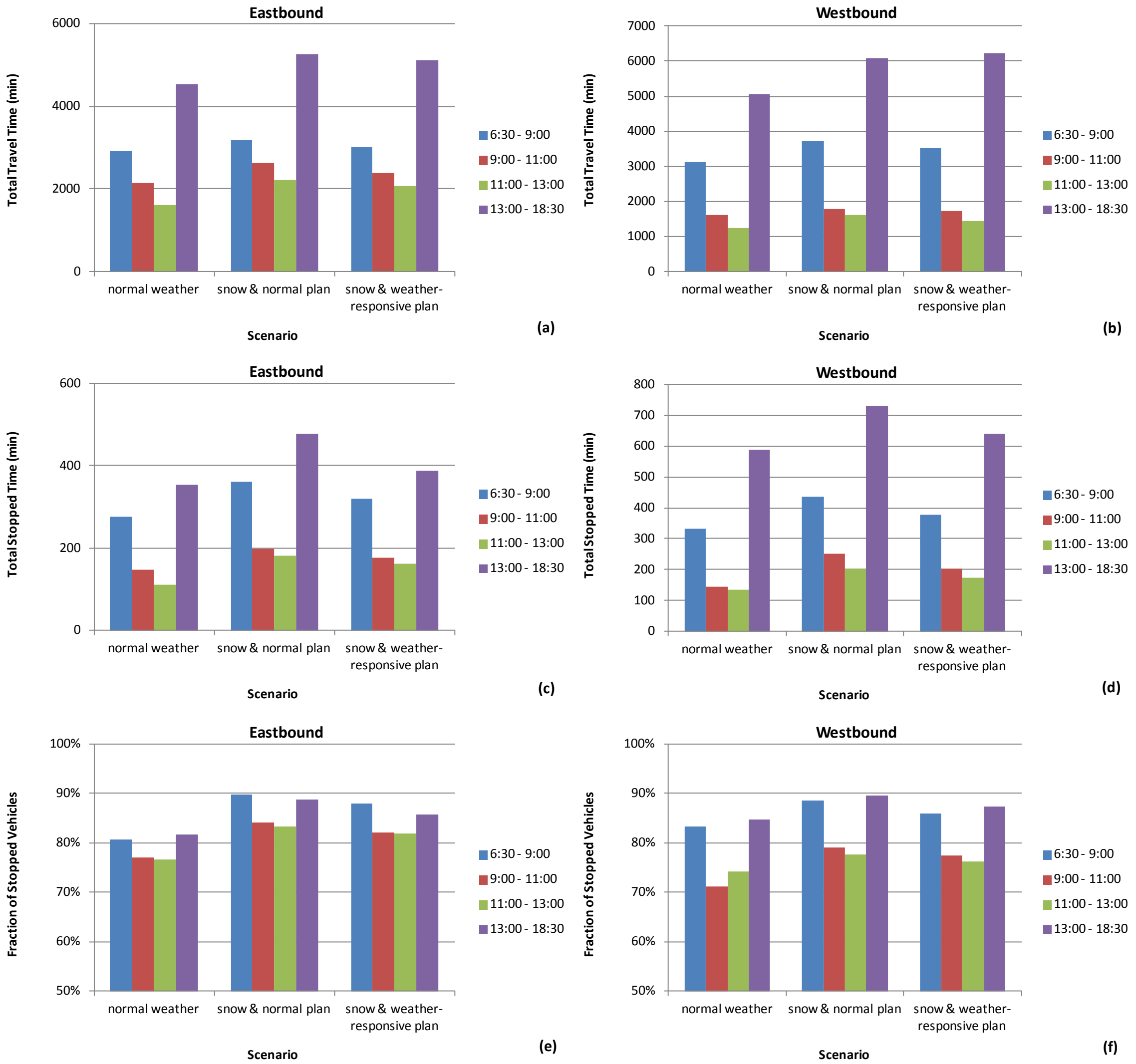


Figure 4-5. Aggregated (a,b) Total Travel Time (c,d) Total Stopped Time (e,f) Total Fraction of Stopped Vehicles for Vehicles Traversing the Sub-Corridor Segment 1

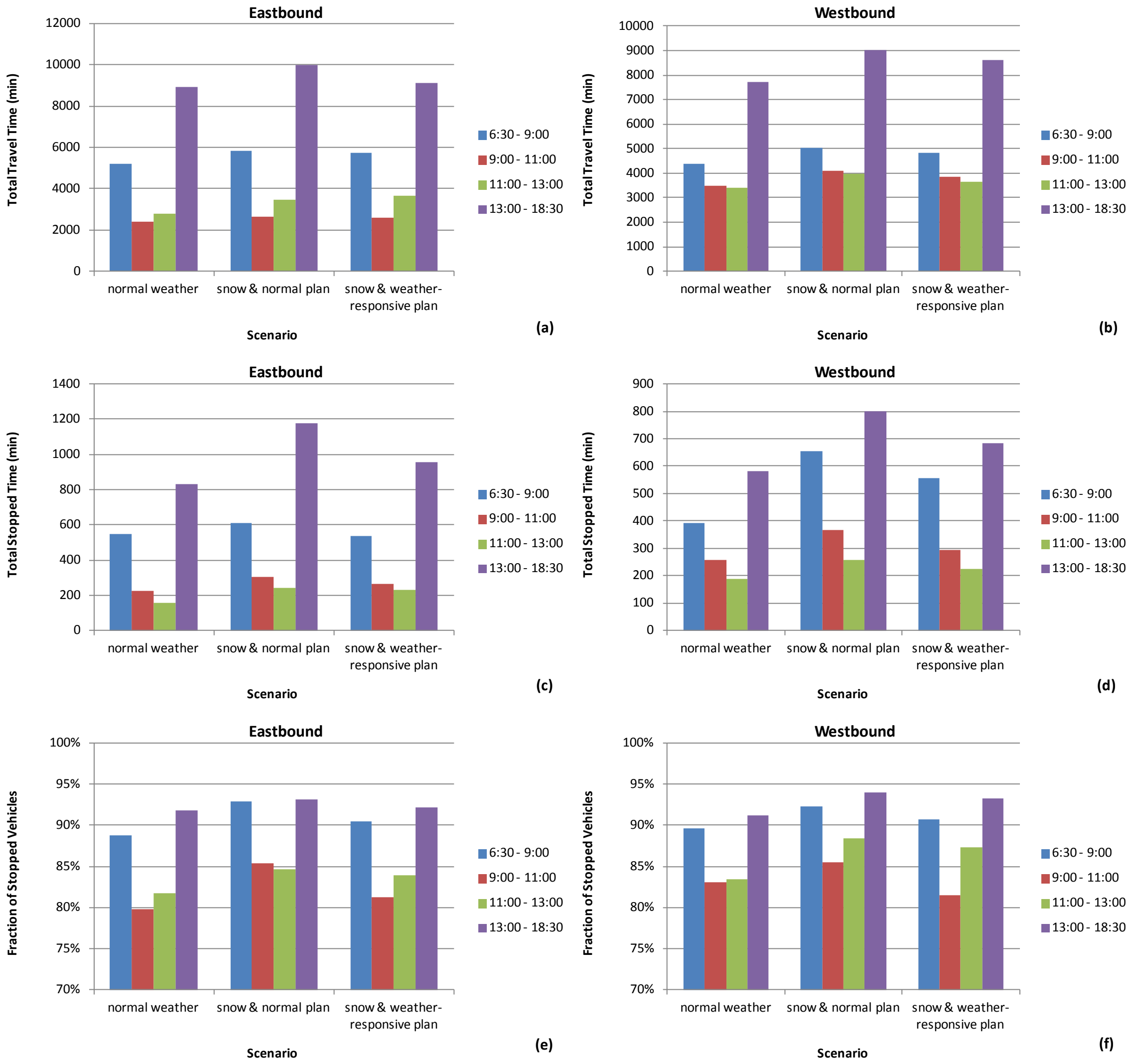


Figure 4-6. Aggregated (a,b) Total Travel Time (c,d) Total Stopped Time (e,f) Total Fraction of Stopped Vehicles for Vehicles Traversing the Sub-Corridor Segment 2

Table 4-4 and Table 4-5 list the total savings in terms of aggregated total travel time, total stopped time, and the fraction of stopped vehicles for vehicles traversing segments 1 and 2, respectively. The amount of improvement due to weather-responsive signal timing plans is consistent with the results for the entire corridor as presented in the previous section. The total travel time savings are around 3% to 5% for both segments in both directions. The savings in total stopped time, at around 13% to 15% for segments 1 and 2 respectively, are greater in relative terms than those obtained in the total travel time.

Table 4-4. Total Savings Due to Weather-Responsive Signal Plans for Vehicles Traversing Sub-Corridor Segment 1

Time-of-Day	Eastbound			Westbound		
	Total Travel Time	Total Stopped Time	Fraction of Stopped Vehicles	Total Travel Time	Total Stopped Time	Fraction of Stopped Vehicles
6:30-9:00	5.46%	11.72%	1.99%	5.72%	13.51%	2.83%
9:00-11:00	8.84%	10.86%	2.23%	4.18%	18.86%	1.99%
11:00-13:00	7.05%	10.53%	1.81%	10.34%	14.39%	1.80%
13:00-18:30	2.61%	18.63%	3.37%	-2.54%	12.34%	2.67%
Overall	5.26%	14.11%	2.54%	2.28%	13.92%	2.59%

Table 4-5. Total Savings Due to Weather-Responsive Signal Plans for Vehicles Traversing Sub-Corridor Segment 2

Time-of-Day	Eastbound			Westbound		
	Total Travel Time	Total Stopped Time	Fraction of Stopped Vehicles	Total Travel Time	Total Stopped Time	Fraction of Stopped Vehicles
6:30-9:00	1.48%	12.09%	2.62%	4.06%	15.16%	1.64%
9:00-11:00	1.27%	13.27%	4.80%	5.35%	19.99%	4.73%
11:00-13:00	-5.49%	3.64%	0.75%	8.15%	12.06%	1.20%
13:00-18:30	8.49%	19.00%	1.05%	4.52%	14.40%	0.72%
Overall	3.53%	14.87%	2.15%	5.22%	15.34%	1.49%

All Impacted Vehicles

As introduced previously, impacted vehicles include not only those traveling along the mainline of the corridor, but also vehicles coming from cross-streets. The same analysis approach is applied to both sub-corridor segments, and the results are presented in Figure 4-7 and Figure 4-8. The total savings are listed in Table 4-6 and Table 4-7.

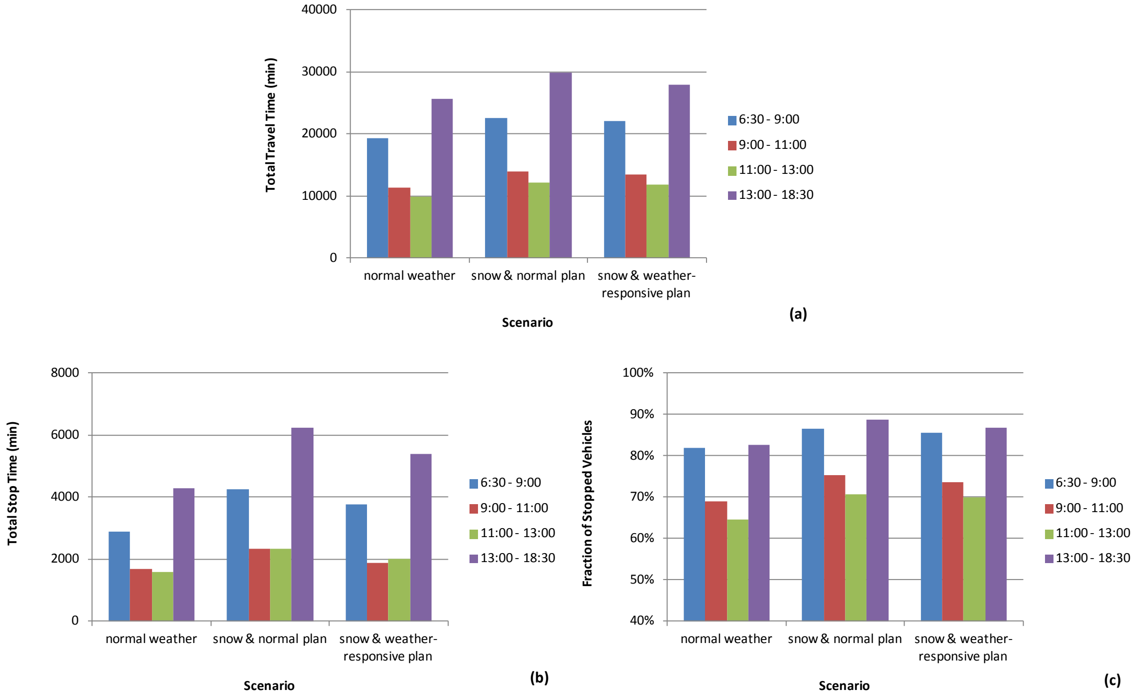


Figure 4-7. Aggregated (a,b) Total Travel Time (c,d) Total Stopped Time (e,f) Total Fraction of Stopped Vehicles for All Impacted Vehicles on Sub-Corridor Segment 1

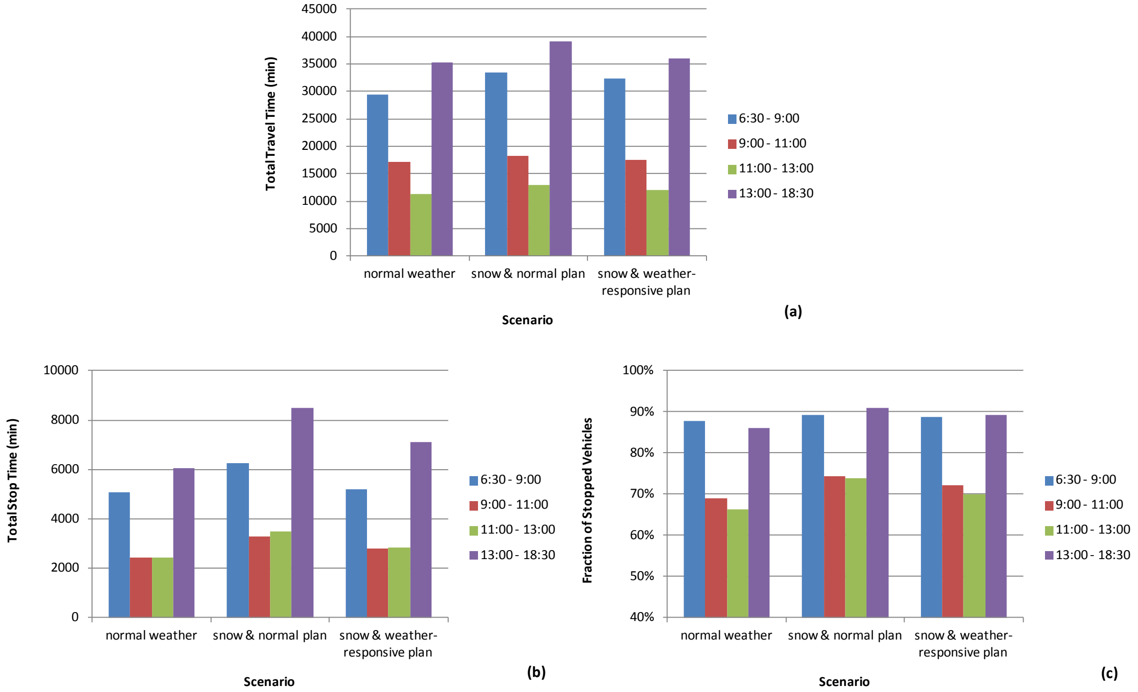


Figure 4-8. Aggregated (a,b) Total Travel Time (c,d) Total Stopped Time (e,f) Total Fraction of Stopped Vehicles for All Impacted Vehicles on Sub-Corridor Segment 2

Table 4-6. Total Savings Due to Weather-Responsive Signal Plans for All Impacted Vehicles on Sub-Corridor Segment 1

Time-of-Day	Total Travel Time	Total Stopped Time	Fraction of Stopped Vehicles
6:30-9:00	2.88%	10.72%	0.74%
9:00-11:00	2.76%	8.45%	2.85%
11:00-13:00	6.38%	17.80%	6.24%
13:00-18:30	8.52%	10.13%	1.71%
Overall	5.39%	11.24%	1.92%

Table 4-7. Total Savings Due to Weather-Responsive Signal Plans for All Impacted Vehicles on Sub-Corridor Segment 2

Time-of-Day	Total Travel Time	Total Stopped Time	Fraction of Stopped Vehicles
6:30-9:00	3.11%	16.65%	0.54%
9:00-11:00	3.73%	14.37%	3.02%
11:00-13:00	7.14%	19.31%	5.57%
13:00-18:30	8.11%	16.34%	1.90%
Overall	5.61%	16.62%	1.87%

4.3.2 Aggregate Level Analysis

The corridor level performance measures are calculated based on simulated vehicle trajectories that traversed the corridor. Analysis is performed for normal weather, snow with normal plan, and snow with weather-responsive signal plan scenarios. For each scenario, we analyzed both directions along the study corridor, i.e., eastbound and westbound. Also, we divided the analysis into two time periods within January 29th 2013, i.e., 7a.m. to 10 a.m., and 11 a.m. to 2p.m. The first time period represents the peak hours, while the second represents off-peak.

4.3.2.1 Travel Time

Time-of-Day Travel Time Variation

Total travel time is the travel time that a vehicle spends when traveling from the first intersection of the study corridor to the last intersection. It is a reflection of the smoothness of the overall traffic state along the study corridor. Figure 4-9 and Figure 4-10 show the simulated average travel time along Riverdale corridor, on eastbound and westbound respectively. The results under three different scenarios are presented.

It is observed that under both snow with normal plan and snow with weather-responsive plan scenarios, drivers experience 5-20% increase in total travel time in both directions as compared with normal weather. It could be a combination effect of weather and different signal timing plan. It is also noted that the travel time during peak hours are generally greater than that during off-peak hours, for both eastbound and westbound directions. Moreover, there is an increase in travel time due to congestion during 8:30am to 9:30am. When comparing the effect of different signal plans under same adverse weather condition, it is observed that UDOT's weather-responsive signal plans help reduce travel time by certain amount on the eastbound direction of Riverdale corridor; while it is not doing as good as normal signal plans on the westbound direction during peak period.

In terms of evaluating the performance of the signalization plan, it should be noted that these travel times are based on simulated network values, by adding up traversal times along the path in question, rather than extracted from the actual traversal experiences of complete vehicle trajectories. This is an important difference because the number of vehicles that traverse the entire corridor is much smaller than those that traverse a portion of the corridor, hence there are few simulated trajectories that traverse the entire corridor in every time period. Since the signalization plan is, by definition, demand-responsive, it is driven by the flow patterns. Therefore, it is better evaluated by examining the travel times and delays actually experienced by the various vehicles for the experienced demand patterns. Analysis based on extracted trajectories is presented next.

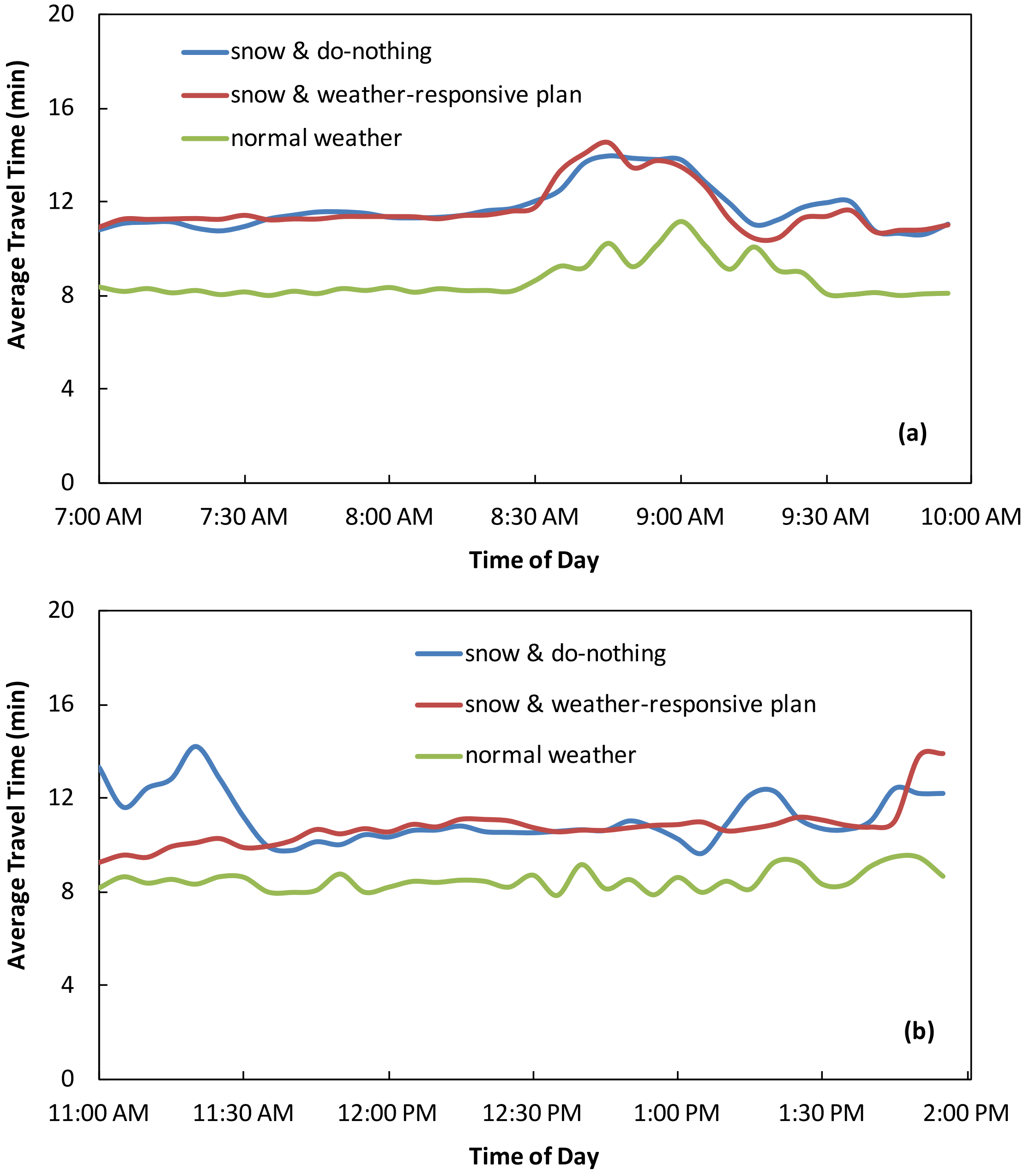


Figure 4-9. Simulated average travel time along Riverdale Road Eastbound: (a) peak; (b) off-peak

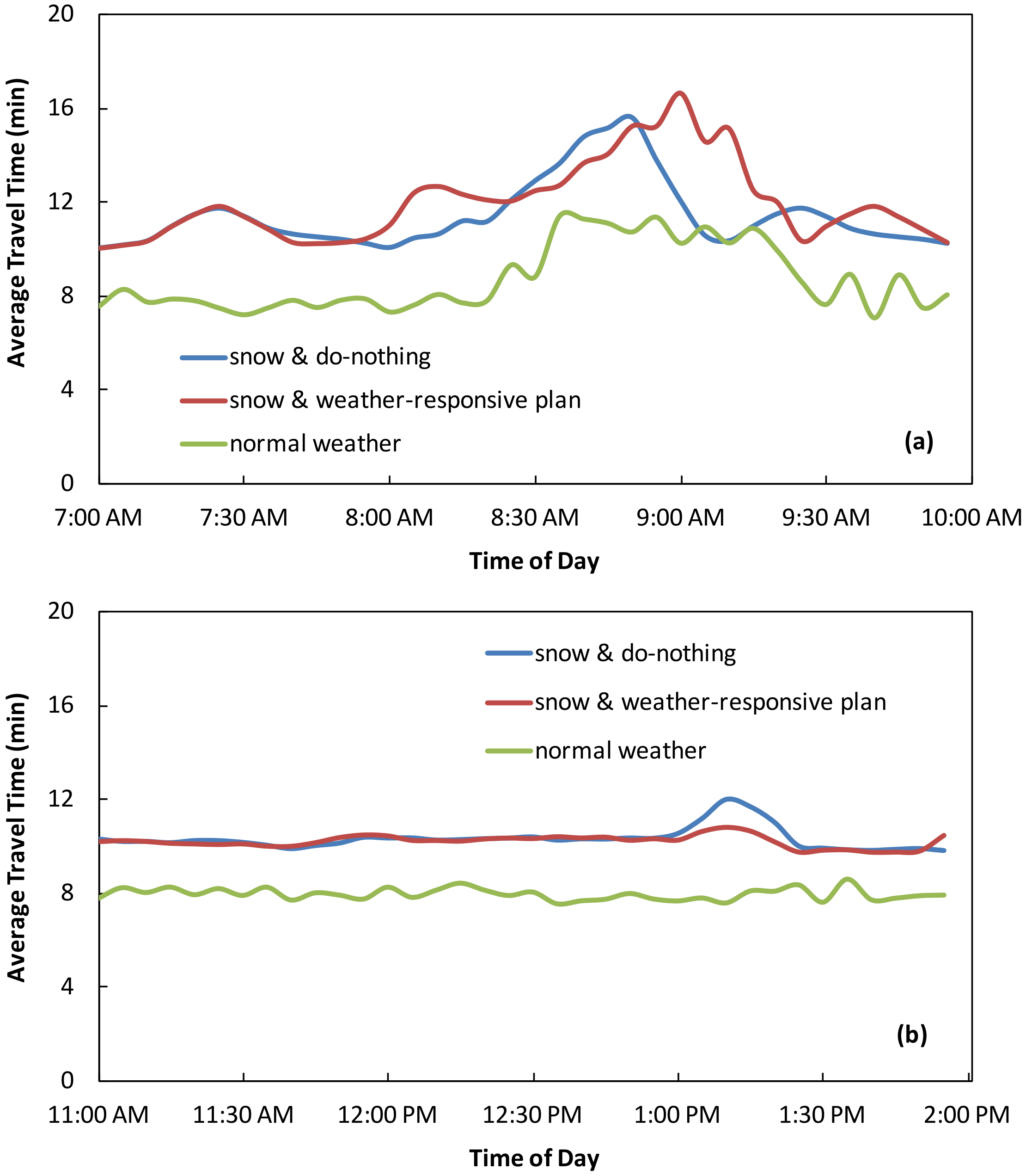


Figure 4-10. Simulated average travel time along Riverdale Road Westbound: (a) peak; (b) off-peak

Travel Time Distribution

In addition to time-of-day variation, variation in travel time can also be evaluated among different vehicles traveling the same path. In order to obtain sufficient amount of vehicles and make statistically solid comparison for different simulation scenarios, we used the two previously selected sub-corridor segments for analysis (Figure 4-4).

The travel times along the selected corridor segments are extracted from vehicle trajectories that passed those segments. It is calculated as the difference between the time when a vehicle enters the starting node of the segment and the time that vehicle exits the ending node of the segment. As two examples, Figure 4-11 and Figure 4-12 show the travel time distributions for the two selected corridor segments under different simulation scenarios, i.e., normal weather, snow with normal plan, and snow with weather-responsive plan.

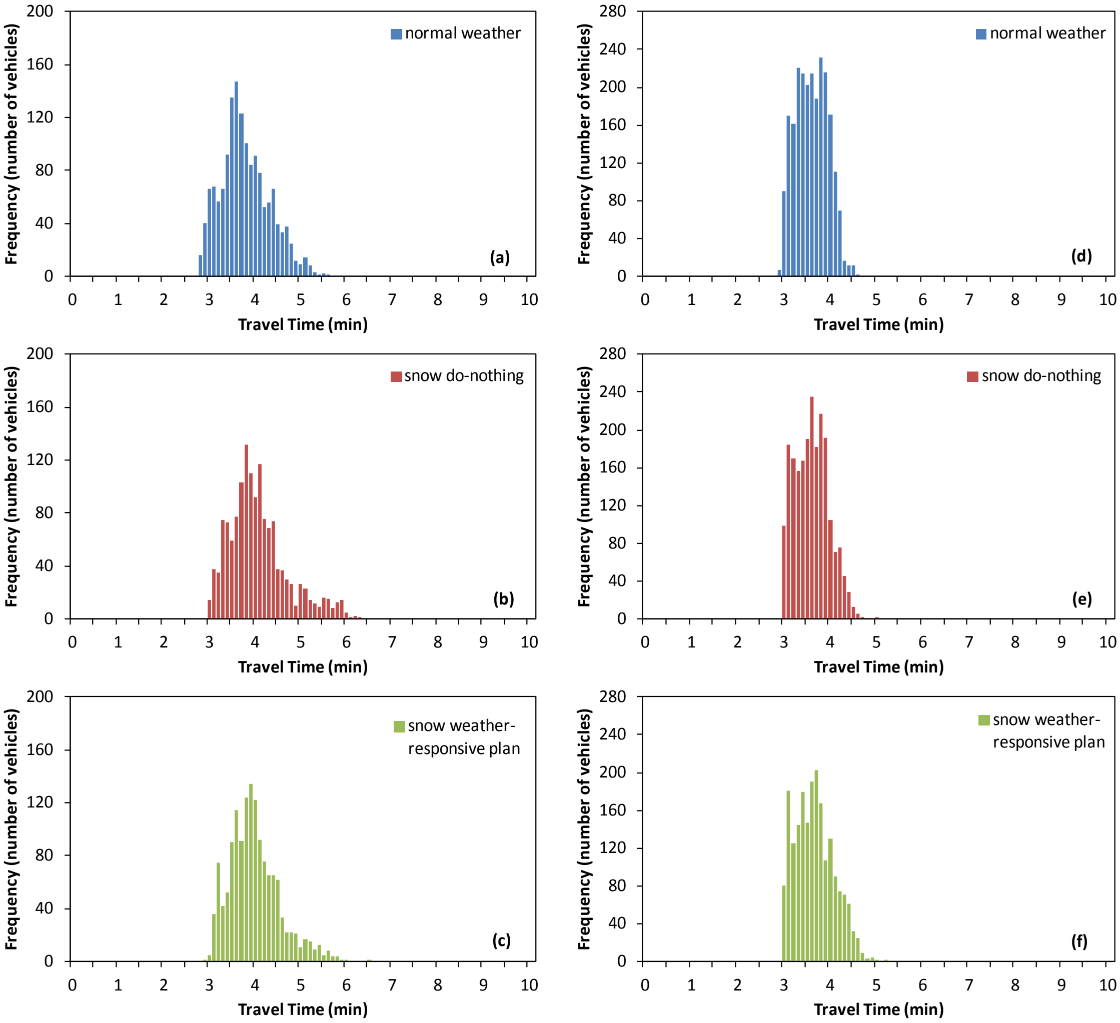


Figure 4-11. Travel Time Distribution under Different Simulation Scenarios for Corridor Segment 1 during peak hours (a,b,c) eastbound; (d,e,f) westbound

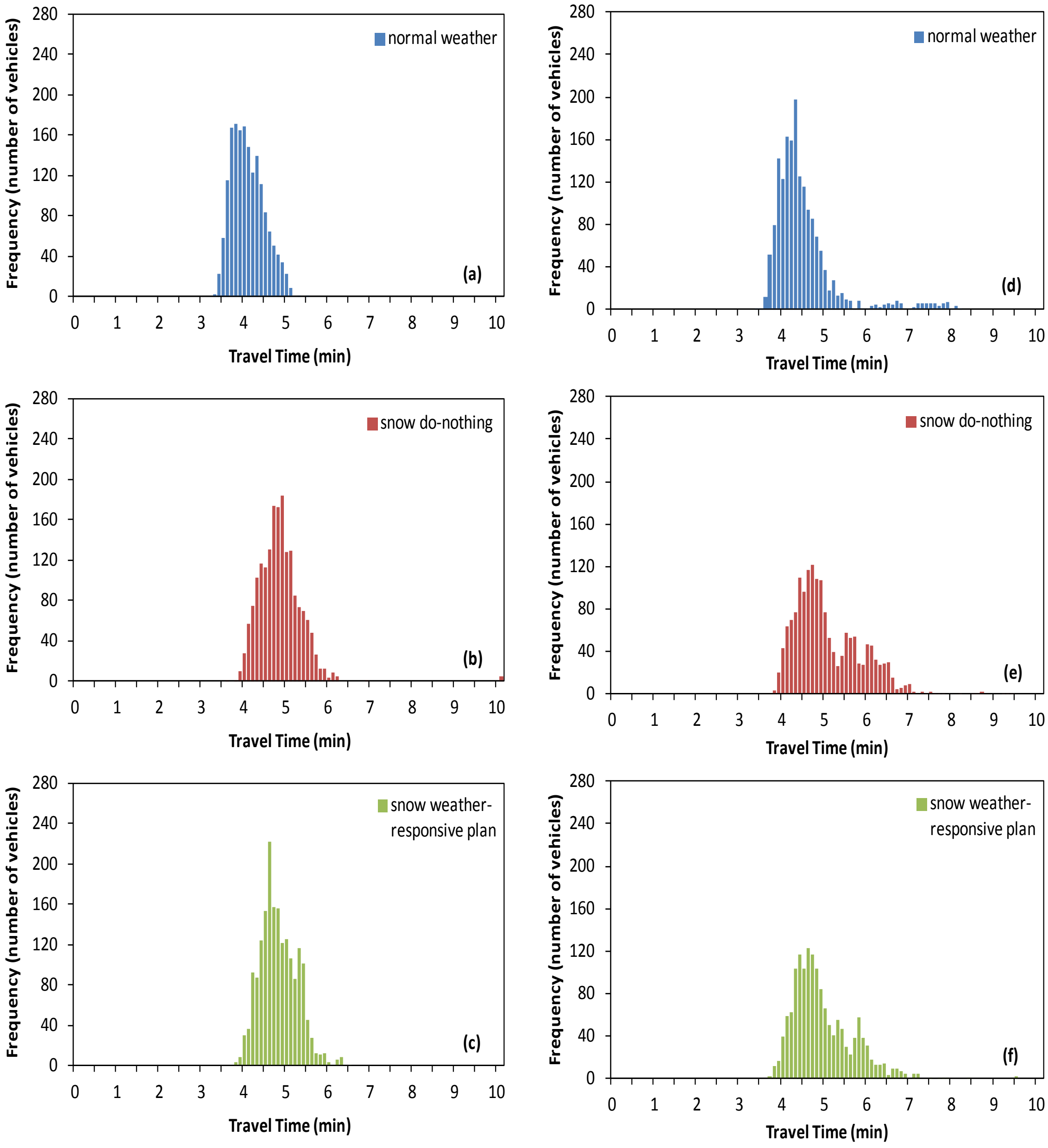


Figure 4-12. Travel Time Distribution under Different Simulation Scenarios for Corridor Segment 2 during peak hours (a,b,c) eastbound; (d,e,f) westbound

Given the histograms of travel time, parametric distribution functions (e.g., log-normal) can be used to fit the empirical distribution. A detailed list of statistics, including mean and standard deviation of travel time of the two selected segments are presented in the Appendix. It is observed that adverse weather has a significant impact on average travel time, for example, it increases the average travel time in eastbound direction for segment 1, from 3.79 min to 4.07 min. The effects of different signal plans on travel time is not as obvious as weather.

4.3.2.2 Stopped Time

The stopped time is an estimate of how long a vehicle will need to stop at intersections when it is traveling along the studied corridor. In this study, we calculated the total stopped time by summing the stopped time at each individual intersection along the entire corridor. As an example, the time-of-day variations of total stopped time in eastbound direction are presented in Figure 4-13, for both peak and off-peak hours. Same as total travel time, the normal weather has the smallest stopped time among all three different scenarios. Adverse weather causes increase in stopped time, and weather-responsive signal plans, in general, help improve traffic progression by reducing the stopped time.

Besides time-of-day variation, the mean and standard deviation of total stopped time among different vehicles are presented in the Table A-1, Table A-2, Table A-3, and Table A-4. The results of both eastbound and westbound directions are presented. The fractions of non-stopped vehicles are also reported, which are the percentages of vehicles that passed the segment without stopping at any intersection due to red signal. The higher the fraction is, the better the signal coordination is. The results show that in most of cases, the snow event has a bad impact on traffic progression, which increases average total stopped time and reduces the fraction of non-stopped vehicles. The weather-responsive signal plan helps reduce the stopped time for westbound direction traffic during both peak and off-peak hours; however it is not doing as good as the normal signal plan for corridor segment 1 eastbound during off-peak period.

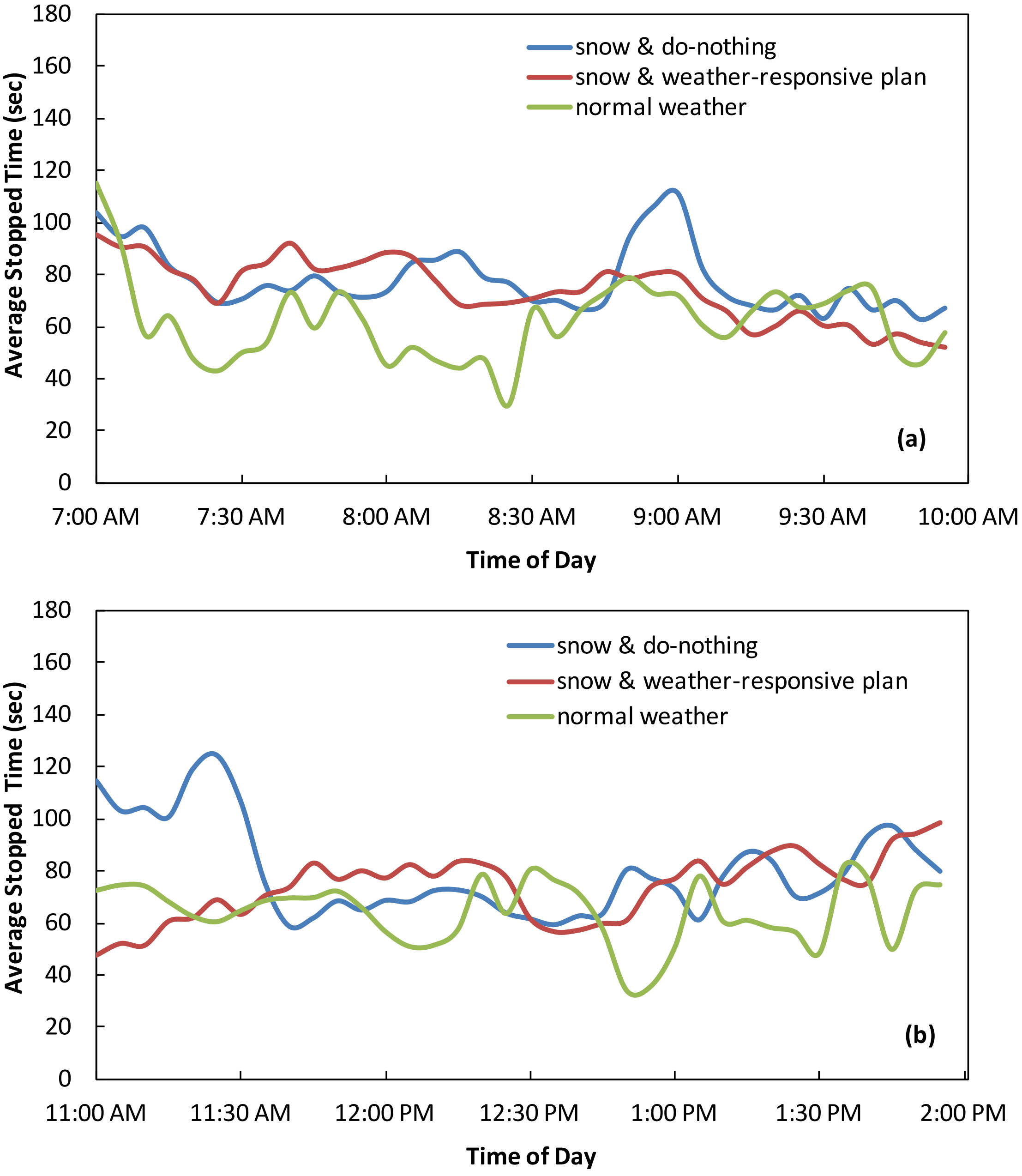


Figure 4-13. Simulated average total stopped time along Riverdale Road Eastbound: (a) peak; (b) off-peak

4.3.3 Intersection Level Analysis

At intersection level, we calculated throughput and stopped time as signal performance measures for selected intersections. We select Intersection 5004 and 5009 as examples to demonstrate the results. Intersection 5004 is located at Riverdale Road and 1500 West, while Intersection 5009 is located at Riverdale Road and 300 West, as shown in Figure 4-14. Same as corridor level, both directions (eastbound and westbound) are analyzed for each scenario, and study period are divided into peaks and off-peaks.

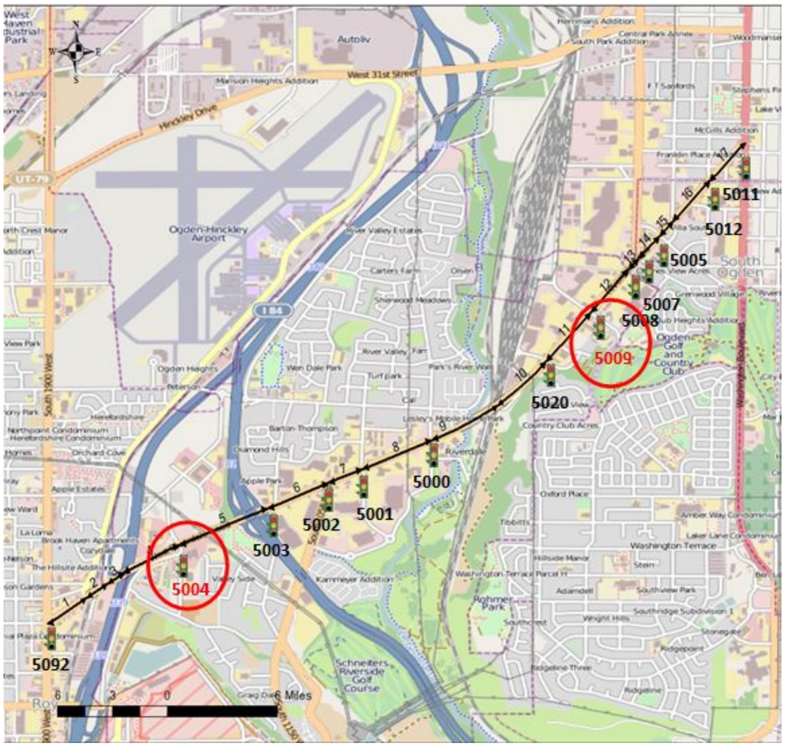


Figure 4-14. Locations of Selected Intersections

4.3.3.1 Throughput

Throughput is defined as number of vehicles that pass the intersection within certain time period. Figure 4-15 and Figure 4-16 show the simulated cumulative throughput during peak and off-peak hours for Intersection 5004 and 5009 respectively. Besides simulated results, link flow observations on that particular day (Jan 29th 2013) are obtained from UDOT's Signal Performance Metrics website, and they are plotted together with simulated link counts. As we can see from the graphs, there is little difference in cumulative traffic counts between the two different scenarios. This is because traffic demand is kept at the same level for all three scenarios, and thus vehicles are following the exact same flow pattern during the simulation. Similar validation work has been discussed in Section 5.4 for estimating the dynamic OD matrix using link counts data. The simulations show generally comparable results to observations by radar detectors.

It should be noted that these results serve more for validation purposes than to compare the effectiveness of the signal plan. The fact that the demand patterns are kept at the same level under all scenarios provides the controlled conditions needed for the performance comparison.

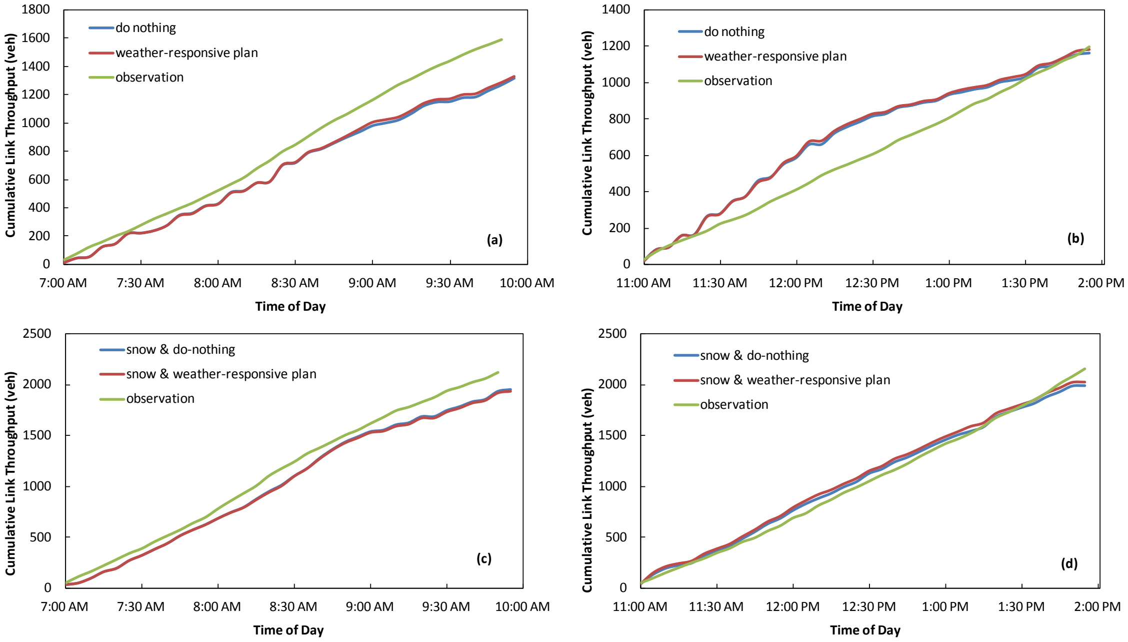


Figure 4-15. Simulated throughput at Intersection 5004: (a) eastbound peak; (b) eastbound off-peak; (c) westbound peak; (d) westbound off-peak

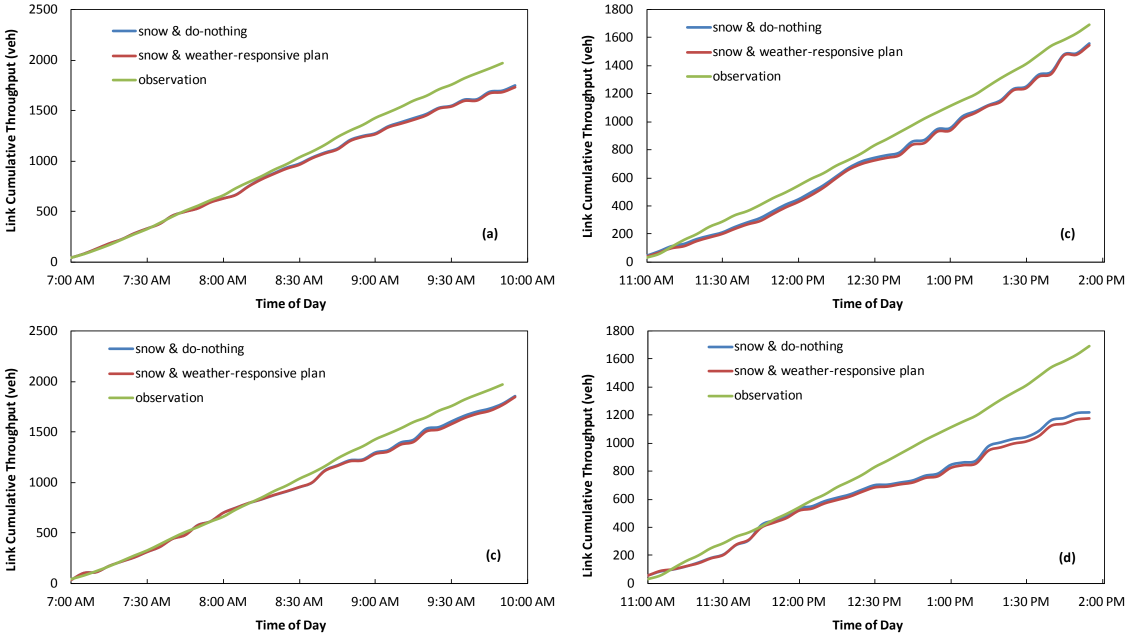


Figure 4-16. Simulated throughput at Intersection 5009: (a) eastbound peak; (b) eastbound off-peak; (c) westbound peak; (d) westbound off-peak

This does not mean that theoretical or maximal throughput could not be increased or improved through signalization; it simply indicates that for the existing demand patterns, as the demand is served, the level of service in terms of vehicles stopped, stopped time, delay and reliability, is improved through the weather-responsive signalization plan, as discussed hereafter.

4.3.3.2 Stopped Time

Similar to corridor level analysis, stopped time is defined as the time that a vehicle spends waiting at the studied intersection. To evaluate the stopped time for individual intersections, vehicle trajectories that passed through those incoming links (from both eastbound and westbound) are studied, and stopped time at those signalized intersections are extracted from trajectories. Figure 4-17 and Figure 4-18 show the temporal profile of stopped time for the two selected Intersection 5004 and 5009.

Table A-5 and Table A-6 in the Appendix A present the statistics (sample size, mean, and standard deviation) of vehicle experienced stopped times at all 13 signalized intersections on Riverdale Road. Results include two major approaches (eastbound and westbound) during both peak and off-peak hours. Same as the corridor level analysis, the fraction of non-stopped vehicles at each intersection are reported under three different simulation scenarios. In many cases the results show that the snow event has adverse effect on traffic progression, and UDOT's weather-responsive signal plan can improve the performance of signal coordination. The results hold for the corridor as a whole, as well as for most of the individual intersections that comprise it, albeit to varying degrees (for example, intersection 5007 eastbound and intersection 5001 westbound do not perform as well under the weather plan under the simulated scenarios).

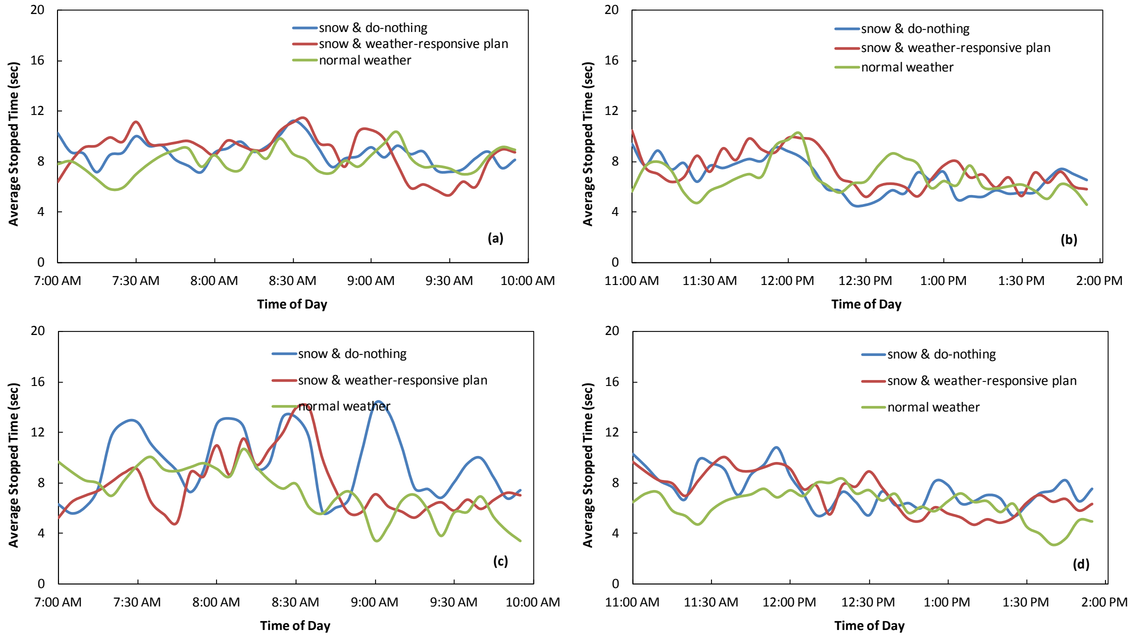


Figure 4-17. Simulated stop time at Intersection 5004: (a) eastbound peak; (b) eastbound off-peak; (c) westbound peak; (d) westbound off-peak

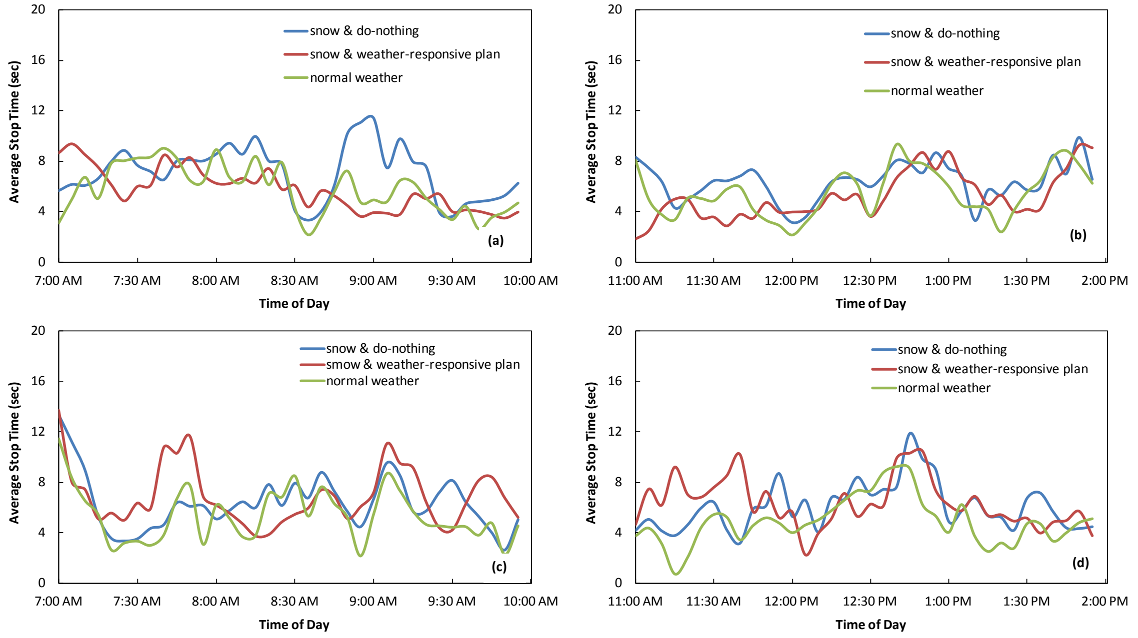


Figure 4-18. Simulated stop time at Intersection 5009: (a) eastbound peak; (b) eastbound off-peak; (c) westbound peak; (d) westbound off-peak

4.3.4 Travel Time Reliability

As the distribution of travel time can be constructed from vehicle trajectory data, travel time reliability measures can be computed from the travel time distribution. Several commonly used travel time reliability measures (Lomax et. al., 2003; Cambridge Systematics, 2010) are introduced here:

- Buffer Index ((95th percentile travel time – mean travel time) / mean travel time)
- Travel Time Index(mean travel time / free flow travel time)
- Planning Time Index (95th percentile travel time / free flow travel time)
- Misery Index (mean of the highest 5% of travel times / free flow travel time)

All these metrics are popular for travel time reliability evaluation; however, they emphasize different aspects. The Travel Time Index represents the average travel time normalized by its free flow travel time. The buffer index represents the extra time that travelers must add to their average travel time when planning trips to ensure on-time arrival. The planning time index represents how much total time a traveler should allow ensuring on-time arrival. While the buffer index shows the additional travel time that is necessary, the planning time index shows the total travel time that is necessary. The Misery Index, on the other hand, seeks to measure the length of delay of the worst trips.

Table 4-8 and Table 4-9 summarize the performance measures of travel time reliability for the two selected corridor segments (Figure 4-4) eastbound and westbound respectively. Figure 4-19 provides visual comparison of travel time reliability performance for the three simulation scenarios.

Table 4-8. Travel Time Reliability Measures for Eastbound Corridor Segments

Scenario	Corridor Segment	Eastbound			
		Buffer Index	Travel Time Index	Planning Time Index	Misery Index
normal weather	segment 1	24%	1.42	1.76	1.87
	segment 2	17%	1.41	1.66	1.70
snow with normal plan	segment 1	35%	1.52	2.06	2.15
	segment 2	16%	1.67	1.93	2.00
snow with weather-responsive plan	segment 1	28%	1.49	1.91	2.02
	segment 2	14%	1.66	1.90	2.00

Table 4-9. Travel Time Reliability Measures for Westbound Corridor Segments

Scenario	Corridor Segment	Westbound			
		Buffer Index	Travel Time Index	Planning Time Index	Misery Index
normal weather	segment 1	14%	1.33	1.52	1.58
	segment 2	17%	1.50	1.76	1.88
snow with normal plan	segment 1	17%	1.33	1.55	1.63
	segment 2	27%	1.71	2.17	2.25
snow with weather-responsive plan	segment 1	21%	1.35	1.63	1.69
	segment 2	23%	1.68	2.07	2.20

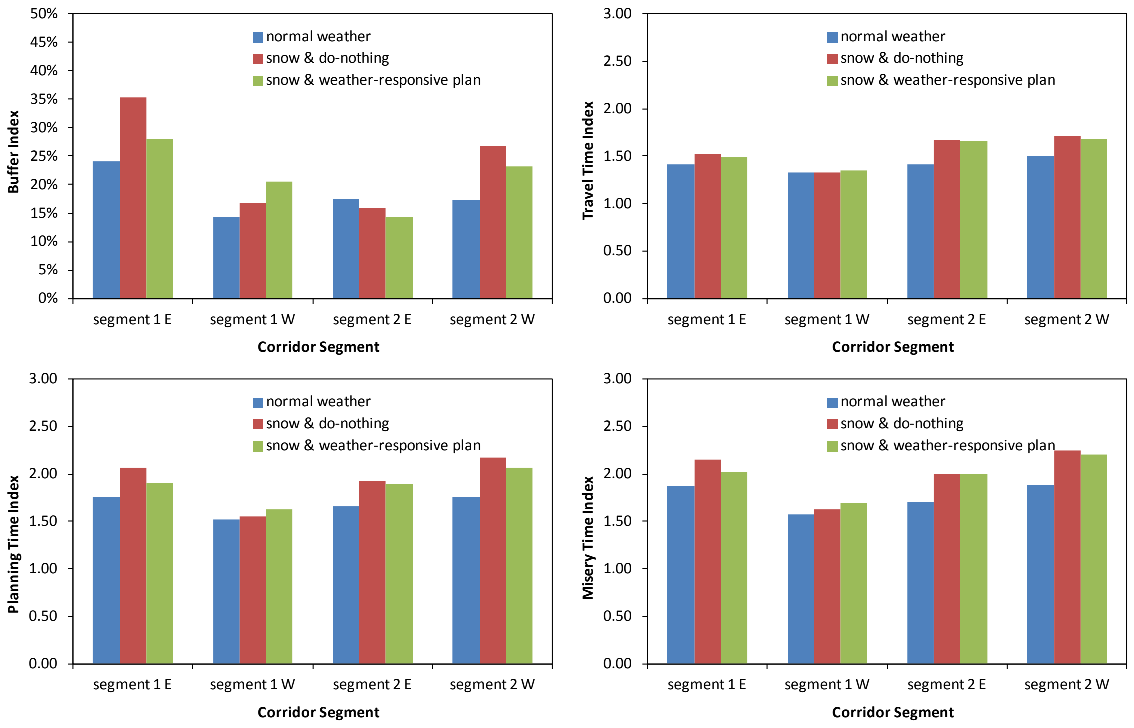


Figure 4-19. Travel Time Reliability Performance Comparison

By comparing the reliability measures under three different scenarios, it is shown that the four different metrics give fairly consistent results. As the buffer index indicates, the travel time on corridor segment 1E, 1W, and 2W become more unreliable under adverse weather condition. Moreover, according to all the metrics discussed in this study, UDOT's weather-responsive signal plans generally help reduce travel time unreliability for the corridor overall, especially segments 1E, 2E, and 2W (the improvement does not hold for corridor segment 1W).

Chapter 5. On-line Weather-Responsive TrEPS Implementation and Evaluation

5.1 Overview of Weather-Responsive TrEPS

It is the main simulation engine that estimates and predicts network conditions under a particular input scenario. This study uses DYNASMART-X, a state-of-the-art real-time TrEPS that is based on a simulation-based Dynamic Traffic Assignment (DTA) model. DYNASMART-X interacts continuously with loop detectors and roadside sensors to receive real-time traffic data, which it uses to estimate and correct the origin-destination (OD) demand through various consistent checking mechanisms (Mahmassani et al., 2009). To account for the uncertainty in OD and network conditions, the model uses the rolling horizon (RH) approach (Peeta and Mahmassani, 1995), where the future network state is predicted for a fixed-length prediction horizon—1 hour ahead in this study—based on the most up-to-date OD information and the prediction result is updated and replaced with a new state prediction for the next prediction interval at every 5 minutes.

5.1.1 Scenario Manager

The Scenario Manager, introduced in Section 1.3, is a scenario generation and management tool that serves as an interface between the TrEPS real-time simulation engine and a human decision maker (Figure 5-1). The role of the Scenario Manager is to facilitate the process of developing and preparing input scenarios for the TrEPS model and the exchange of information between TrEPS and TMC operators, as shown in Figure 1-3. Figure 5-1 illustrates three different cases where TMC operator, Scenario Manager and TrEPS interact with one another during the real-time TrEPS implementation.

- *Scenario Initialization*: at the beginning of the implementation, the operator uses the Scenario Manager to prepare an initial scenario set for the given day (e.g., 24-hr weather scenario and TOD signal timing plans) and launch the TrEPS model.
- *Scenario Generation*: during the implementation, if TrEPS predicts a noticeable decrease in corridor link speed due to a weather event, the TMC operator can use the Scenario Manager to obtain suggestions for an alternative signal timing plan, which the Scenario Manager retrieves from a Scenario Library—a database of available weather-responsive signal timing plans (see below for more details)—based on TrEPS-predicted link speeds. The Scenario Manager creates necessary input files associated with the alternative plan to initiate another branch of TrEPS simulation to observe the alternative future under the new scenario. The TrEPS model can predict the network state under the new scenario (with

intervention) in parallel with the network state under the original scenario (without intervention).

- *Scenario Evaluation*: once the TrEPS completes the state prediction for the next prediction interval, the Scenario Manager extracts various performance measures from the simulation output and presents to the TMC operator a side-by-side comparison of network states with and without intervention. If the TMC operator concludes that the expected benefit of switching to the alternative plan is significant, the selected alternative timing plan is deployed to the real network through the TMC's traffic signal control system. If the expected benefit is not significant enough, another alternative scenario may be considered by going back to the *Scenario Generation* step.

The *Scenario Generation* and *Scenario Evaluation* procedures may be repeated whenever there is a need for considering an alternative weather-responsive plan or switching back to the normal TOD plan due to changes in network conditions. Scenarios generated by the Scenario Manager are mainly weather and signal timing scenarios. For generating weather scenarios, the Scenario Manager receives current and forecasted weather information from various sources such as road weather information system (RWIS), TMC meteorologist and national weather service (NWS), and constructs the software-specific input file specifying the required weather parameters (e.g., visibility, precipitation type and intensity). For signal timing scenarios, the Scenario Manager interacts with the *Scenario Library*, which is a database or a set of rules defining which signal timing plan should be used under what circumstances, to identify the best-matching timing plan in response to changing traffic conditions. A detailed user's guide for the Scenario Manager Is provided in Appendix B.

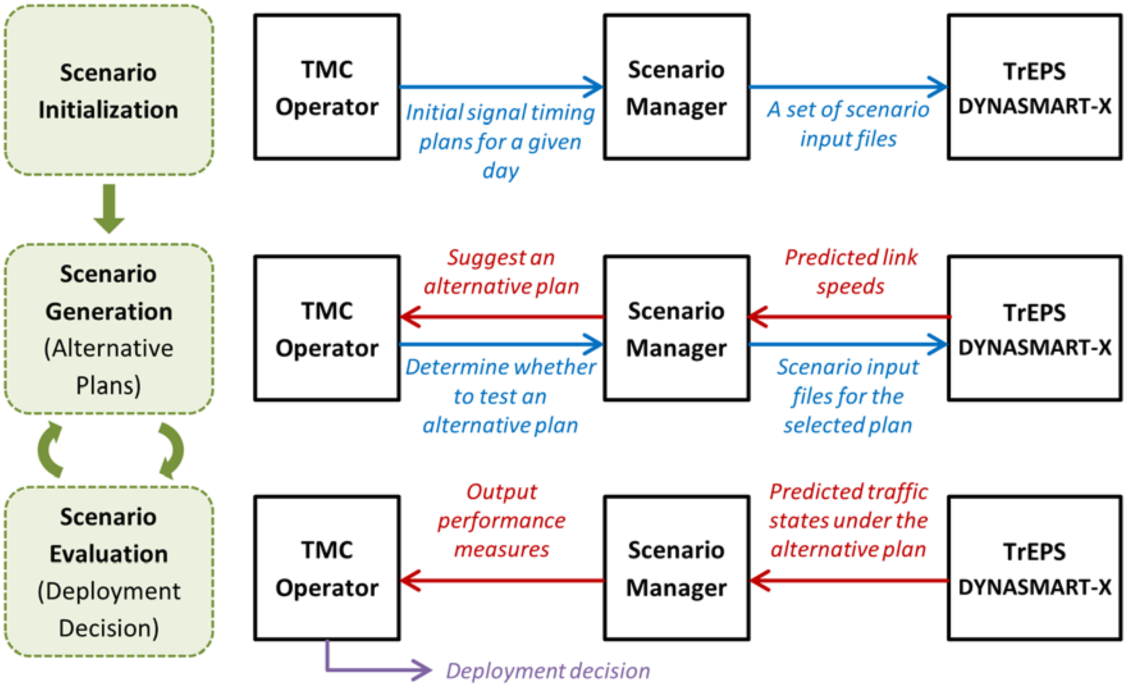


Figure 5-1. Framework of TrEPS-based Decision Support System for Weather-responsive Traffic Signal Operations

5.1.2 Scenario Library: Weather Responsive Signal Timing Plans

Deploying a particular signal plan involves setting a large number of control parameters for individual traffic signals. From a practical point of view, it is often not feasible for TMC operators to create a new plan whenever parameter adjustments are needed. As such, it is a common practice that TMC operators maintain a manageable number of pre-defined "canned" action sets, each of which defines all the parameters and coordination settings for the entire corridor associated with each timing plan, and simply switch between these existing plans during the operation. The Scenario Library approach is introduced to aid this type of operation.

Table 5-1 shows an example of the signal timing plan deployment rules defined in Scenario Library. UDOT implements four TOD plans (Plan ID=1, 4, 13, 19) during weekdays under normal conditions. Each plan specifies cycle length, split and offset for each of the 13 signals in Riverdale Rd. The offset value of each signal is determined based on the posted link speed for the incoming links of the intersection. For each TOD plan, UDOT has developed three weather plans, where only offset values are adjusted based on assumed speed drops in the link speeds—5, 10 and 15 mph, respectively—and all other parameters are unchanged from its base-case TOD plan. For instance, between 6:30 and 9:00, Plan 1 is deployed when there is no weather. When the overall link speeds along the corridor decreases by 5 mph (with respect to their associated posted speeds) due to a weather event, Plan 60 is deployed instead. Plan 58 and 64 are deployed when speed drops are 10 mph and 15 mph, respectively.

Table 5-1. Scenario Library Defining Deployment Rules for Normal and Weather-Responsive Signal Timing Plans (Weekdays)

Time period	**Signal Timing Plan ID**			
	Time-of-day plan	***Weather plans***		
		Speed reduction level[a]		
		-5 mph	*-10 mph*	*-15 mph*
6:30-9:00	1	60	58	64
9:00-13:00	4	69	67	70
13:00-18:30	13	57	55	61
18:30-21:00	19	69	67	70

a. Assumed speed reduction in link speed with respect to the posted speed

5.1.3 DYNASMART-X

Inheriting the core simulation components from the offline planning tool (DYNASMART-P), the primary distinction of the online operational tool (DYNASMART-X) used in this study is its capability of interacting with multiple sources of real-time information and providing reliable estimates of network traffic conditions and predictions of network flow patterns.

A comprehensive DYNASMART-X simulation is triggered by the following six algorithmic modules:

(i) Network State Estimation (RT-DYNA) module provides up-to-date estimates of the current state of the network. It has the full simulation functionality as DYNASMART-P, and its execution is synchronized to the real-world clock.

(ii) Network State Prediction (P-DYNA) module provides future network traffic states for a pre-defined horizon, as an extension from the current network state estimated by RT-DYNA.

(iii) OD Estimation (ODE) module uses a Kalman filtering approach to estimate the coefficients of a time-varying polynomial function that is used to describe the structural deviation of OD demand in addition to a historical regular pattern.

(iv) OD Prediction (ODP) module uses the predicted OD coefficients provided by ODE to calculate the demand that is generated from each origin to each destination at each departure time interval. The predicted time dependent OD matrices are used for both current (RT-DYNA) and future (P-DYNA) stages.

(v) Short Term Consistency Checking (STCC) module uses the link densities and speeds of the simulator to evaluate the consistency of the flow propagation with the real-world observations and correct the simulated speeds.

(vi) Long Term Consistency Checking (LTCC) module compares the simulated and observed link counts to calculate scaling factors that are used to adjust the demand level in both RT-DYNA and P-DYNA.

It is noted that STCC is executed much more frequently than LTCC. The purpose of these two levels of consistency checking is to minimize the deviation or discrepancy between what is estimated by the system and what is occurring in the real world, in an effort to control error propagation.

The algorithmic components described above form the main structure of the DYNASMART-X system. The inter-connection between these components and the basic data flow model are illustrated in Figure 5-2. It also includes the interaction between DYNASMART-X system and external real world, as STCC, LTCC, and ODE form the data interface, which receives real-time measurements (count, speed, and occupancy) continuously from traffic detectors.

Two additional modules, namely the Data Broker (DBK) module and the Management (MAN) module, serve as supporting entities that are used to integrate the algorithmic modules, implement the simulation logic and to maintain efficient and consistent communication of the different data elements. Specifically, DBK is a central database for the simulation system, which provides means for transferring run-time data between modules and components. The management module, which plays the role of the central controller of the simulation system, is responsible for bootstrapping the system, synchronizing and scheduling the execution of different modules, and interfacing with external clients.

The entire system is implemented as a distributed application using the CORBA (Common Object Request Broker Architecture) communication protocol, in which each module within the system is acting as a CORBA object that exhibits its own functionality. The system is designed to run in a rolling horizon framework (Peeta and Mahmassani 1995), with multiple asynchronous horizons for the various modules, as shown in Figure 5-3. CORBA ensures that the running time is in sync with the real world clock.

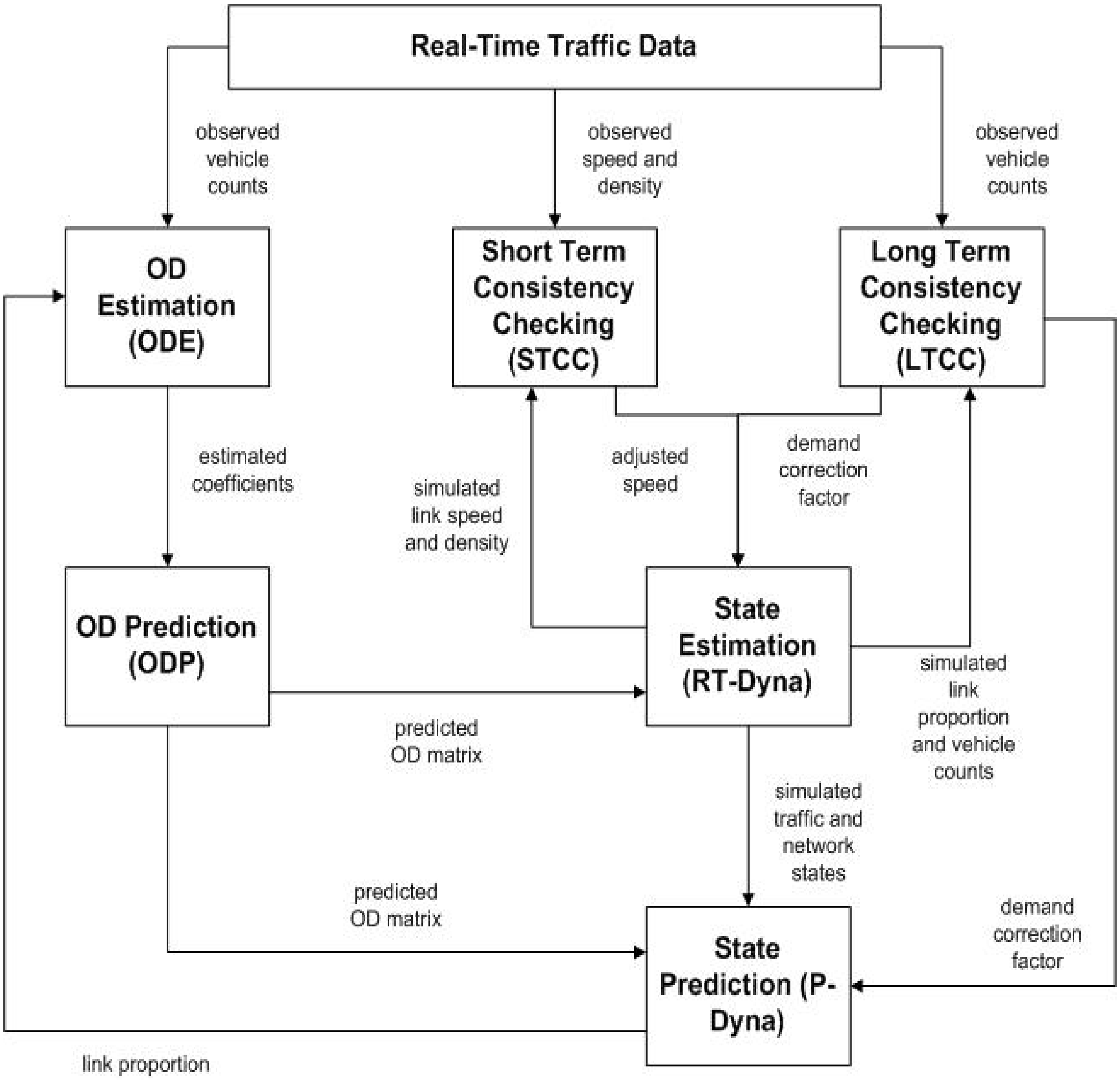


Figure 5-2. System Structure of DYNASMART-X and Data Flow

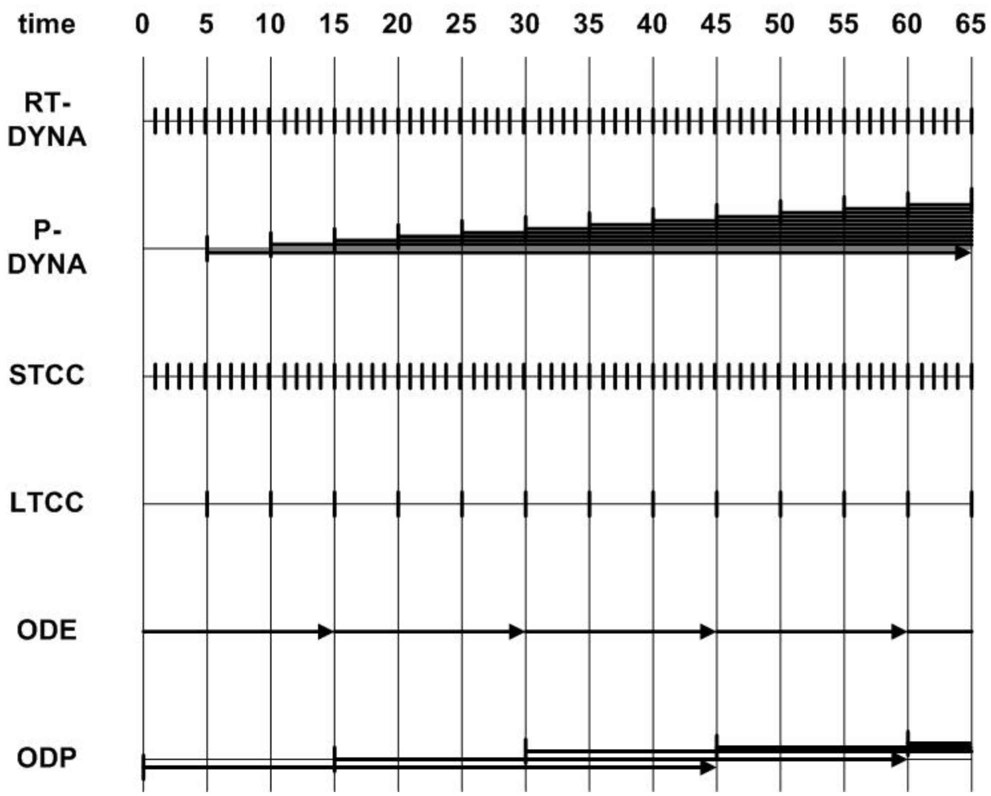
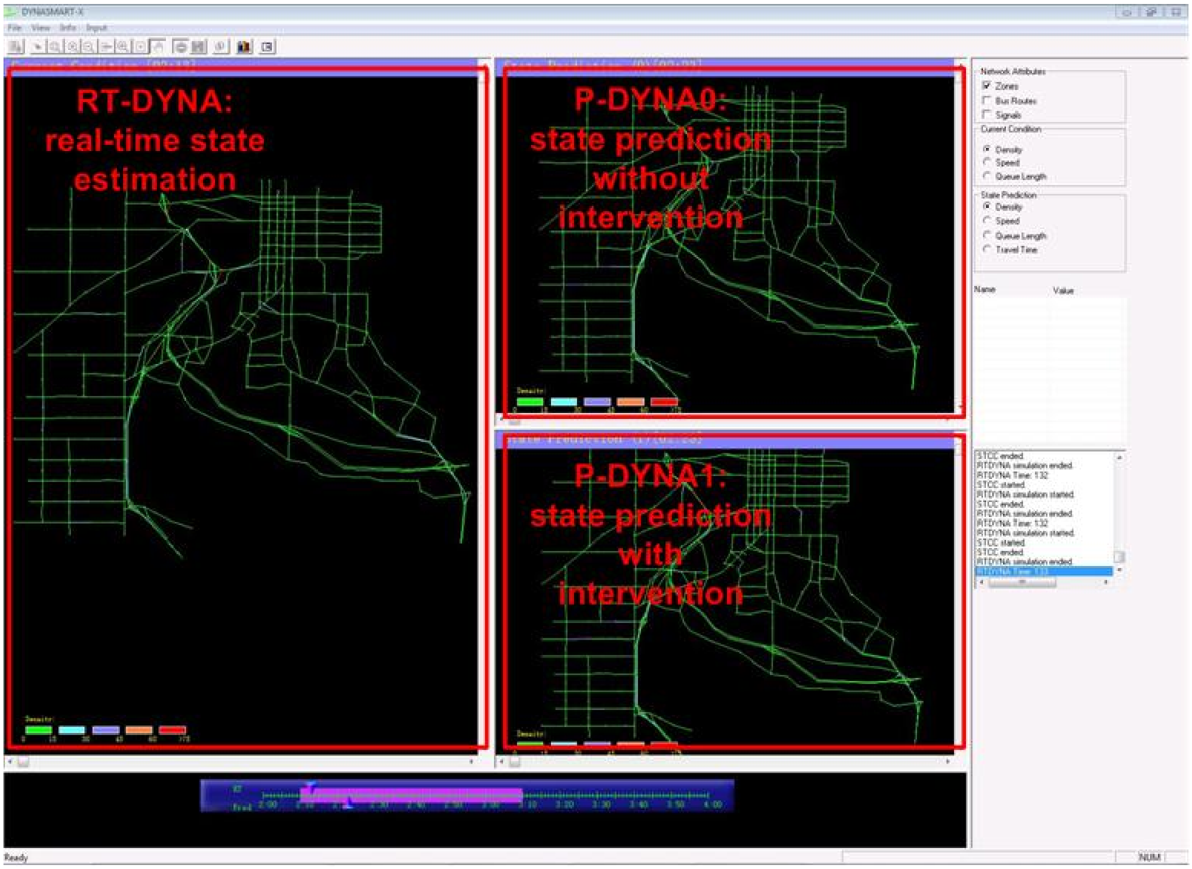


Figure 5-3. Rolling Horizon Framework of DYNASMART-X

The RT-DYNA module is executed every 30 seconds to continuously provide up-to-date estimates of the current state of the network. The P-DYNA module is executed less frequently, i.e. every 5 minutes, to project the current network state for a period (1 hour) in the future. The ODE and ODP modules provide the time-dependent OD desires in the network to be used in the simulation-assignment procedures of the state estimation and prediction. They also run periodically. The Consistency Checking modules (STCC and LTCC) interface periodically with the surveillance data collected from sensors and probes in the network, and correct some of the state estimation variables for discrepancies between the estimated values and the measured ones. The running periods of each module are all design parameters that can vary according to the particular network being modeled and the experimental setting.

The graphical user interface (GUI) is another supporting component in DYNASMART-X, which aims to provide a convenient environment for executing the algorithms by allowing users to enter input data and enables users to view and analyze simulation results "on the fly". Figure 5-4 presents a snapshot of the DYNASMART-X system running for the extracted Riverdale network. The three windows in the user interface display the current prevailing traffic conditions, a predicted traffic condition without implementing traffic management strategy, and a predicted traffic condition with management strategy.



Network Attributes
☑ Zones
☐ Bus Routes
☐ Signals

Current Condition
● Density
○ Speed
○ Queue Length

State Prediction
● Density
○ Speed
○ Queue Length
○ Travel Time

```
STCC ended.
RTDYNA simulation ended.
RTDYNA Time: 132
STCC started.
RTDYNA simulation started.
STCC ended.
RTDYNA simulation ended.
RTDYNA Time: 132
RTDYNA simulation started.
STCC started.
STCC ended.
RTDYNA simulation ended.
RTDYNA Time: 132
```

Figure 5-4. Riverdale Network (Ogden, UT) as Displayed in DYNASMART-X GUI

5.2 Real-Time Traffic Estimation and Prediction

5.2.1 Real-Time Traffic Data

As a real-time dynamic traffic simulation system, DYNASMART-X reads real-time traffic data and makes use of those data for adjusting simulated results. As introduced before, the real-time adjustment is performed by two separate functional components, namely Short Term Consistency Checking (STCC) unit and Long Term Consistency Checking (LTCC) unit. STCC adjusts discrepancies in the prevailing speed of observation links in the network, while LTCC adjusts discrepancies in the OD demand data that is fed into the DTA simulator.

Both consistency checking units interact with real-world traffic surveillance data and calculate correction factors that are fed back into real-time traffic simulator (RT-DYNA) and applied to the appropriate variables in the “immediate future”, i.e. the instance of RT-DYNA that runs after these correction factors are obtained. In this experiment, there are two distinct sets of real-time traffic data available from two different data sources. Freeway traffic data (on Interstate I-15), which include occupancy, speed, and flow, are transmitted in the XML format from the Freeway Performance Measurement System (PeMS); while arterial data (on Riverdale Road), which include speed and vehicle counts, are queried from UDOT's local database system. The locations of the available detectors are displayed in Figure 5-5. The consistency checking units within DYNASMART-X are developed in a way that they accommodate real-time traffic information from both sources.

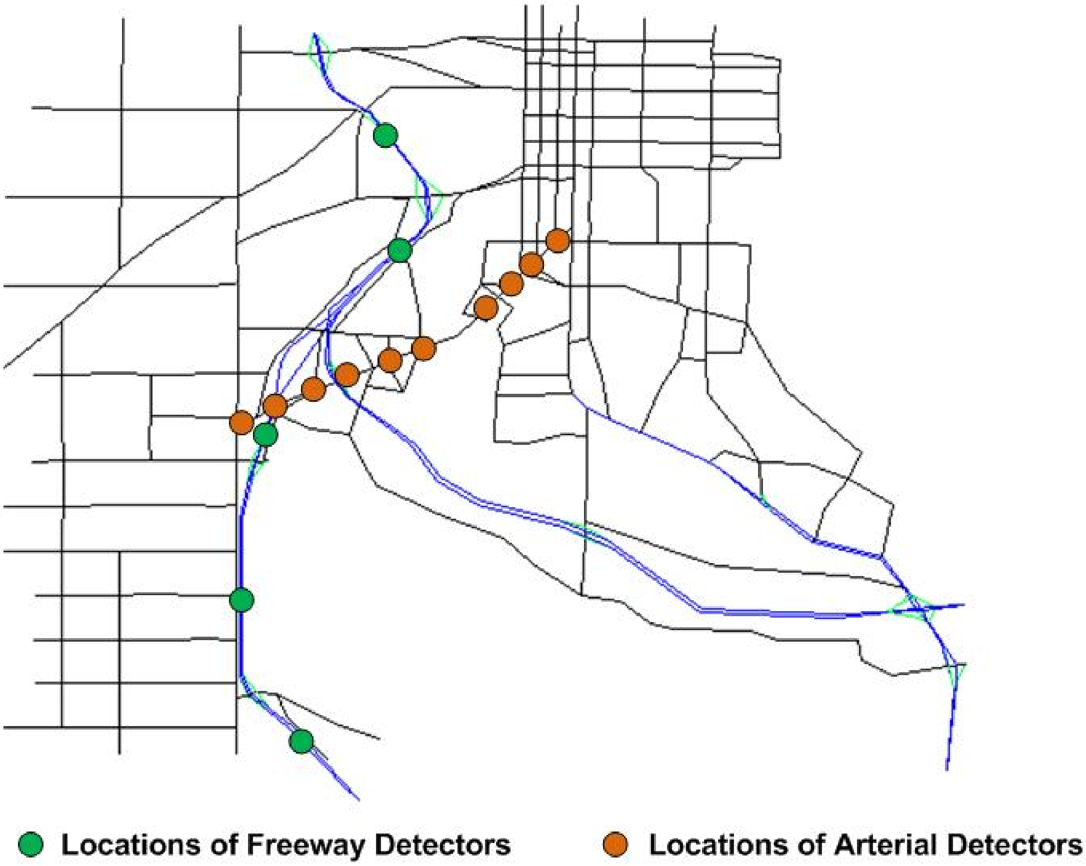


Figure 5-5. Locations of Detectors with Real-time Traffic Information

5.2.2 Supply-side Real-time Estimation and Prediction

DYNASMART-X uses modified Greenshields model to simulate traffic propagation. The model is a static speed-density relation, which can be expressed in mathematical forms as:

$$v_i = v_0 + (v_f - v_0) \cdot (1 - \frac{k_i}{k_{jam}})^a \tag{5-1}$$

where v_i is speed on link *i*; v_f is speed-intercept; v_0 is minimum speed of the link; k_i is density on link *i*; and k_{jam} is jam density of the link. During the simulation process, the STCC function is triggered every 30 second when new real-time traffic data become available. In this experiment, no real-time trajectory data is available, and traffic data collected from fixed sensors are instead used for demonstration purpose.

Depending on the information contained within the data, different algorithms are used to adjust the simulated link speeds for links on observation links (Doan et al. 1999). When real-time speed information is available, we adjust the speed by adding a fraction of the discrepancy between measured and simulated speed according to the following equation.

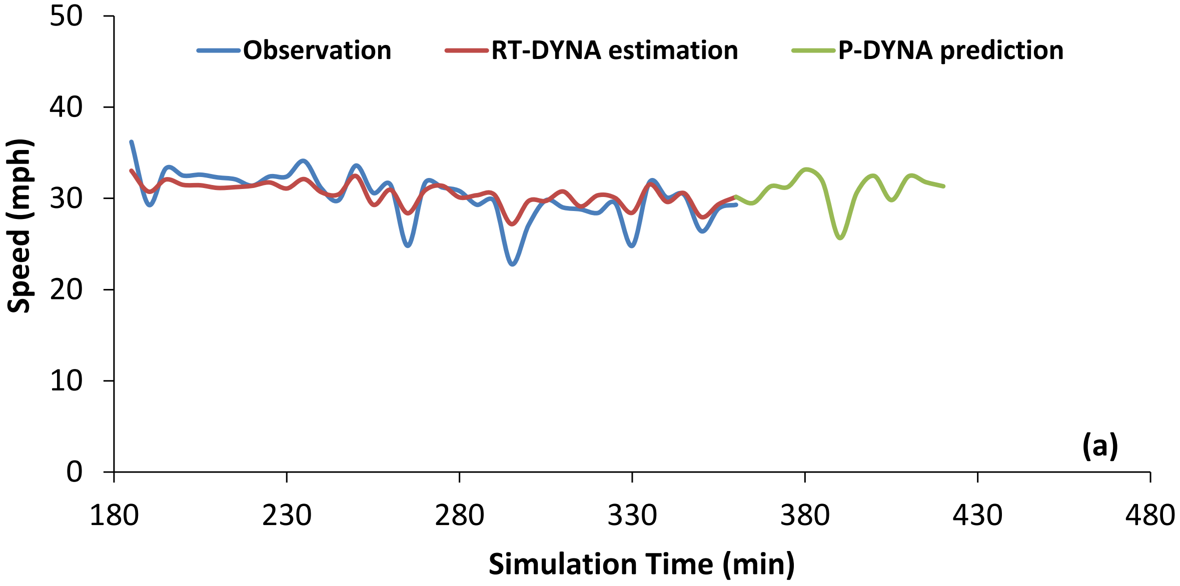
$$\begin{aligned} v_{adjusted} &= v_{simulated} + \Delta v \\ &= v_{simulated} + \alpha \cdot \left(v_{measured} - v_{simulated}\right) \end{aligned} \tag{5-2}$$

where $v_{adjusted}$ is link speed after adjustment; $v_{simulated}$ is simulated link speed before adjustment; $v_{measured}$ is real-time speed measurement; and α is a fractional factor between 0 and 1, which is a user specified number reflecting the confidence in real-time measurement. When speed data is not available, short term consistency checking can still be performed if real-time density information is available. In this case, we first compute the difference between the latest simulated link density and real-world measured link density, and then uses this discrepancy on density to adjust link speed according to the following equation. The adjusted link speed is later used in the following simulation interval.

$$\begin{aligned} v_{adjusted} &= v_{simulated} + \Delta v \\ &= v_{simulated} + \frac{dv}{dk}\Delta k + \frac{1}{2}\frac{d^2 v}{dk^2}(\Delta k)^2 + o(\Delta k) \end{aligned} \tag{5-3}$$

Equation 6-3 is based on second order Taylor approximation, where $v_{adjusted}$ is link speed after adjustment; $v_{simulated}$ is simulated link speed before adjustment; $\frac{dv}{dk}$ is first order derivative of link speed with respect to density; $\frac{d^2v}{dk^2}$ is second order derivative of link speed with respect to density; Δk is difference between simulated link density and measured link density; $o(\Delta k)$ is high order terms of density discrepancy which is negligible. Note that when density information is not directly available, occupancy data need to be first converted to density before the adjustment procedure is carried out.

In this experiment, speed data is directly recorded by the radar detectors on Riverdale road, and thus STCC is conducted using Equation 5-2, in which we specified α to be 0.5. As an example, the simulated link speed and adjusted link speed after reading real-world measurements, for two selected links on Riverdale Road are presented in Figure 5-6. The results indicate that DYNASMART-X performed fairly well in estimating and predicting vehicle moving speeds as compared to real-world observations.



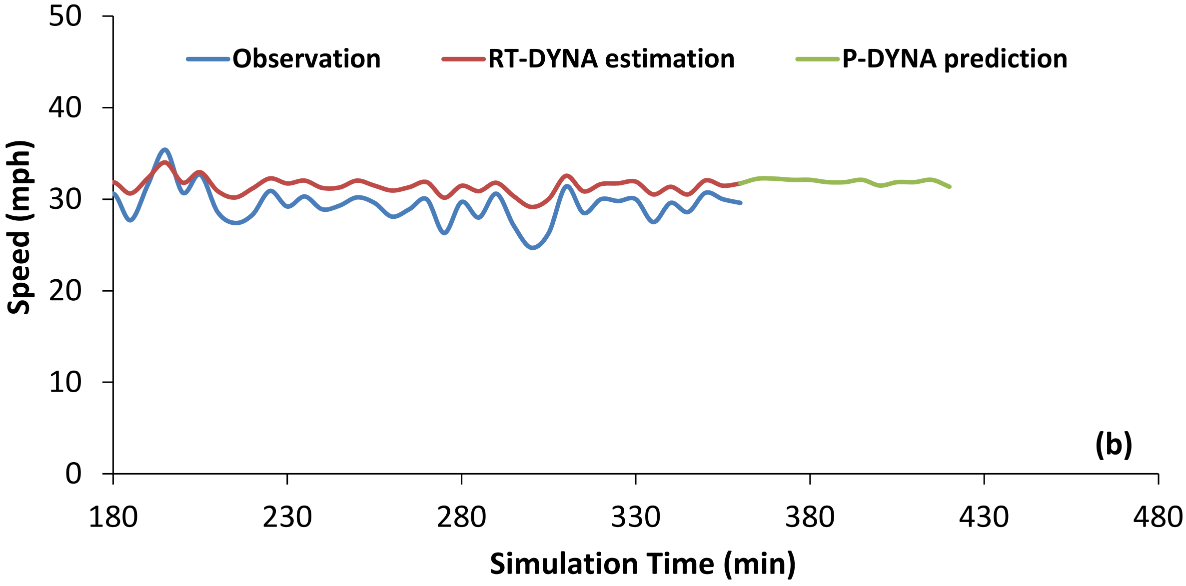


Figure 5-6. Online Estimated and Predicted Speed vs Observed Speed for Selected Links Eastbound on Riverdale Road (a) upstream of 700W; (b) upstream of E40th St.

5.2.3 Demand-side Real-time Estimation and Prediction

Dynamic origin-destination (OD) demand estimation and prediction is an essential support function for real-time dynamic traffic assignment model systems for ITS applications. By using historical demand information and real-world traffic measurements from surveillance devices, the goal of the dynamic OD demand estimation and prediction problem is to estimate time-dependent OD trip demand patterns at the current stage, and to predict demand volumes over the near and medium terms in a general network (Mahmassani and Zhou, 2005).

This section describes the functionality of on-line traffic demand estimation and prediction modules, which generate time-dependent traffic demand matrices for the dynamic traffic assignment and associated network traffic simulation. In the context of real-time dynamic traffic assignment and based on a Kalman filtering framework, an optimal adaptive procedure is used by DYNASMART-X in capturing day-to-day demand evolution.

5.2.3.1 Methodology and Mechanism

In general, most travelers travel between their residences and work places on a more or less fixed schedule, contributing to the daily dynamic traffic patterns. Hence, regular day-to-day OD trip demand is a repeated process with similar within-day dynamic patterns, albeit with some fluctuations. By utilizing data from household interview surveys and off-line estimation results on multiple days, historical demand data represents a priori estimate of the regular OD demand pattern. Especially, in the context of long-range demand prediction, reliable historical data can serve as an informative source under normal conditions. However, some severe weather conditions, special events or the responses of travelers to information and/or other system management measures may result in the structural deviations of real-time OD demand from the regular pattern. Severe weather conditions and special events critically affect the effectiveness of travel demand management systems. With increasing accessibility, traveler information plays an important role in gradually changing day-to-day trip-making decisions and generating temporal distributions of daily OD demand.

To provide accurate and robust demand estimation and prediction for real-time dynamic traffic assignment in operational settings, the following primary functional requirements need to be satisfied: (1) incorporate regular demand information into the real-time demand prediction process; (2) recognize and capture possible structural changes in demand patterns under various conditions; and (3) optimally update the a priori estimate of the regular pattern using new real-time estimation results and traffic observations. In DYNASMART-X, we assume the actual dynamic OD demand, $D_{(j,\tau)}$, consists of three components, namely, the regular pattern, structural deviations, and random fluctuations (Zhou and Mahmassani, 2007).

$$D_{(j,\tau)} = \tilde{D}_{(j,\tau)} + \mu_{(j,\tau)} + \varepsilon_{(j,\tau)} \tag{5-4}$$

where,

$D_{(j,\tau)}$ = demand volume from origin-destination pair *j* during departure time interval τ;

$\tilde{D}_{(j,\tau)}$ = a priori estimate of regular demand volume for origin-destination pair *j* during departure time interval τ;

$\mu_{(j,\tau)}$ = structural demand deviation from a priori estimate $\tilde{D}_{(j,\tau)}$ for OD pair *j* with departure time τ;

$\varepsilon_{(j,\tau)}$ = error term in approximating true demand for OD pair *j* with departure time τ.

The error term is assumed to follow a normal distribution with zero mean. Theoretically, before processing real-time estimation, only the a priori estimate $\tilde{D}_{(j,\tau)}$ of the regular demand, representing prior survey data and surveillance information, which are related to the historical data, is available. For describing the structural deviations $\mu_{(j,\tau)}$, a polynomial model is introduced based on the following assumptions.

$$\mu_{(j,\tau+\zeta)} = b_0 + b_1\zeta + b_2\zeta^2 + \cdots b_p\zeta^p + \cdots + b_m\zeta^m \tag{5-5}$$

According to Taylor's theorem, $\mu_{(j,\tau+\zeta)}$ can be expanded about the point $\mu_{(j,\tau)}$ as:

$$\mu_{(j,\tau+\zeta)} = \mu_{(j,\tau)} + \zeta\mu'_{(j,\tau)} + \frac{\zeta^2}{2!}\mu''_{(j,\tau)} + \cdots + \frac{\zeta^2}{(p)!}\mu^{(p)}_{(j,\tau)} \cdots + \frac{\zeta^m}{(m)!} + \mu^{(m)}_{(j,\tau)} \tag{5-6}$$

where,

p = order index of a polynomial model;

m = maximum order of a polynomial model;

$\mu^{(p)}_{(j,\tau)}$ = p^{th}-order derivative of demand deviation $\mu_{(j,\tau)}$.

While derivatives of higher orders are assumed to be zero, i.e., $\mu^{(p)}_{(j,\tau)} = 0$ for *p* > *m*, an *m*th-order polynomial function as Equation (5-6) near time *τ* for a small value of ζ can adequately represent deviation at time $\tau + \zeta$.

Based on these assumptions, the Kalman filtering algorithm is integrated into the following recursive estimation and prediction algorithm.

[Step 1]: (Initialization) Set up initial estimates $P_{0,0} = Var(Z_0)$ and $\hat{Z}_{0,0} = E(Z_0)$. Let k=1.

[Step 2]: (Prediction) Propagate the mean and covariance estimates from k-1 to k.

$$\hat{Z}_{k,k-1} = A_k\hat{Z}_{k-1,k-1} \tag{5-7}$$

$$P_{k,k-1} = A_k P_{k-1,k-1} A'_k + W_k$$

[Step 3]: (Estimation of state variable) After receiving new link proportions and link observations, calculate the weighting matrix as

$$K_k = P_{k,k-1}H_k^T(H_k P_{k,k-1} H_k^T + V_k)^{-1} \tag{5-8}$$

and then update the a posteriori mean and covariance estimates.

$$\hat{Z}_{k,k} = \hat{Z}_{k,k-1} + K_k(Y_k - H_k\hat{Z}_{k,k-1}) \tag{5-9}$$

$$P_{k,k} = (I - K_k H_k)P_{k,k-1} \tag{5-10}$$

[Step 4]: (Estimation of real-time demand) Calculate the estimation of real-time demand using new estimates $\hat{\mu}_{(j,\tau)}$

$$\hat{D}_{(j,\tau)} = E(\hat{D}^{r}_{(j,\tau)} + \mu_{(j,\tau)} + \varepsilon_{(j,\tau)}) = \hat{D}^{r}_{(j,\tau)} + \hat{\mu}_{(j,\tau)} \tag{5-11}$$

where τ = kl, kl+1, …, (k+1)l-1.

[Step 5]: Move estimation stage forward from *k* to *k*+1, and then go back to Step 2.

Furthermore, if it is assumed that measurement errors are independent, in order to avoid complicated matrix inversion in a real-time setting, a scalar updating strategy can be applied.

The next section first describes a rolling horizon execution framework for real-time OD estimation and prediction in the integration with real-time DTA simulators, followed by the introduction of a structural state space model for real-time OD estimation and prediction. By considering demand deviations from the a priori estimate of the regular pattern as a time-varying process, a polynomial filter is developed as the core model to capture possible structural deviations in real-time demand.

5.2.3.2 The Recursive Procedure of ODE (OD Estimation) and ODP (OD Estimation)

Figure 5-7 displays the recursive OD estimation and prediction procedure. Generally, this approach integrates real-time OD estimation and prediction with other on-line DTA components; specifically, the DTA simulator, which is relied upon to generate link proportions for the OD estimation module at the current stage, and OD prediction provides future OD demands for the assignment and simulation in the next stage. The prediction (or planning) horizon represents the time length for which forecasted OD demand should be available for the DTA simulator. The prediction horizon starts at the end of each estimation stage. For a given period, predictions are based on the estimation results obtained during the estimation stage, using observations streaming in real-time over a certain observation period. The real-time OD demand estimation and prediction procedure is briefly described in the following steps.

[Step 1]: Receive real-time traffic measurements from surveillance system.

[Step 2]: Acquire link proportion data from the DTA simulator.

[Step 2]: (ODE) Estimate time-varying OD demand matrices involved in the current estimation stage using the Kalman filtering method.

[Step 4]: (ODP) Predict OD demand matrices over next future horizon.

[Step 5]: Move to the next estimation stage, and then go back to Step 1.

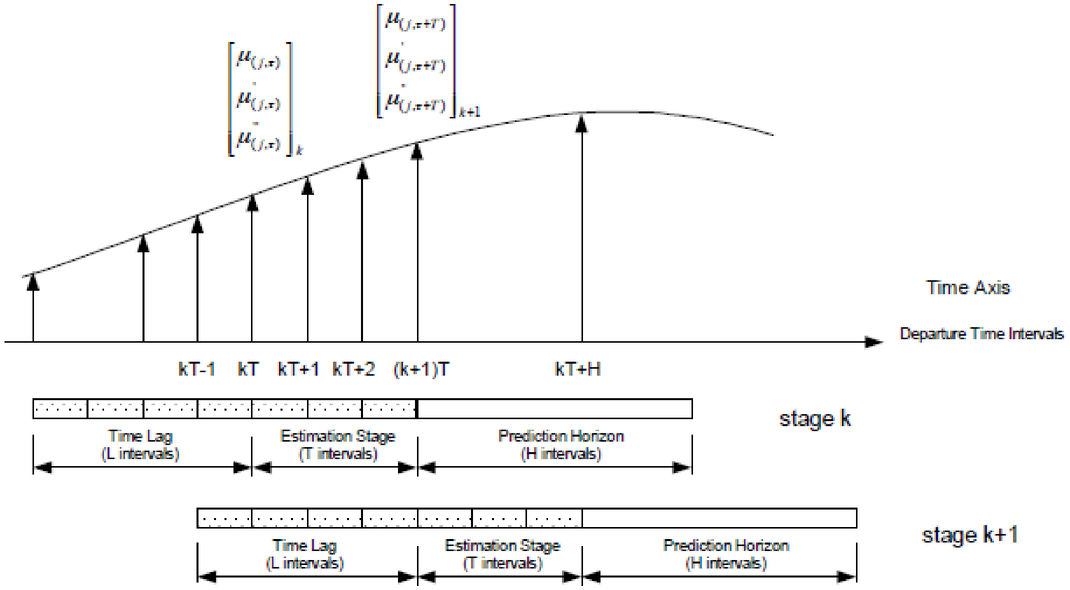


Figure 5-7. Illustration of Recursive Estimation Prediction Implementation

With the Kalman filtering technology, the estimated demand for all OD pairs is shown in Figure 1. The orange line represents the observation flow of Riverdale network from 2:00 pm to next day at 6:00 am. The blue line displays the estimated flow from May 29th 2:00 pm to May 30th 6:00 am. It can be observed that the estimated demand incorporates the historical information and at the same time access the real-time information given by the incoming sensor data to accommodate the day-to-day changes in traffic demand. The estimated demand matrices load vehicles to the network in traffic estimation procedure. The average RMSE of flow over all the observed links in online estimation is 75.143 against 81.185 in off-line estimation. Since the offline simulation only load predetermined OD demand tables, the online estimation keeps obtaining real-time data, which is used in updating quasi-continuously the internal representation of the system state by means of consistency checking and ODE and ODP. Hence, online application provides more accurate estimation than offline application does.

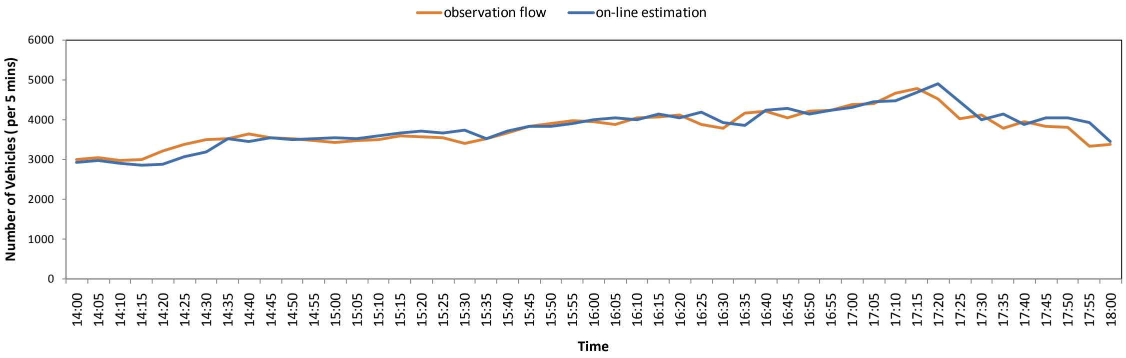


Figure 5-8. Comparison of Observed and On-line Estimated Demand

5.3 Implementation under Rain Scenario

5.3.1 System Setup and Scenario Preparation

Before the on-line experiment was implemented, it was predicted some weather forecast sources that there will be significant amount of rain precipitation on Saturday, April 26th 2014. In order to cover the whole rain period, and ensure there is enough time for the software to warm-up before rain starts, the simulation was started early at 4am on that day.

The input files needed to run the TrEPS system, including 24-hour demand, signal control, and weather files, are prepared by Scenario Manager. The rain scenario (visibility and precipitation intensity) is predicted as shown in Figure 5-9. According to the prediction, rain starts around 12pm in the noon, and the intensity increases from light to moderate at 6pm in the evening.

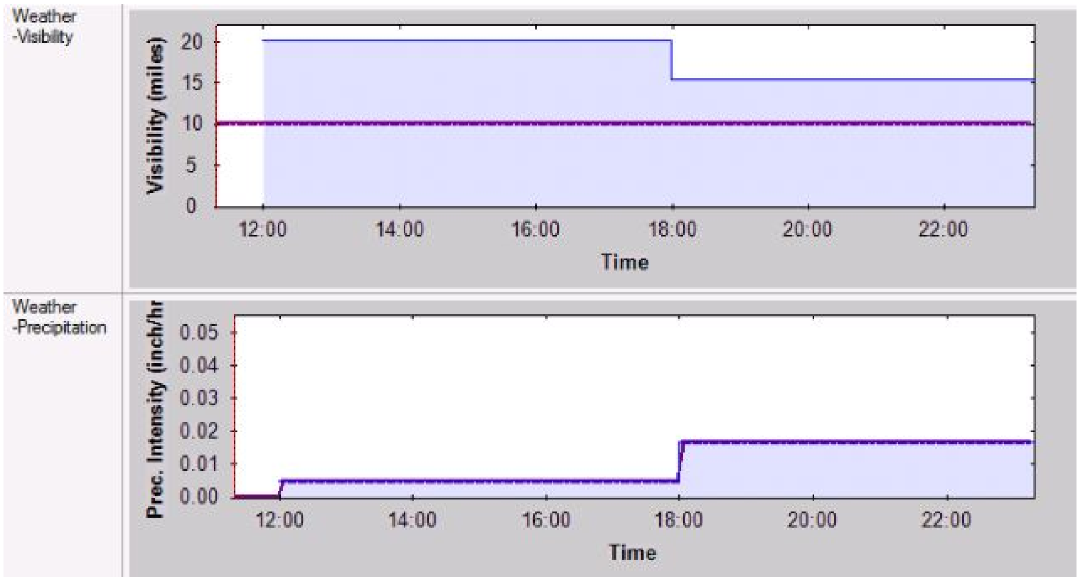


Figure 5-9. Visibility and Rain Intensity on April 26th 2014

On Saturdays, under clear weather condition, signal plans on Riverdale corridor are usually implemented in the following sequence:

12am-8am actuated, 8am-10am plan 1, 10am-6:30pm plan 13, 6:30pm-9pm plan 19, 9pm-12am actuated.

The purpose of running this experiment is to find out if a weather-responsive signal plan is necessary for rainy weather, and if yes, how these plans could improve traffic performance. The answers are examined in the following section.

5.3.2 Online Performance Monitoring

A main purpose of using TrEPS is to continuously monitor the performance of network traffic state through real-time estimation and prediction. In a traditional way, this is usually accomplished by keeping close watch over the speed or density measurements at certain selected links within the network, as what was done in the previous section. However, the traffic states in the links that are measured by detectors do not necessarily represent the performance of the entire network, and system-wide evaluation requires incorporating macroscopic or network traffic flow models. The geographically wide spread trajectory data generated by DYNASMART-X provides us a way of estimating and predicting network traffic states from different perspectives. The offline models and methodologies can be directly applied in the online environment with minimum modifications.

The on-the-fly monitoring of network performance and its changes over time could help agencies better understand the causes and develop necessary treatments. A properly calibrated network model can serve as the basis for an operational scheme for network traffic management and control. Some common strategies to improve network traffic conditions include pricing, dedicated lanes, signal control, ramp metering, variable message sign, variable speed limit, traffic incident management, etc. Recently, Haddad et al. (2012) and Keyvan-Ekbatani et al. (2012) have investigated perimeter control strategies based on the notion of NFD. They found out that, by restricting the accumulation of vehicles in a protected sub-network through gating control on the periphery of the sub-network, a satisfactory level of network throughput can be maintained saturated traffic conditions, and the vehicular accumulation will never enter the gridlock regime. However, most of these management strategies are mainly based on results from offline simulation experiments, and have not been verified under real-world environment.

In this study, a total number of 13 signalized intersections are identified along the Riverdale corridor (Figure 2-6) in the study network. The actual timing plans of these 13 signals are provided by UDOT. The information are then converted into DYNASMART required simulation input format, which includes control type, number of phases, cycle length, maximum green, minimum green, offset, amber time etc. In this example, signal coordination on Riverdale Road was initially operated under the base plan. The advantage of using DYNASMART-X TrEPS is that we can continuously monitor the actual speed along the corridor of interest, and decide which signal plan to implement based on short-term predictions.

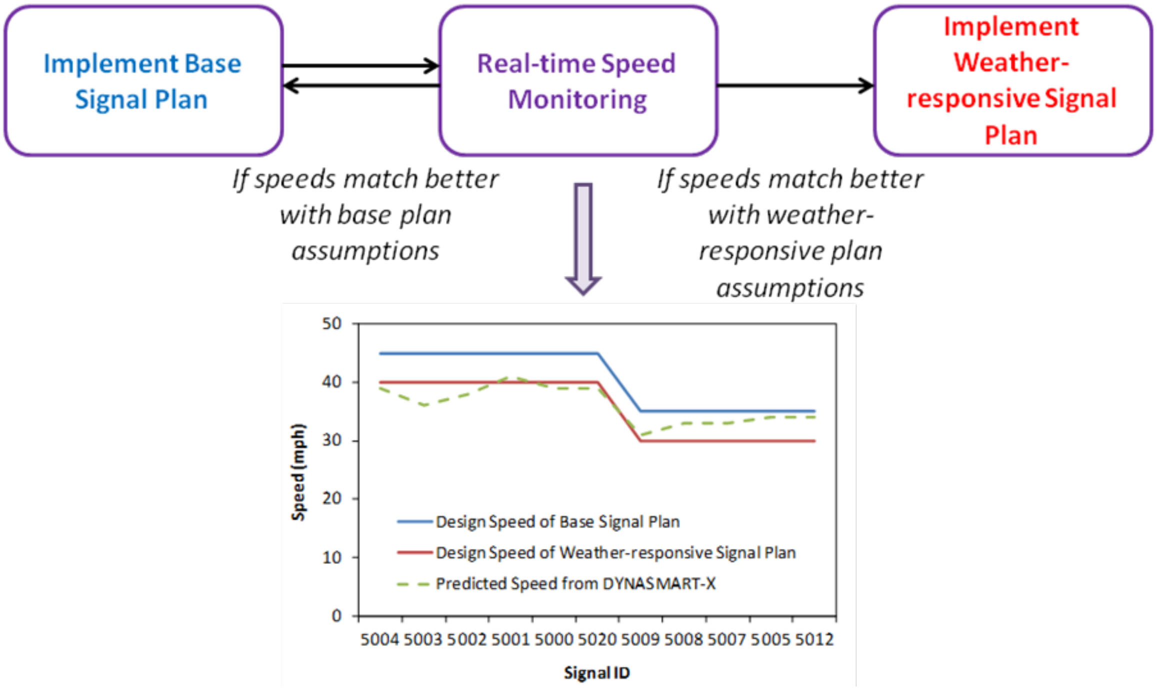
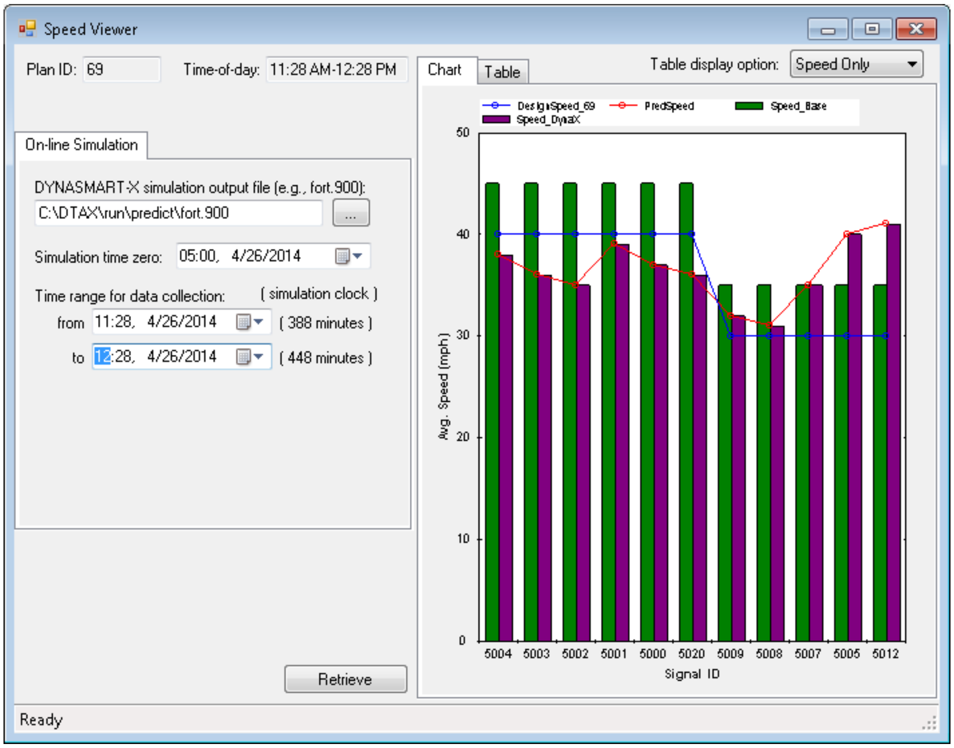


Figure 5-10. Speed Prediction Framework

Traffic estimation and predictions are then running continuously synchronized to real-world clock. The system consists of seven major functional modules, i.e., real-time estimation (RT-Dyna), traffic prediction (P-Dyna), OD estimation (ODE), OD prediction (ODP), long-term consistency checking (LTCC), and short-term consistency checking (STCC). Among all these modules, ODE, LTCC, and STCC are interacting with traffic data collected on both I-15 and Riverdale road to adjust the simulation on a continuous real-time basis.

Traffic prediction is implemented every 5 minutes, for a one-hour horizon. The prediction results are analyzed by Scenario Manager to provide on-site guidance for weather-responsive signal operations. Based on the analysis as shown in Figure 5-11, it is observed that, under rain, the prevailing speed on the links on Riverdale corridor falls to the range of 35-40mph, as compared to the original designed speed of 45mph (45 mph is also the posted speed limit). And a weather-responsive signal plan (plan No. 69) is recommended for implementation. The main difference between a weather-responsive plan and the original plan is the coordinated offsets for Riverdale Corridor designed by different assumptions of the prevailing speed. In this case, Plan No. 19 is a weather-responsive signal plan with a design speed of 40 mph, i.e., 5mph reduction under rain condition.



Speed Viewer

Plan ID: 69

Time-of-day: 11:28 AM-12:28 PM

Table display option: Speed Only

On-line Simulation

DYNASMART-X simulation output file (e.g., fort.900):

C:\DTAX\run\predict\fort.900

Simulation time zero: 05:00, 4/26/2014

Time range for data collection: (simulation clock)

from 11:28, 4/26/2014 (388 minutes)

to 12:28, 4/26/2014 (448 minutes)

Ready

Figure 5-11. Predicted Speed Reductions under Rainy Weather

We extracted speed observations from several Saturdays in this year, for intersection 5008 at Riverdale and Shopko. The selected Saturdays are March 8th, March 15th, March 22nd, March 29th, April 19th, and April 26th. Among these dates, the first five had clear weather, and the last one (April 26th) has experienced rain precipitations, on which we also ran the TrEPS model and had simulation outputs.

The posted speed limit or the design speed for coordinated signal plans under clear weather on this intersection is 35mph. Figure 5-13 compares the observed speed data with simulated speed by TrEPS. It is shown that the model underestimated the speed in the early morning, however, the estimation and prediction got much closer to the observations after 11am. It is also shown that the observed speed reduced from around 37mph in the morning to around 31mph in the afternoon. Figure 5-13 compares the observed speeds across different Saturdays. The orange color line represents April 26th which had rains. According to the data, there is not much evidence showing there is significant reduction on speed due to rain.

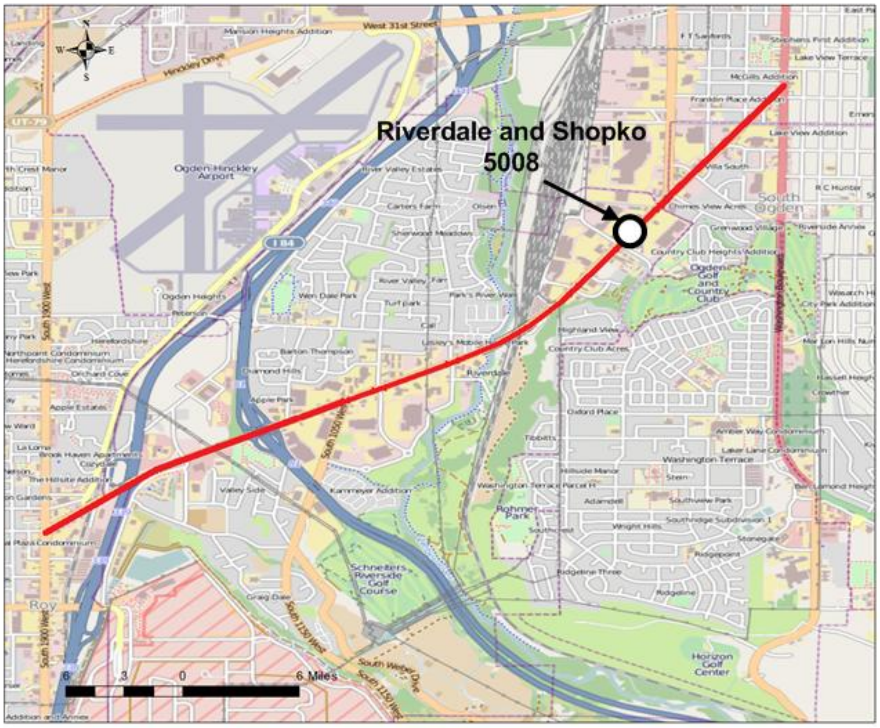


Figure 5-12. Intersection 5008 at Riverdale and Shopko

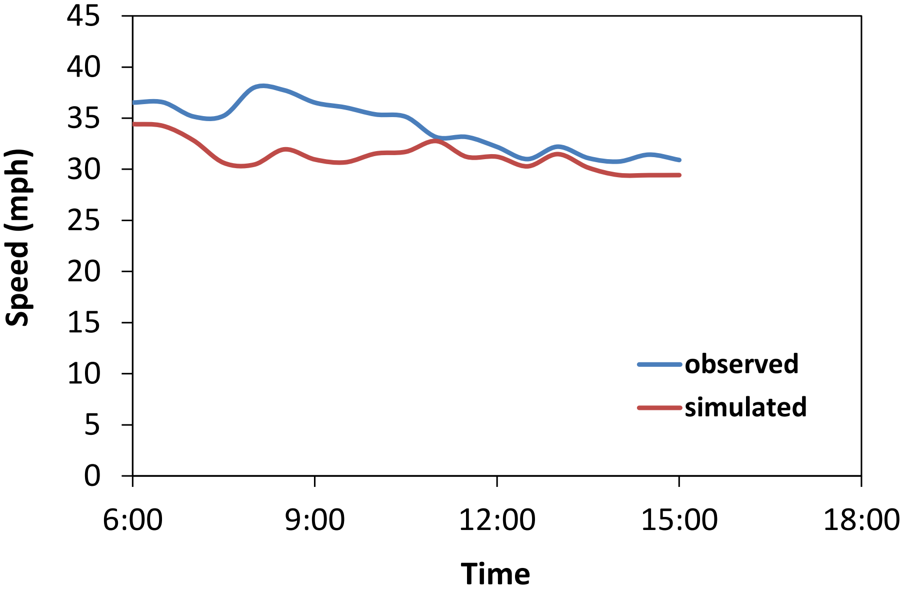


Figure 5-13. Comparison of Observed and Simulated Speed Data for Intersection 5008 on April 26th 2014

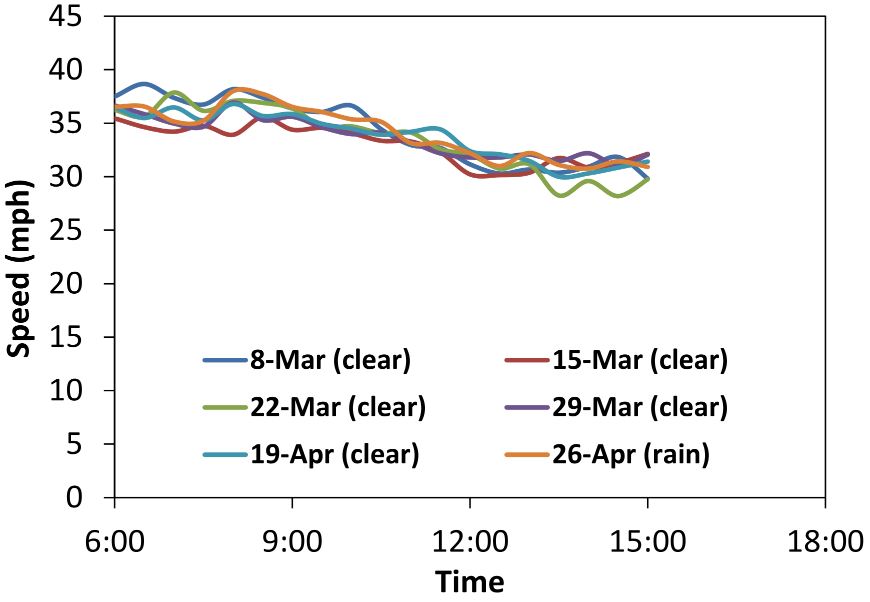


Figure 5-14. Comparison of Observed Speed Data for Intersection 5008 on Several Selected Saturdays

5.3.3 Evaluation of Weather-Responsive Signal Plans

Following the recommendations based on the speed analysis, the effectiveness of the recommended plan is evaluated before real-world implementation. To do so, another set of input files (control.dat) is generated by the Scenario Manager, and fed into the traffic prediction module (P-Dyna1). It is noted that during the simulation, two separate prediction modules, P-Dyna0 and P-Dyna1, are running simultaneously in parallel. Typically, P-Dyna0 will give the prediction results based on the scenario without any traffic management intervention, while P-Dyna1 will give prediction results that have the effects of traffic management interventions, and in this case, it will be the weather-responsive signal plan. The comparison of P-Dyna0 and P-Dyna1 are shown in Figure 5-16 and Figure 5-17, in terms of average travel time and percentage of stopped vehicles. The comparisons are conducted for both eastbound and westbound directions along the study corridor, and for the two selected road segments. Segment 1 is between intersection 5092 (Riverdale and SR-126) and intersection 5002 (Riverdale and 1050 West). Segment 2 is between intersection 5001 (Riverdale and 900 West) and intersection 5007 (Riverdale and Wall Ave). The locations of these two selected segments are shown in Figure 5-15.

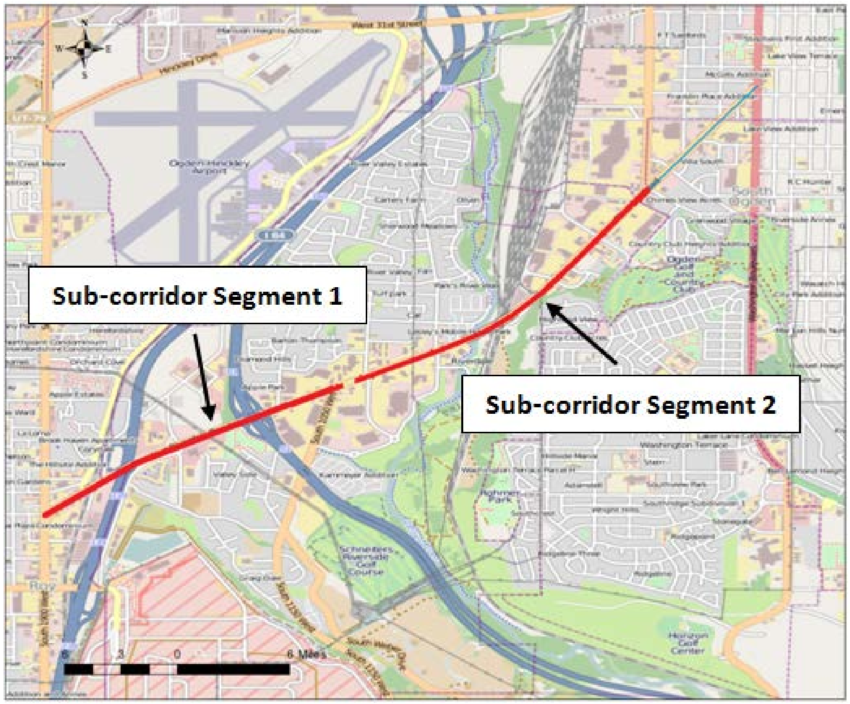


Figure 5-15. Selected Sub-Corridor Segments

According to the traffic prediction results, under rain condition, when weather-responsive signal plan (plan No. 69), there is obvious reduction in total travel time on segment 2 for both eastbound and west bound directions. For segment 1, the performance of the weather-responsive plan is not consistent during all the time intervals, as for some time periods, the total travel time may increase. The improvement in total travel time can be due to the reduction of percentage of stopped vehicles as shown in Figure 5-17. As a conclusion, the prediction results show that the weather-responsive plan is able to make traffic progress more smoothly along the corridor, with fewer stops at signalized intersections.

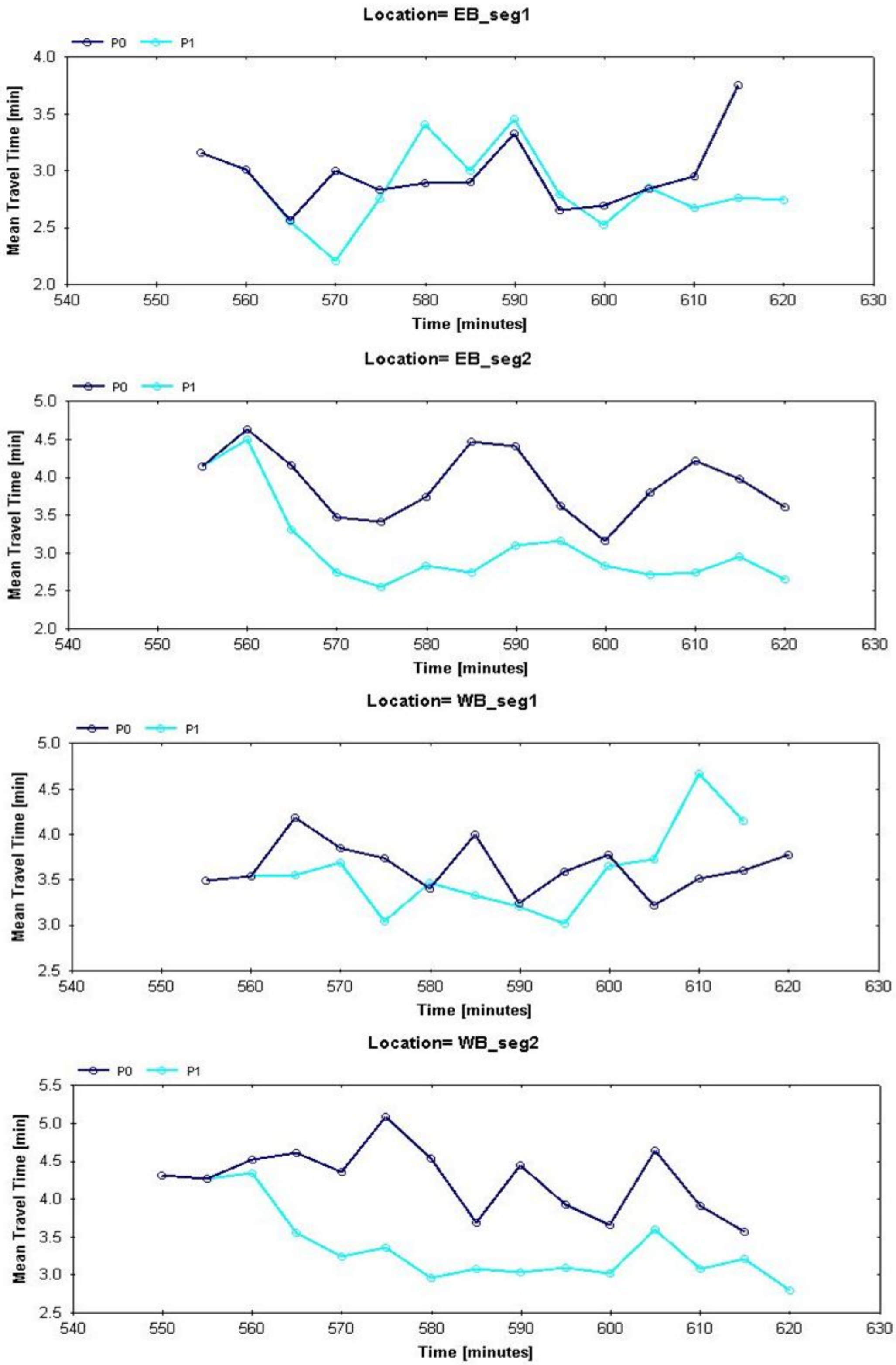


Figure 5-16. Comparison of Average Travel Time under Original Signal Plan and WR Plan

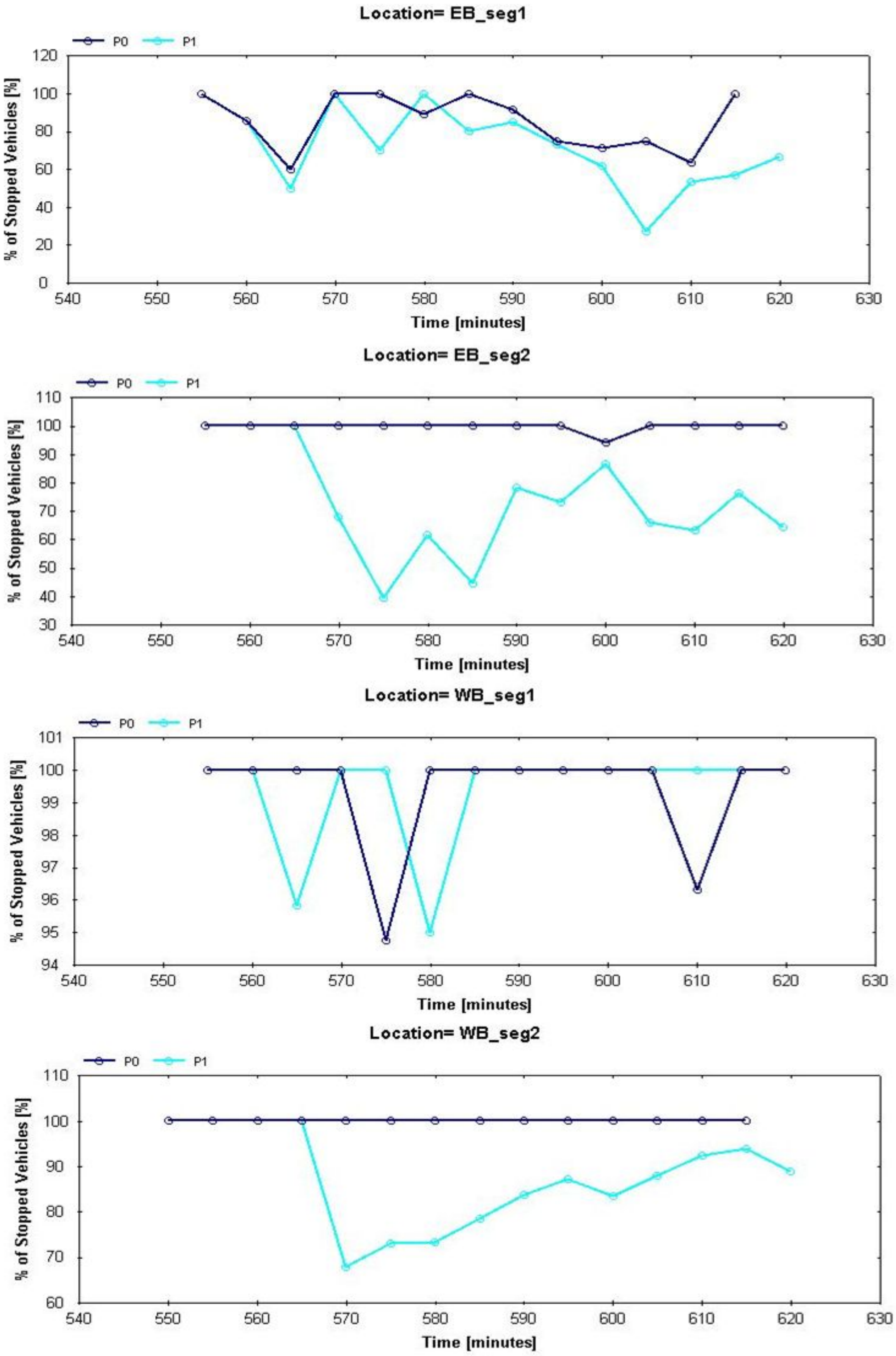


Figure 5-17. Comparison of Percentage of Stopped Vehicles under Original Signal Plan and WR Plan

Chapter 6. Conclusion

6.1 Summary of Findings and Accomplishments

This report has described the development and implementation of weather responsive TrEPS for the Ogden metropolitan area, Salt Lake City network, with specific focus on the signal control along Riverdale corridor to support weather-responsive traffic signal timing implementation. It illustrates the integration and operation of the weather-sensitive TrEPS models, the calibration of the input relationships, i.e. traffic flow model parameters, weather adjustment factor, and OD-estimation for DYNASMART-X to provide estimation of current traffic states and prediction of future states, and systematic validation of assessing the quality of the estimates and predictions obtained with the model.

The results confirm the ability of the DTA system to replicate observed traffic patterns in a large corridor network. With the current detectors and roadside sensors coverage, DYNASMART-X is able to use available real-time measurements to improve the quality of its estimation and future prediction, and thus provide a reliable basis for improved traffic management decisions that anticipate future conditions.

For the off-line experiments, under selected severe weather events, the off-line models are tested and the effectiveness of various signal timing plans are evaluated. The results help illustrate and quantify the adverse effect of snow events on traffic progression, overall as well as along specific segments of the Riverdale corridor. The results show that UDOT’s weather-responsive signal plan improves the performance of signal coordination in terms of travel time, delay and progression quality metrics. The results hold for the corridor as a whole, as well as for most of the individual intersections that comprise it, albeit to varying degrees. Similarly, UDOT’s weather-responsive signal plans generally help improve travel time reliability for the corridor overall, and for most segments.

For the on-line experiments, the results of estimation and prediction of traffic states show that weather-responsive plan is able to make traffic progress more smoothly along the corridor with fewer stops at signalized intersections, even though, according to the data, there is not much evidence showing the significant reduction on speed due to rain.

In addition to demonstrating the applicability and usefulness of predictive traffic management strategies in the context of weather-related conditions, and the role that weather-sensitive network traffic estimation and prediction tools such as DYNASMART-X play in this regard, several accomplishments were achieved in this study. A notable one is the development of a Scenario Manager, which facilitates application of the TrEPS for different types of scenarios, including weather, signal control, incident and demand scenarios. With the aid of the Scenario Manager, the weather conditions could be automatically translated into a corresponding scenario file for the TrEPS, demand scenarios are easily generated according to the current time, and direct comparison among different signal control plans can be performed in a user-friendly environment. As such, capabilities provided by the Scenario Manager can go a long way towards enhancing the acceptability, usability and effectiveness of weather-related traffic management approaches.

6.2 Recommendations for Further Development and Deployment

This study has successfully demonstrated a working TrEPS system installed at the UDOT Traffic Management Center. It has leveraged the existing traffic detection installation to extract real-time traffic state variables as a real-time input to the system. It has also demonstrated a Scenario Manager to simplify and facilitate the human operator's interaction with the predictive system. Together, the TrEPS and Scenario Manager define the basic blocks of a decision support system for managing network operations. At the current development stage, it supports signal control actions especially under weather-related events, but the basic TrEPS methodology can support a whole range of traffic management functions under any kind of scenario.

While considerable progress has been accomplished to date on the successful deployment of weather responsive TrEPS in Utah, there remain several aspects that could be improved towards accomplishing the primary goals of weather-related signal control. More important, considerable additional capabilities for a wider range of traffic management interventions could be leveraged with the existing TrEPS with relatively small amount of effort. Identified below are recommended steps for (1) enhancing the present functionalities as deployed, and (2) adding functionalities to address a wider range of management strategies.

6.2.1 Recommended Additional Activities with Implemented System

1. One of the lessons learned in this test deployment, which has helped improve on previous attempts to introduce management capabilities based on predictive analytics and real-time data, is the importance of engaging the end user, in this case the TMC staff, in the development and deployment process. Introducing new tools and new capabilities is a time-consuming process for resource-constrained agency staff—but they are willing to invest the time if they can see a potential return. The study team was very fortunate to have the full cooperation of the UDOT operations group, in all aspects of the work; accordingly many of the features that were built into the Scenario Manager were a direct outgrowth of their engagement, and interaction with them. Given the level of familiarity and interest that has already been established, the next logical step is to work with the staff as they learn and use the implemented system, in order to both increase their engagement and level of confidence with its recommendations, and improve and tweak the system's features to increase its usefulness. Often it is small changes, which do not affect the core of the methodology that can make a major difference in the ability of the end user to put these capabilities into action. Accordingly, *our highest priority recommendation is to initiate and conduct an "assisted in-situ deployment" that would cover a period of twelve to eighteen months* of up time, to include several actual instances of inclement weather intervention. This would accomplish several goals, including (a) providing training through actual use for the key TMC staff, (b) enhancing

the level of confidence that they place in the system by giving the testing agency the ability to deploy different strategies as a result of the TrEPS-supported analysis, and (c) provide a laboratory within which to refine the system features, including the scenario manager capabilities, e.g. by building the library of scenario types and possible interventions.

2. An important area where the quality of predictions and applicability of recommendations made by the TrEPS –based decision support system could be improved is in the development of demand libraries. Previous work has shown that a better staring point, i.e. a priori O-D patterns can influence the accuracy of the on-line TrEPS. Through the application of clustering techniques using archived data, a base demand library could be built, providing a more applicable starting point that would be retrieved from this library when specifying a demand scenario for DYNASMART-X. The current version of the Scenario Manager already has the capability to make the selection and create the correct starting point, however the underlying knowledge to take full advantage of this capability does not exist yet. The study team believes that with available data, application of clustering techniques will yield the desired patterns, so that the accuracy of estimation and prediction at this site as well as for other areas will be greatly improved.

3. In conjunction with the above-recommended assisted operation period, developing more complete libraries of signal timing plans for varying conditions (to include weather, demand levels as well as other special events) would go a long way towards greater usefulness of the system as a decision support tool. In addition, it would be useful to examine the relative value, and potential disadvantages, of computing offsets (and other timing parameters) on the fly vs. reliance on pre-computed plans developed to reflect the main types of patterns (determined using clustering techniques).

4. Besides the current short-term correction mechanisms applied to reduce the discrepancy between predicted and actual values of the traffic parameters of interest, there remains much scope to develop a range of adaptive short-term correction mechanisms (STCC) that provides more accurate speed prediction.

5. In the current weather responsive TrEPS version, two possible real-time data sources have been considered in the short-term correction mechanisms (STCC) and long-time correction mechanisms (LTCC). However, it is also possible to consider other real-time data sources, such as radar system data or mobile data. In particular, the potential role of mobile data in connection with TrEPS-based WRTM has been identified in a separate study (Mahmassani et al., 2012). Mobile data holds considerable promise in a real-time setting, though the institutional aspects of obtaining such data remain challenging. Deployment-based development and testing of the methodology would be improved by incorporating mobile data; however, adequate resources must be provided to enable procurement of such data

6. In conjunction with the above-recommended deployment, it would be important to conduct a behavior tracking study that would allow observation of actual user responses to WRTM strategies, with particular focus on demand management strategies. As noted, this is an important gap in existing knowledge, and a critical opportunity from the standpoint of agencies' abilities to mitigate inclement weather. The results would be

incorporated in the TrEPS methodology, to improve its ability to predict ways to attain desired demand reduction targets.

7. In the interest of wider and more effective technology transfer of tools and approaches developed through FHWA research such as the present effort, the study team has determined that a template for adoption by operating agencies of WRTM-sensitive TrEPS would be beneficial. The template would present several adoption models that range from a remote-hosted calibrated platform, with interactive assistance in the initial stages, towards locally-oriented content for the enhanced scenario manager proposed herein. The latter would play the primary role in terms of eliciting and facilitating local engagement in the development and application of WRTM strategies, and in the use of the TrEPS tools for evaluation and decision support. The template would also include a systematic process for monitoring and tracking the value of the TrEPS deployment, particularly through the resulting impact of the TrEPS-enabled WRTM strategies.

6.2.2 Recommended Extensions of TrEPS-based Decision Support System

There exist several opportunities to improve the methodological basis of existing TrEPS approach, particularly with regard to expanding the range of its usefulness to a more comprehensive scope of WRTM activities.

1. Integration of accident response functionality with WRTM in the real-time TrEPS platform. While the primary usefulness of TrEPS for WRTM lies in terms of near-term preparedness, within 12 to 48 hours of the onset of predicted inclement weather, the impact of crashes during bad weather is further amplified by the prevailing weather conditions. Accordingly, the online TrEPS would gain in effectiveness if crash responsiveness and WRTM-related functionality are more closely integrated.

2. A primary consideration for introducing WRTM, in addition to congestion mitigation, is the concern for motorist safety. Current analysis tools do not consider safety, in the form of crash occurrence or severity, in the context of weather-related scenario analysis. It would be important to enhance the ability of the TrEPS simulation tools to assess the impact on relative safety of inclement weather, and correspondingly the impact of WRTM measures on that important system performance dimension.

3. Along the same lines, incorporating transit-related capabilities is needed to provide essential functionality in larger metropolitan areas with substantial reliance on transit services, or in smaller-sized areas that wish to take advantage of the additional mobility provided by transit during weather-related disruptions.

4. Similarly, integration of fleet routing functionality, e.g. for snow removal equipment, preventive sanding and freeze-melting agent spreading, and other logistical processes, with the TrEPS platform can greatly enhance the effectiveness of WRTM in the context of overall weather readiness and system management. This would entail incorporating fleet routing and snow-related operations optimization algorithms with the TrEPS-predicted traffic conditions and associated travel times. This capability would have proved

invaluable to areas such as Atlanta and other cities in the Southern United States that were caught unprepared during the snow events of the winter of 2014.

5. Expanding the behavioral content of the WRTM capabilities to consider a range of interventions that target user behavior, such as demand management, advanced multimodal traveler information, use of social media are important dimensions to incorporate in effective system management tools as we look at future opportunities.

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Appendix A. Off-line Signal Performance Statistics

Table A-1. Corridor Level Travel Time Statistics during Peak Hours (7a.m. to 10 a.m.)

Scenario	Corridor Segment	Eastbound		Westbound	
		mean travel time (min)	standard deviation (min)	mean travel time (min)	standard deviation (min)
normal weather	segment 1	3.79	0.53	3.55	0.34
	segment 2	4.09	0.38	4.35	0.43
snow with normal plan	segment 1	4.07	0.64	3.61	0.78
	segment 2	4.86	0.72	4.97	0.68
snow with weather-responsive plan	segment 1	3.98	0.55	3.64	0.66
	segment 2	4.81	0.44	4.87	0.63

Table A-2. Corridor Level Travel Time Statistics during Off-peak Hour (11a.m. to 2 p.m.)

Scenario	Corridor Segment	Eastbound		Westbound	
		mean travel time (min)	standard deviation (min)	mean travel time (min)	standard deviation (min)
normal weather	segment 1	3.36	0.35	3.30	0.36
	segment 2	4.15	0.65	4.18	0.58
snow with normal plan	segment 1	3.64	0.72	3.44	0.55
	segment 2	5.01	0.60	4.19	0.31
snow with weather-responsive plan	segment 1	3.75	1.09	3.51	0.59
	segment 2	4.87	0.77	4.22	0.33

Table A-3. Corridor Level Stopped Time Statistics during Peak Hours (7a.m. to 10 a.m.)

	Corridor Segment	Eastbound				Westbound			
		sample size (number of vehicles)	mean stopped time (sec)	standard deviation (sec)	fraction of non-stopped vehicles	sample size (number of vehicles)	mean stopped time (sec)	Standard deviation (sec)	fraction of non-stopped vehicles
normal weather	segment 1	1523	37.7	25.9	28%	1718	49.6	42.6	23%
	segment 2	1702	26.5	20.6	24%	2168	37.2	39.3	29%
snow with do nothing	segment 1	1523	41.6	27.6	24%	1718	49.0	44.5	19%
	segment 2	1702	34.4	39.1	27%	2168	59.6	66.8	17%
snow with weather-responsive plan	segment 1	1523	38.1	23.8	24%	1718	45.7	51.8	24%
	segment 2	1702	30.8	22.0	28%	2168	48.2	48.5	16%

Table A-4. Corridor Level Stopped Time Statistics during Off-peak Hour (11a.m. to 2 p.m.)

	Corridor Segment	Eastbound				Westbound			
		sample size (number of vehicles)	mean stopped time (sec)	standard deviation (sec)	fraction of non-stopped vehicles	sample size (number of vehicles)	mean stopped time (sec)	Standard deviation (sec)	fraction of non-stopped vehicles
normal weather	segment 1	814	22.1	18.8	18%	826	36.9	27.4	21%
	segment 2	1555	44.8	41.5	22%	739	23.6	17.8	22%
snow with do nothing	segment 1	814	27.5	32.6	15%	826	45.0	30.2	18%
	segment 2	1555	46.1	22.1	13%	739	33.1	32.0	20%
snow with weather-responsive plan	segment 1	814	33.6	24.0	11%	826	35.3	21.4	26%
	segment 2	1555	43.5	41.5	15%	739	32.8	22.7	28%

Table A-5. Intersection Level Stopped Time Statistics during Peak Hours (7a.m. to 10 a.m.)

	Inter-section ID	Eastbound				Westbound			
		sample size (number of vehicles)	mean stopped time (sec)	standard deviation (sec)	fraction of non-stopped vehicles	sample size (number of vehicles)	mean stopped time (sec)	Standard deviation (sec)	fraction of non-stopped vehicles
normal weather	5092	-	-	-	-	530	2.5	5.3	72%
	5004	4165	9.0	15.5	55%	1651	4.0	13.3	87%
	5003	5326	16.0	13.3	53%	1974	6.1	19.4	70%
	5002	5296	8.6	12.0	74%	4528	6.9	15.6	77%
	5001	2778	18.2	14.2	74%	3050	25.6	29.4	60%
	5000	3143	13.1	14.3	55%	3580	11.6	18.6	61%
	5020	2620	3.4	6.2	68%	3917	17.9	24.5	73%
	5009	2728	6.2	9.8	58%	2644	17.7	27.4	62%
	5008	3157	3.4	6.7	71%	2737	17.2	19.7	61%
	5007	3127	5.1	10.3	67%	3105	17.5	13.3	57%
	5005	1135	4.5	11.0	74%	4538	13.9	18.0	61%
	5012	486	1.9	4.2	76%	1309	9.4	10.9	39%
	5011	78	8.2	7.5	32%	-	-	-	-
snow with do nothing	5092	-	-	-	-	530	2.8	6.7	72%
	5004	4165	10.0	13.0	48%	1651	18.7	15.5	84%
	5003	5326	14.9	20.2	44%	1974	28.9	35.5	68%
	5002	5296	5.1	27.8	73%	4528	23.4	44.0	80%
	5001	2778	17.6	22.9	70%	3050	18.8	23.9	59%
	5000	3143	12.6	23.0	51%	3580	28.8	39.1	59%
	5020	2620	10.1	16.1	61%	3917	25.2	32.9	65%
	5009	2728	10.9	11.8	47%	2644	17.1	29.8	64%
	5008	3157	17.7	20.2	65%	2737	11.8	19.9	66%
	5007	3127	4.7	9.7	70%	3105	16.5	11.1	47%
	5005	1135	3.9	10.3	78%	4538	12.6	25.0	53%
	5012	486	2.9	6.7	72%	1309	11.3	18.2	39%
	5011	78	6.8	7.4	32%	-	-	-	-
snow with weather-responsive plan	5092	-	-	-	-	530	2.9	7.3	75%
	5004	4165	10.3	13.2	48%	1651	3.6	13.1	86%
	5003	5326	13.2	18.9	48%	1974	7.9	16.1	68%
	5002	5296	5.0	12.8	72%	4528	5.2	15.4	79%
	5001	2778	15.7	21.5	71%	3050	19.4	20.6	52%
	5000	3143	17.2	22.1	52%	3580	18.4	19.4	54%
	5020	2620	5.2	8.5	62%	3917	5.9	11.5	68%
	5009	2728	12.0	17.4	55%	2644	14.3	19.9	64%
	5008	3157	10.3	22.2	67%	2737	26.8	39.4	63%
	5007	3127	4.8	10.4	68%	3105	18.7	21.0	49%
	5005	1135	3.7	10.4	78%	4538	16.8	28.3	49%
	5012	486	2.7	14.8	80%	1309	9.5	11.6	40%
	5011	78	6.8	6.2	23%	-	-	-	-

Table A-6. Intersection Level Stopped Time Statistics during Off-peak Hour (11a.m. to 2 p.m.)

		Eastbound				Westbound			
	Inter-section ID	sample size (number of vehicles)	mean stopped time (sec)	standard deviation (sec)	fraction of non-stopped vehicles	sample size (number of vehicles)	mean stopped time (sec)	Standard deviation (sec)	fraction of non-stopped vehicles
normal weather	5092	-	-	-	-	302	3.8	8.2	64%
	5004	3674	8.2	16.1	61%	1256	14.8	24.9	65%
	5003	4019	14.6	28.9	60%	1280	19.6	45.6	56%
	5002	3807	13.4	31.3	72%	3580	19.3	35.6	69%
	5001	2197	32.2	44.6	84%	3266	36.2	58.8	31%
	5000	2398	5.5	15.5	76%	3186	14.3	11.9	41%
	5020	1886	5.0	10.3	74%	2867	6.5	13.1	71%
	5009	2130	7.1	13.3	68%	1869	3.8	8.8	75%
	5008	2311	6.8	33.5	73%	2389	5.9	13.0	69%
	5007	2397	23.3	17.3	70%	3204	8.2	17.0	70%
	5005	1024	22.8	22.6	73%	3896	5.7	12.2	70%
	5012	620	11.0	28.6	63%	1111	9.8	9.4	31%
	5011	105	24.0	19.4	14%	-	-	-	-
snow with do nothing	5092	-	-	-	-	302	5.3	13.1	50%
	5004	3674	6.9	14.4	63%	1256	14.3	38.9	63%
	5003	4019	20.3	40.0	63%	1280	19.5	52.5	52%
	5002	3807	5.2	10.1	70%	3580	28.3	42.6	70%
	5001	2197	34.4	33.5	82%	3266	33.0	41.6	35%
	5000	2398	15.0	26.4	74%	3186	23.3	61.2	37%
	5020	1886	23.8	38.6	71%	2867	12.5	27.6	39%
	5009	2130	22.0	37.9	63%	1869	9.0	16.9	60%
	5008	2311	26.8	19.0	64%	2389	5.6	13.4	55%
	5007	2397	13.3	19.1	71%	3204	7.4	18.8	51%
	5005	1024	33.8	34.6	78%	3896	8.7	16.6	68%
	5012	620	11.0	24.4	58%	1111	11.9	14.7	31%
	5011	105	37.2	55.0	36%	-	-	-	-
snow with weather-respon-sive plan	5092	-	-	-	-	302	8.4	17.9	69%
	5004	3674	8.3	18.9	62%	1256	14.4	36.8	82%
	5003	4019	14.1	26.8	70%	1280	16.1	35.0	66%
	5002	3807	7.5	19.6	68%	3580	33.3	61.8	73%
	5001	2197	30.0	43.7	80%	3266	38.9	55.4	57%
	5000	2398	14.0	15.1	77%	3186	19.8	31.7	43%
	5020	1886	26.4	33.2	68%	2867	10.6	22.1	71%
	5009	2130	21.3	38.7	56%	1869	10.7	16.0	55%
	5008	2311	17.2	16.9	65%	2389	3.4	9.9	52%
	5007	2397	19.8	17.3	63%	3204	5.0	6.7	39%
	5005	1024	17.1	12.4	78%	3896	8.5	5.5	64%
	5012	620	12.5	22.4	56%	1111	11.6	15.7	32%
	5011	105	25.4	38.1	25%	-	-	-	-

Appendix B. User's Guide for Scenario Manager

Software Quick Start Guide

This appendix is a User's Guide of Scenario Manager and DYNASMART-X. The purpose is to provide traffic managers a reference of how to use the software to test various signal timing strategies and examine their effectiveness in mitigating weather-related congestion before making a deployment decision.

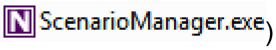
Scenario Manager is developed as a user-friendly interface that helps simplify file transfers to and from the DYNASMART-X simulation engine and minimize the direct interaction between users and DYNASMART-X. In general, there are four major steps in working with the software system:

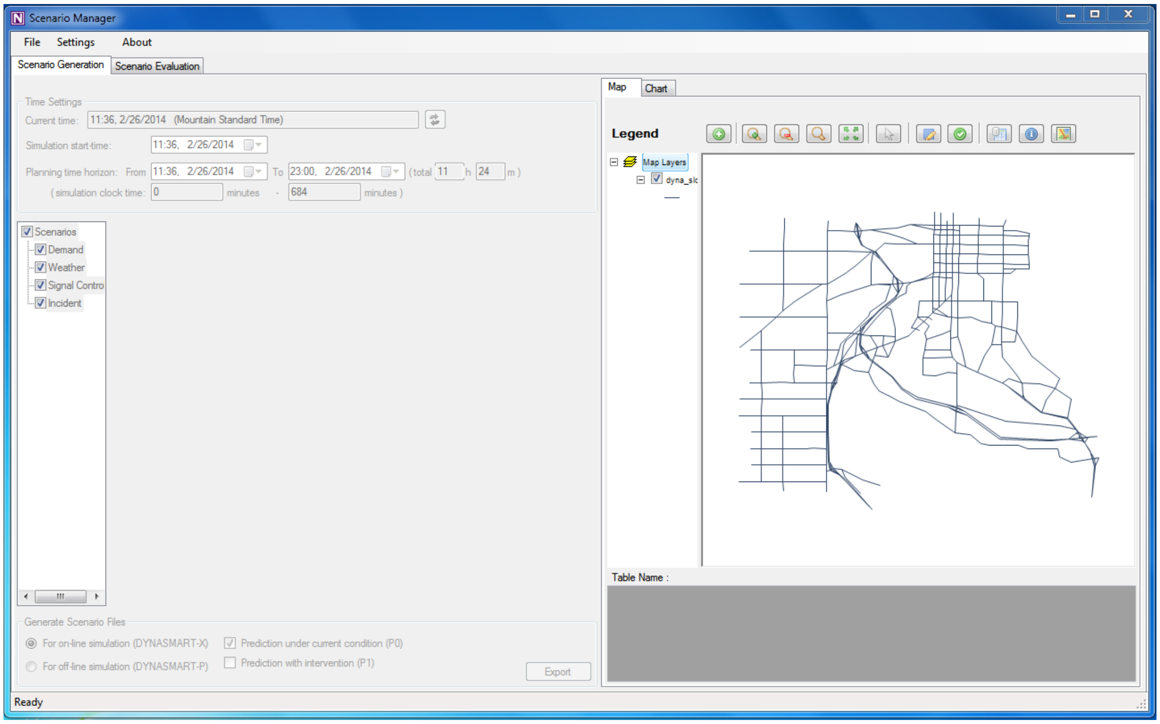
1. Start Scenario Manager
2. Prepare Initial Scenario Set
3. Launch DYNASMART-X
4. Evaluate and Update Scenarios

Starting the Software

The Scenario Manager and DYNASMART-X software have been installed on one of UDOT's computers in the Traffic Operation Center (TOC). Before starting the software, please make sure you can locate the two software systems under **C:\ScenarioManager** and **C:\DTAX**, respectively.

More specifically, **C:\ScenarioManager** contains two subfolders: **Release** and **SMwd**. The **Release** folder includes application executable and libraries. The **SMwd** is a Scenario Manager working directory, where various input files used by Scenario Manager are present. **C:\DTAX** is DYNASMART-X folder which contains various subfolders for input and output files of different modules of DYNASMART-X.

To start Scenario Manager, click the Scenario Manager executable file (ScenarioManager.exe) in C:\ScenarioManager\Release. When Scenario Manager first loads itself, you should see the Scenario Manager application main window as shown in **Figure B-1**.



Time Settings

Current time: 11:36, 2/26/2014 (Mountain Standard Time)

Simulation start-time: 11:36, 2/26/2014

Planning time horizon: From 11:36, 2/26/2014 To 23:00, 2/26/2014 (total 11 h 24 m)

(simulation clock time: 0 minutes - 684 minutes)

☑ Scenarios
  ☑ Demand
  ☑ Weather
  ☑ Signal Contro
  ☑ Incident

Generate Scenario Files

● For on-line simulation (DYNASMART-X)

○ For off-line simulation (DYNASMART-P)

☑ Prediction under current condition (P0)

☐ Prediction with intervention (P1)

Figure B-1. Scenario Manger Application Main Window

Prepare Initial Scenario Set

In this step, we prepare initial demand, weather, signal control and incident scenarios input files through the Scenario Manager interface.

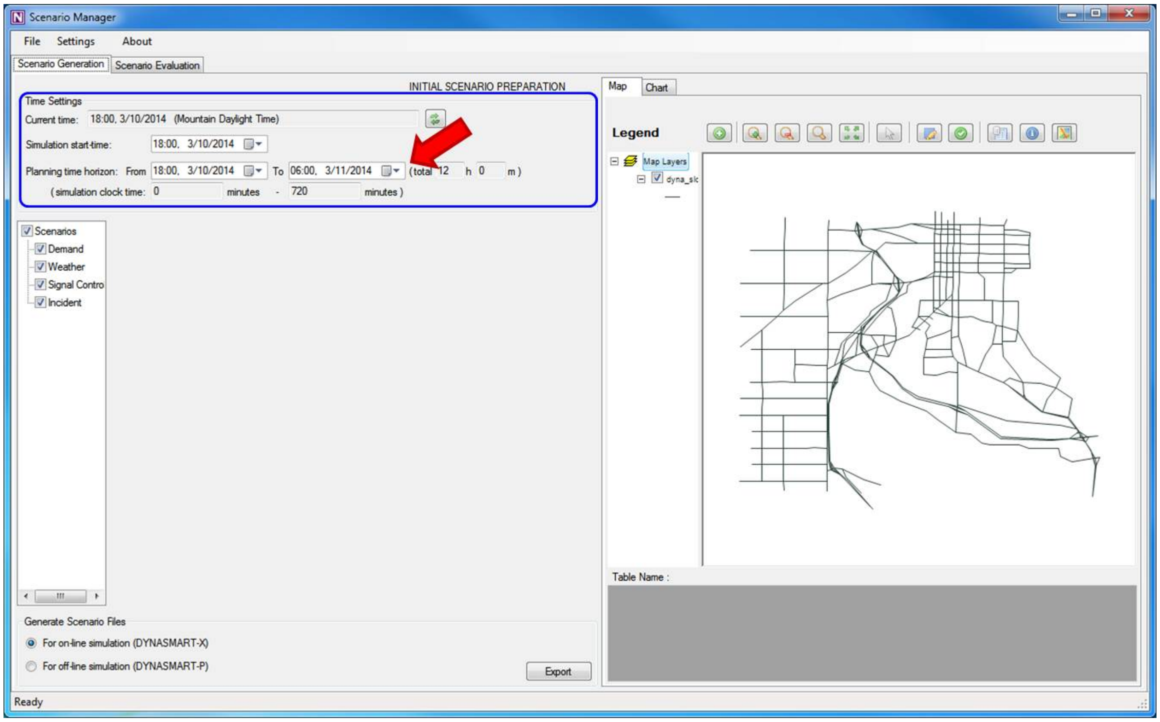
To start this step, click **File → 1: Prepare Initial Scenarios** in the Scenario Manger application main window.

Specify the Planning Horizon

Under the 'Time Settings' panel, it shows overall simulation time configurations as in Figure B-2:

- **Current time** (*can be updated by clicking refresh button*): real-world clock time
- **Simulation start-time**: time at which TrEPS (DYNASMART-X) will be started
- **Planning time horizon**: start- and end-times of scenarios
- **Simulation clock time** (*automatically calculated*): total minutes from **Simulation start-time**

At the time when you launch Scenario Manager, 'Current Time', 'Simulation start-time', and 'Planning time horizon' are all the same. By default, 'Planning time horizon' is set to be 12 hours starting from 'Current time'. Users could change the 'Planning time horizon' by adjusting the 'end-time'.



Time Settings
Current time: 18:00, 3/10/2014 (Mountain Daylight Time)
Simulation start-time: 18:00, 3/10/2014
Planning time horizon: From 18:00, 3/10/2014 To 06:00, 3/11/2014 (total 12 h 0 m)
(simulation clock time: 0 minutes - 720 minutes)

☑ Scenarios
- ☑ Demand
- ☑ Weather
- ☑ Signal Contro
- ☑ Incident

Generate Scenario Files
● For on-line simulation (DYNASMART-X)
○ For off-line simulation (DYNASMART-P)

Figure B-2. Simulation Time Settings

Demand Generation

The purpose of this step is to generate 24-hour demand input file based on the current starting time. To do this, follow the following procedures:

1. Click **Demand** node from **Scenarios** tree.
2. Simply check the **Base demand start-time** (should be 6h0m) adjusted **New demand start-time.** No further action is required.

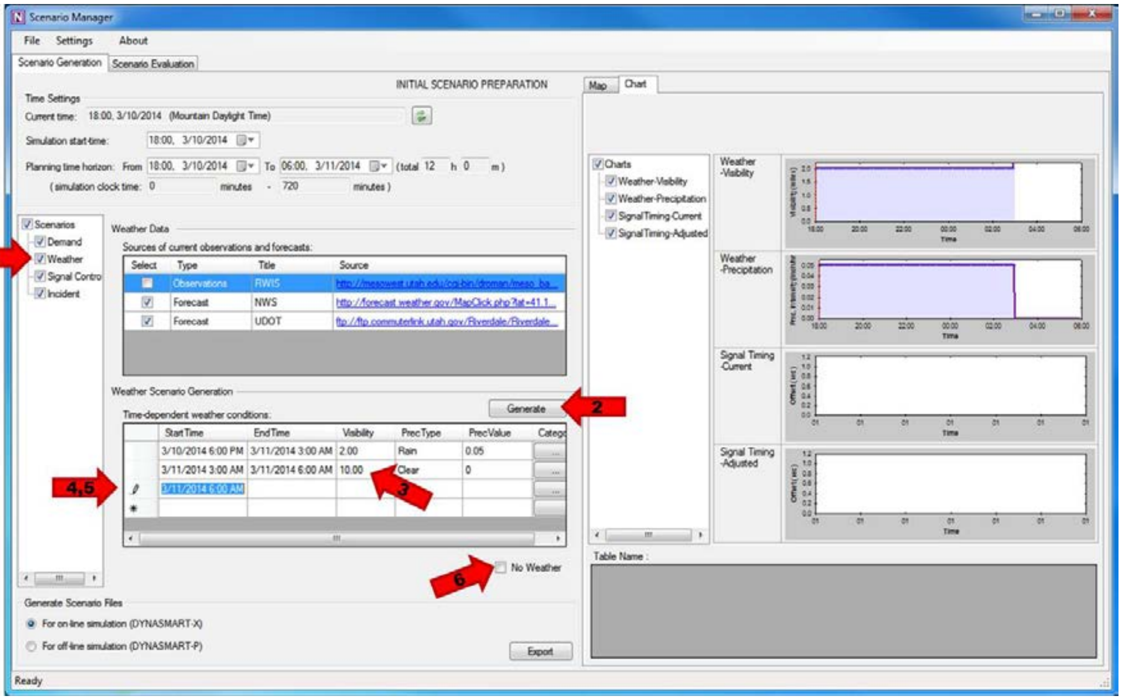
Weather Scenario Generation

Given the sources of weather data, which include RWIS or ASOS weather stations for recent observations and National Weather Service or UDOT report for weather forecast information, and the ability to connect them in real-time, this step to produce a weather scenario input file from the specified weather scenario to supply to the DYNASMART-X as a simulation input.

Steps for generating a weather scenario in the Scenario Manager:

1. Click **Weather** node from **Scenarios** tree.
2. Click **Generate** button to generate weather scenario.
3. After weather scenario is generated, users can further **edit** weather parameters by double-clicking cells.
4. Users can also manually **add** a new weather event line by typing values on the last empty row (formats must be valid).

5. Users can **delete** a weather row by clicking a row header and hitting the keyboard “delete” key.
6. In the case of no weather event, check **No Weather** checkbox to ignore any specified weather conditions. This will simply export a “Clear” weather scenario.



Current time: 18:00, 3/10/2014 (Mountain Daylight Time)

Simulation start-time: 18:00, 3/10/2014

Planning time horizon: From 18:00, 3/10/2014 To 06:00, 3/11/2014 (total 12 h 0 m)

(simulation clock time: 0 minutes - 720 minutes)

Sources of current observations and forecasts:

Select	Type	Title	Source
☐	Observations	RWIS	http://mesowest.utah.edu/cgi-bin/droman/meso_ba...
☑	Forecast	NWS	http://forecast.weather.gov/MapClick.php?lat=41.1...
☑	Forecast	UDOT	ftp://ftp.commuterlink.utah.gov/Riverdale/Riverdale...

Time-dependent weather conditions:

	StartTime	EndTime	Visibility	PrecType	PrecValue	Categ
	3/10/2014 6:00 PM	3/11/2014 3:00 AM	2.00	Rain	0.05	...
	3/11/2014 3:00 AM	3/11/2014 6:00 AM	10.00	Clear	0	...
✎	3/11/2014 6:00 AM					...
*						

☐ No Weather

● For on-line simulation (DYNASMART-X)

○ For off-line simulation (DYNASMART-P)

Figure B-3. Generating Weather Scenarios in the Scenario Manager

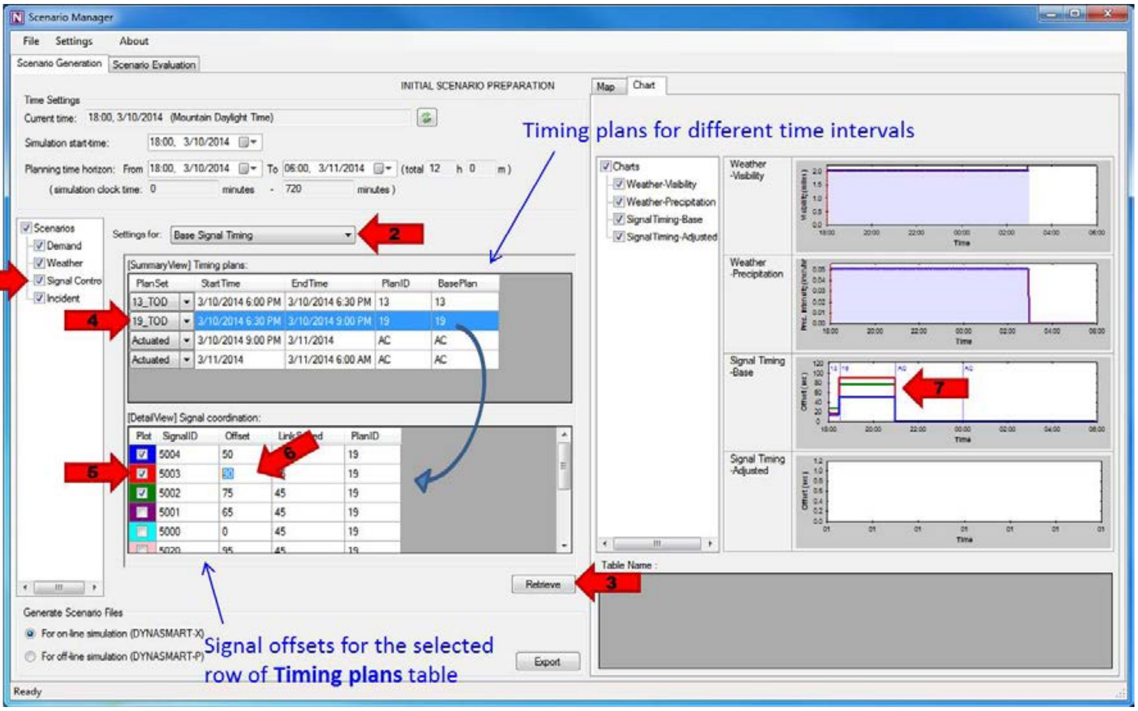
Traffic Signal Control Scenario Generation

Based on a scenario time horizon and the associated weather scenario, the traffic signal control scenario needs to be determined and created. A traffic signal control “scenario” represents a sequence of signal timing “plans” that are applied to the entire Riverdale corridor over the given scenario time horizon (e.g., Plan IDs: 58→67→69→57 from 7AM to 12PM), with the associated start- and end- times of each signal timing plan. The focus of this step is to generate a set of traffic signal control scenarios in the DYNASMART-specific input file format.

Steps for generating a traffic signal control scenario in the Scenario Manager:

1. Click **Signal Control** node from **Scenarios** tree.
2. Select **Base Signal Timing** (time-of-day plan) from the drop-down list.
3. Click **Retrieve** button to retrieve “time-of-day” plans for the given planning time horizon.
4. Users can change the plan by selecting different plans from **PlanSet** drop-down list.
5. Check/uncheck to show/hide the offset profile of a particular signal on the **Signal Timing-Base** chart.
6. Users can **edit** the offset by entering a value on the cell.

7. Users can **view** the modified offset from the chart.



Time Settings
Current time: 18:00, 3/10/2014 (Mountain Daylight Time)
Simulation start-time: 18:00, 3/10/2014
Planning time horizon: From 18:00, 3/10/2014 To 06:00, 3/11/2014 (total 12 h 0 m)
(simulation clock time: 0 minutes - 720 minutes)

Settings for: Base Signal Timing

[SummaryView] Timing plans:

PlanSet	StartTime	EndTime	PlanID	BasePlan
13_TOD	3/10/2014 6:00 PM	3/10/2014 6:30 PM	13	13
19_TOD	3/10/2014 6:30 PM	3/10/2014 9:00 PM	19	19
Actuated	3/10/2014 9:00 PM	3/11/2014	AC	AC
Actuated	3/11/2014	3/11/2014 6:00 AM	AC	AC

[DetailView] Signal coordination:

Plot	SignalID	Offset	LinkSpeed	PlanID
☑	5004	50	[illegible]	19
☑	5003	50	[illegible]	19
☑	5002	75	45	19
☐	5001	65	45	19
☐	5000	0	45	19
☐	5020	95	45	19

Generate Scenario Files
● For on-line simulation (DYNASMART-X)
○ For off-line simulation (DYNASMART-P)

Timing plans for different time intervals

Signal offsets for the selected row of **Timing plans** table

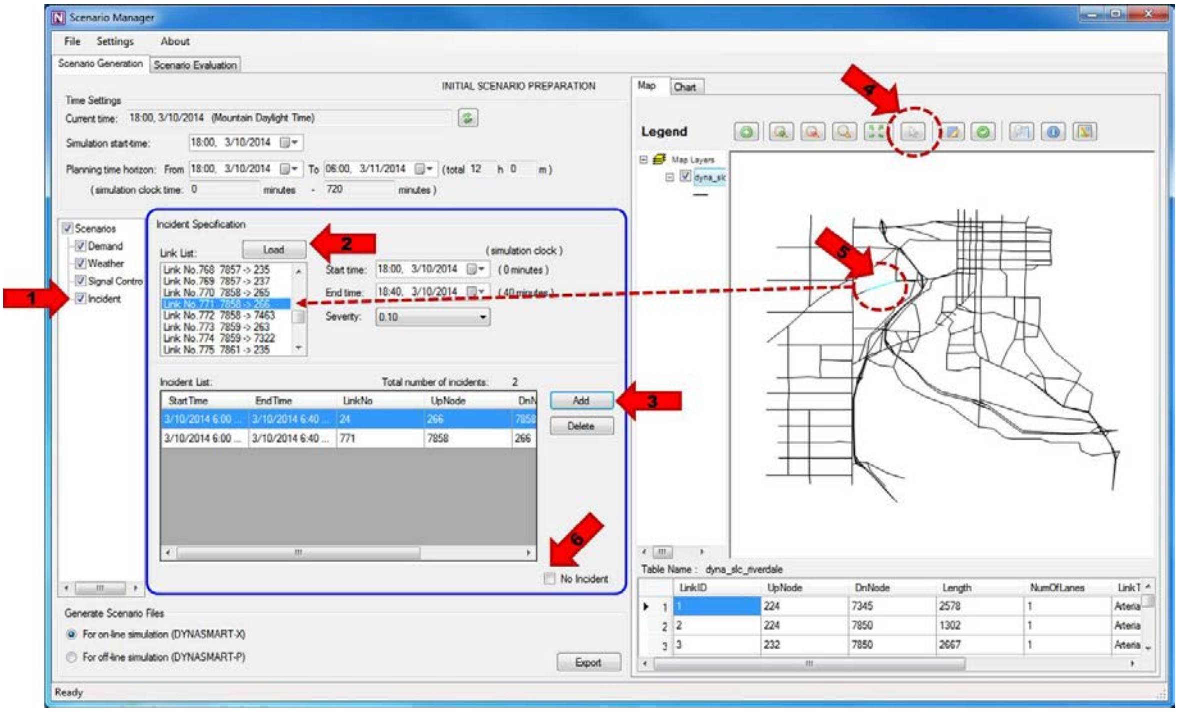
Figure B-4. Generating Traffic Signal Control Scenarios in the Scenario Manager

Incident Scenario Generation

The purpose of this step is to generate incident scenarios with certain duration and severity level within the planning time horizon in the study network.

Steps for generating incident scenario in the Scenario Manager:

1. Click **Incident** node from **Scenarios** tree.
2. Click **Load** to load the link list.
3. Click **Add** after specifying an incident:
    a. **Location** (select a link from the list),
    b. **Start** and **End times**, and
    c. **Severity** (fraction of the link capacity loss due to the incident; e.g., 0.1 = 10% capacity loss = the remaining link capacity is 90%).
4. Users can select the incident links using the **map** on the right; Click **pointer** button on the map menu to enter the "map-selection" mode (the pointer changes to a hand shape).
5. Select a link on the map; the selected link will be automatically highlighted (selected) in the **Link List** on the left.
6. In the case of no incident, check **No Incident** checkbox to ignore any specified incidents. This will simply export a zero-incident scenario.



INITIAL SCENARIO PREPARATION

Time Settings

Current time: 18:00, 3/10/2014 (Mountain Daylight Time)

Simulation start-time: 18:00, 3/10/2014

Planning time horizon: From 18:00, 3/10/2014 To 06:00, 3/11/2014 (total 12 h 0 m)

(simulation clock time: 0 minutes - 720 minutes)

☑ Scenarios
- ☑ Demand
- ☑ Weather
- ☑ Signal Contro
- ☑ Incident

Incident Specification

Link List:

Link No.768 7857 -> 235
Link No.769 7857 -> 237
Link No.770 7858 -> 265
Link No.771 7858 -> 266
Link No.772 7858 -> 7463
Link No.773 7859 -> 263
Link No.774 7859 -> 7322
Link No.775 7861 -> 235

(simulation clock)

Start time: 18:00, 3/10/2014 (0 minutes)

End time: 18:40, 3/10/2014 (40 minutes)

Severity: 0.10

Incident List: Total number of incidents: 2

StartTime	EndTime	LinkNo	UpNode	DnN
3/10/2014 6:00 ...	3/10/2014 6:40 ...	24	266	7858
3/10/2014 6:00 ...	3/10/2014 6:40 ...	771	7858	266

☐ No Incident

Generate Scenario Files

● For on-line simulation (DYNASMART-X)

○ For off-line simulation (DYNASMART-P)

Ready

Table Name : dyna_slc_riverdale

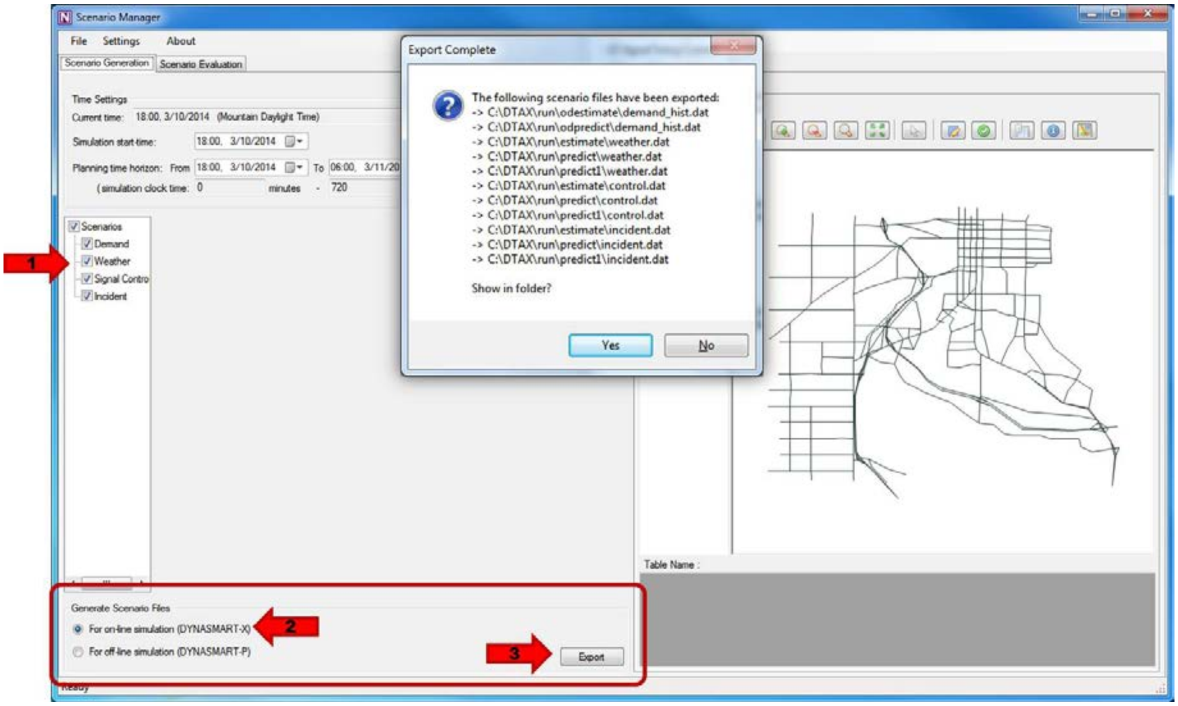
	LinkID	UpNode	DnNode	Length	NumOfLanes	LinkT
1	1	224	7345	2578	1	Arteria
2	2	224	7850	1302	1	Arteria
3	3	232	7850	2667	1	Arteria

Figure B-5. Generating Incident Scenarios in the Scenario Manager

Export Scenario Input Files to DYNASMART-X

After setting all the parameters for the scenario, the following steps let users export the scenario input files into DYNASMART-X working folders.

1. Check/uncheck the scenarios to be exported. Only the checked scenarios will be exported.
2. Select **For on-line simulation (DYNASMART-X)** to export scenarios to DYNASMART-X input folders.
3. Click **Export** to export the associated scenarios files. The **Export Complete** dialog will show the list of all the generated files.



Time Settings
Current time: 18:00, 3/10/2014 (Mountain Daylight Time)
Simulation start time: 18:00, 3/10/2014
Planning time horizon: From 18:00, 3/10/2014 To 06:00, 3/11/20
(simulation clock time: 0 minutes - 720

- ☑ Scenarios
  - ☑ Demand
  - ☑ Weather
  - ☑ Signal Contro
  - ☑ Incident

Generate Scenario Files
● For on-line simulation (DYNASMART-X)
○ For off-line simulation (DYNASMART-P)

Export Complete

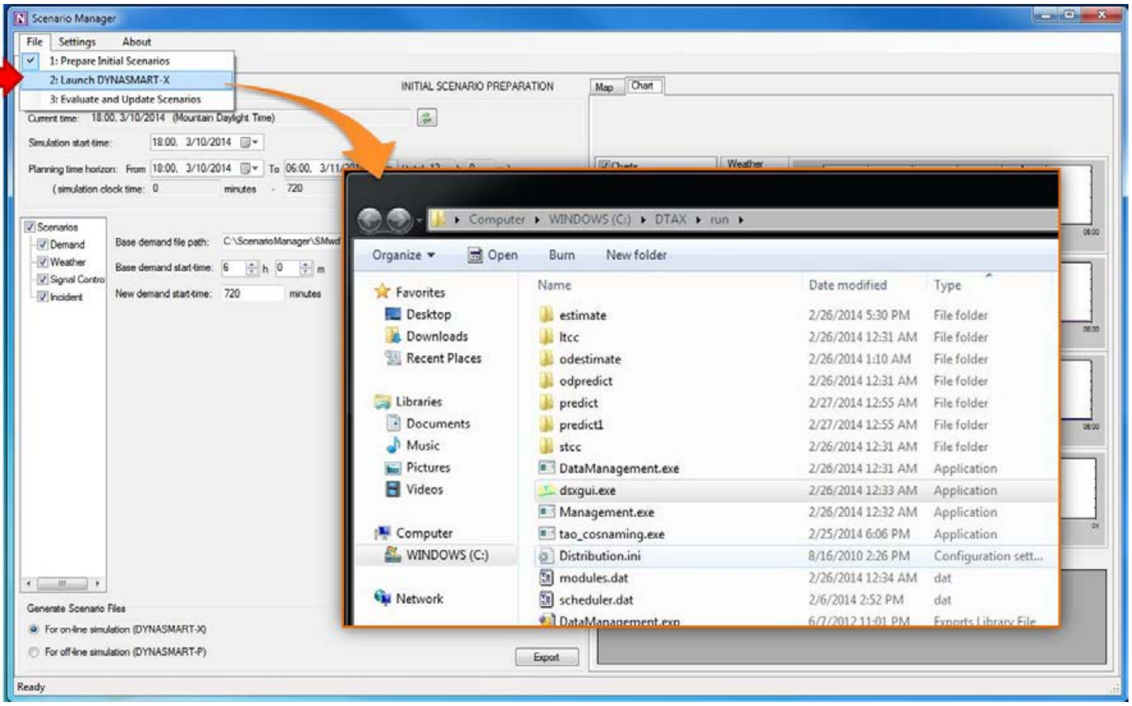
```
The following scenario files have been exported:
-> C:\DTAX\run\odestimate\demand_hist.dat
-> C:\DTAX\run\odpredict\demand_hist.dat
-> C:\DTAX\run\estimate\weather.dat
-> C:\DTAX\run\predict\weather.dat
-> C:\DTAX\run\predict1\weather.dat
-> C:\DTAX\run\estimate\control.dat
-> C:\DTAX\run\predict\control.dat
-> C:\DTAX\run\predict1\control.dat
-> C:\DTAX\run\estimate\incident.dat
-> C:\DTAX\run\predict\incident.dat
-> C:\DTAX\run\predict1\incident.dat

Show in folder?
```

Figure B-6. Exporting Scenario Input Files to DYNASMART-X

Launch DYNASMART-X

Clicking **Launch DYNASMART-X** will open the file explorer to point the DYNASMART-X GUI application file (**C:\DTAX\run\dsxgui.exe**)



Current time: 18:00, 3/10/2014 (Mountain Daylight Time)

Simulation start time: 18:00, 3/10/2014

Planning time horizon: From 18:00, 3/10/2014 To 06:00, 3/11/201

(simulation clock time: 0 minutes - 720

Base demand file path: C:\ScenarioManager\SMwd

Base demand start-time: 6 h 0 m

New demand start-time: 720 minutes

● For on-line simulation (DYNASMART-X)

○ For off-line simulation (DYNASMART-P)

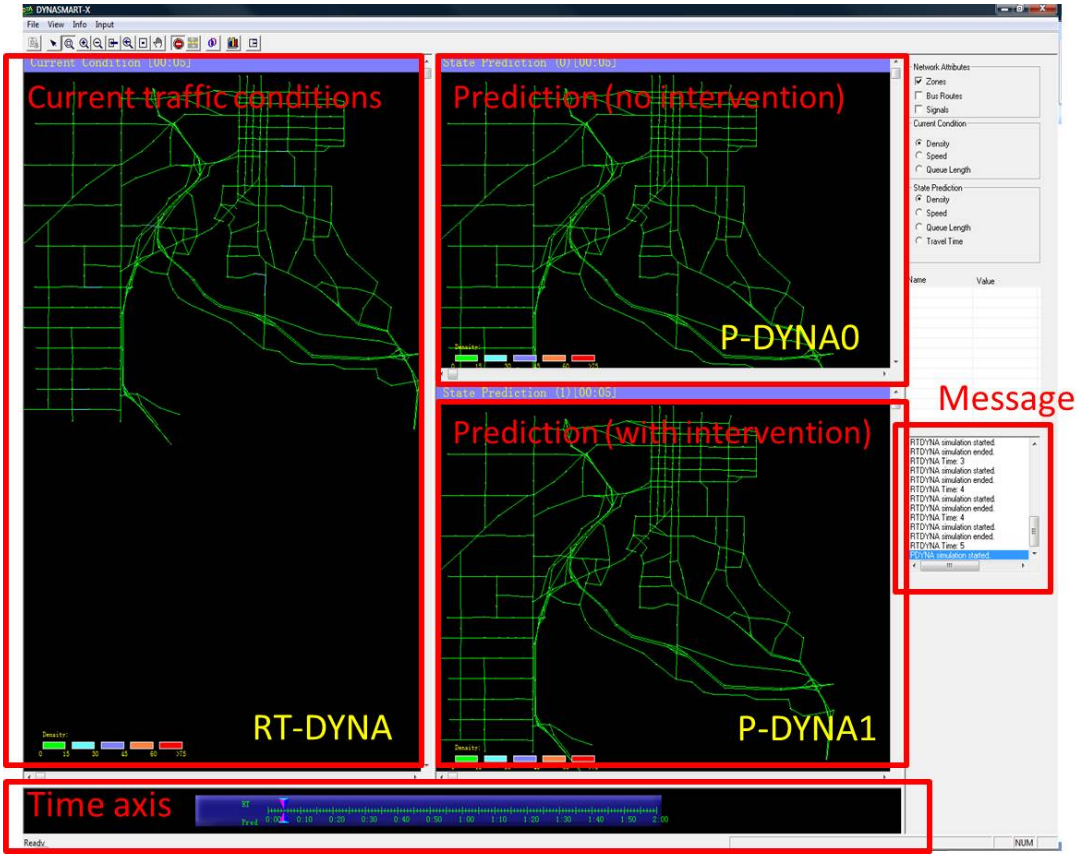
Name	Date modified	Type
estimate	2/26/2014 5:30 PM	File folder
ltcc	2/26/2014 12:31 AM	File folder
odestimate	2/26/2014 1:10 AM	File folder
odpredict	2/26/2014 12:31 AM	File folder
predict	2/27/2014 12:55 AM	File folder
predict1	2/27/2014 12:55 AM	File folder
stcc	2/26/2014 12:31 AM	File folder
DataManagement.exe	2/26/2014 12:31 AM	Application
dsxgui.exe	2/26/2014 12:33 AM	Application
Management.exe	2/26/2014 12:32 AM	Application
tao_cosnaming.exe	2/25/2014 6:06 PM	Application
Distribution.ini	8/16/2010 2:26 PM	Configuration sett...
modules.dat	2/26/2014 12:34 AM	dat
scheduler.dat	2/6/2014 2:52 PM	dat
DataManagement.exp	6/7/2012 11:01 PM	Exports Library File

Figure B-7. Launch DYNASMART-X

Start DYNASMART-X

To start DYNASMART-X, follow the following procedures on DYNASMART-X window (Figure 0-8):

1. Click **File → Load Data** to show the network on GUI.
2. Click **File → 1. Check System Settings**; Choose **Real Time Mode**; Click **OK**.
3. Click **File → 2. Activate Naming Service.** A console window will pop out.
4. Click **File → 4. Activate Modules on Server Machine**. Nine executable windows will start right afterwards, which are Management, Data Management, RT-Dyna, P-Dyna, P-Dyna1, ODP, ODE, STCC, and LTCC.
5. Click **File → 5. Setup CORBA and Start DYNASMART-X**. DYNASMART-X will then be initialized and start running.



Network Attributes
☑ Zones
☐ Bus Routes
☐ Signals

Current Condition
● Density
○ Speed
○ Queue Length

State Prediction
● Density
○ Speed
○ Queue Length
○ Travel Time

Name	Value

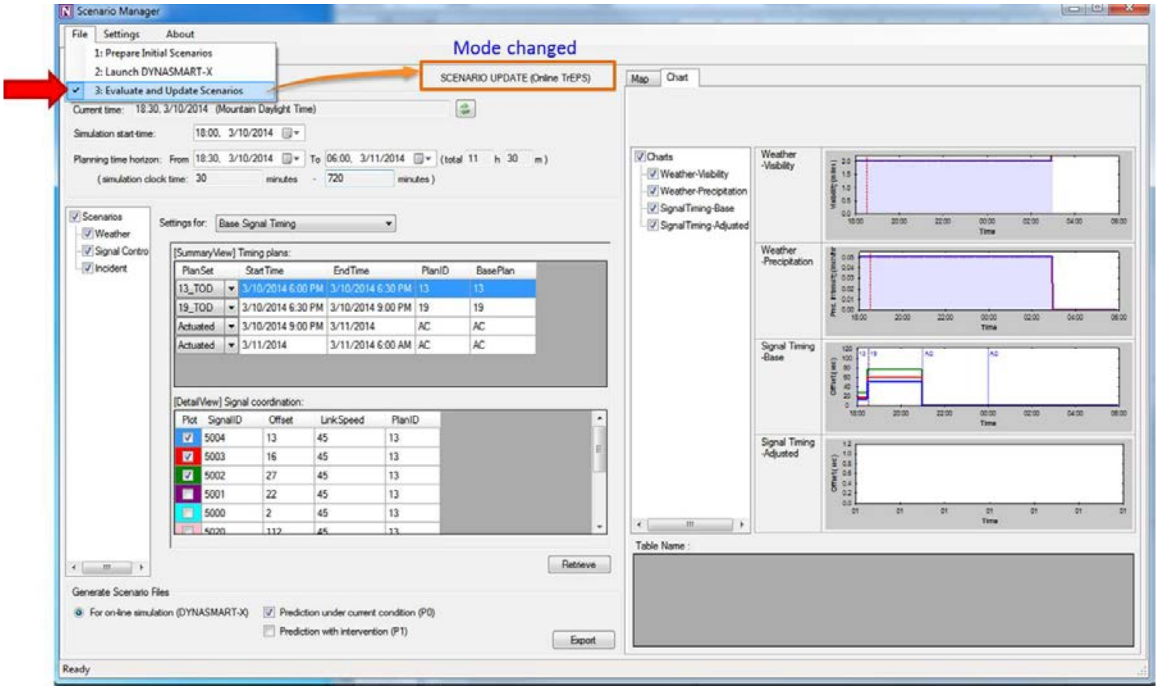
```
RTDYNA simulation started.
RTDYNA simulation ended.
RTDYNA Time: 3
RTDYNA simulation started.
RTDYNA simulation ended.
RTDYNA Time: 4
RTDYNA simulation started.
RTDYNA simulation ended.
RTDYNA Time: 4
RTDYNA simulation started.
RTDYNA simulation ended.
RTDYNA Time: 5
PDYNA simulation started.
```

Figure B-8. DYNASMART-X Main Window

Evaluate and Update Scenarios

When DYNASMART-X is running, users can continuously evaluate and update scenarios by working on Scenario Manager. To do this, click **File → 3: Evaluate and Update Scenarios** (Figure B-9). Users will then notice several changes on the 'Time Settings' panel:

1. Notice that **Current time** is updated to the real current time;
2. The **Simulation start-time** will remain the same what it was when preparing initial scenarios.
3. The start-time of **Planning time horizon** is shifted to the current time;



Current time: 18:30, 3/10/2014 (Mountain Daylight Time)

Simulation start-time: 18:00, 3/10/2014

Planning time horizon: From 18:30, 3/10/2014 To 06:00, 3/11/2014 (total 11 h 30 m)

(simulation clock time: 30 minutes - 720 minutes)

Settings for: Base Signal Timing

[SummaryView] Timing plans:

PlanSet	StartTime	EndTime	PlanID	BasePlan
13_TOD	3/10/2014 6:00 PM	3/10/2014 6:30 PM	13	13
19_TOD	3/10/2014 6:30 PM	3/10/2014 9:00 PM	19	19
Actuated	3/10/2014 9:00 PM	3/11/2014	AC	AC
Actuated	3/11/2014	3/11/2014 6:00 AM	AC	AC

[DetailView] Signal coordination:

Plot	SignalID	Offset	LinkSpeed	PlanID
☑	5004	13	45	13
☑	5003	16	45	13
☑	5002	27	45	13
☐	5001	22	45	13
☐	5000	2	45	13
☐	5020	112	45	13

Generate Scenario Files

● For on-line simulation (DYNASMART-X)

☑ Prediction under current condition (P0)

☐ Prediction with intervention (P1)

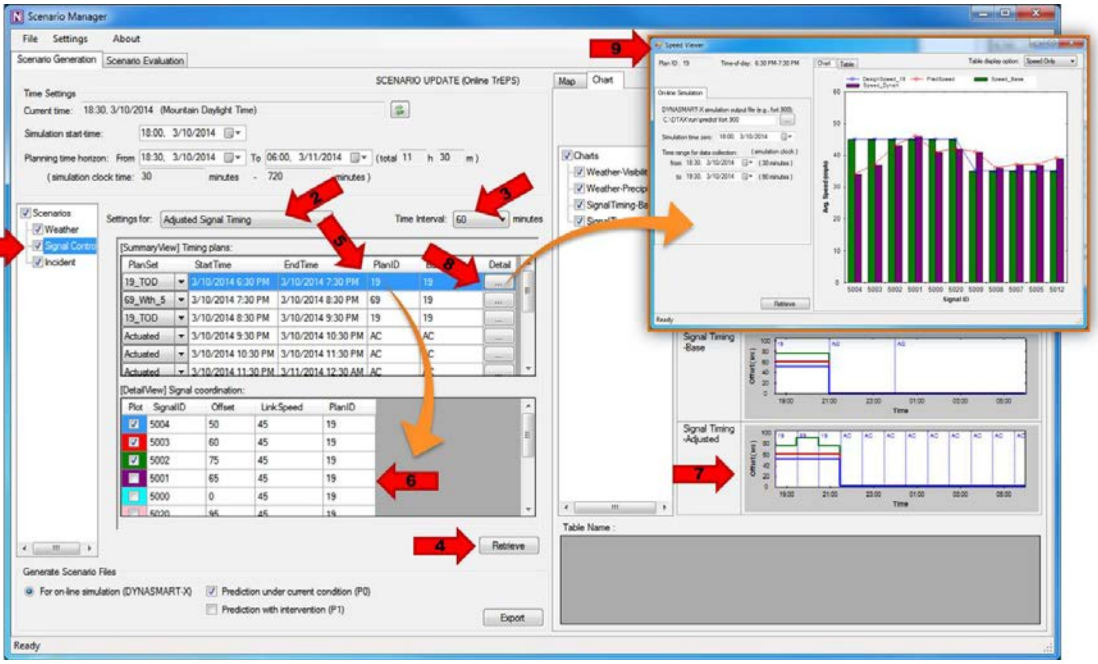
Figure B-9. Start Evaluate and Update Scenarios

Select Alternative Signal Timing Plans

Several pre-defined coordinated signal plans are store within Scenario Manager's signal plan library. During the execution of DYNASMART-X, users can continuously monitor the predicted link speed, and switch between different signal timing plans. Steps for selecting alternative signal timing plan in the Scenario Manager are as follows:

1. Click **Signal Control** node from the tree.
2. Select **Adjusted Signal Timing** to specify alternative plans for testing (before deployment).

3. Select a **time interval**, i.e., aggregation interval for estimating link speeds.
4. Click **Retrieve** to retrieve adjusted plans for the given planning time horizon.
5. For each time interval (e.g., 60 min), the Scenario Manager suggests the best-matching plan (e.g., **PlanID**=69) among the available plan set {e.g., 19, 69, 67, 70}.
6. The signal offset values for the selected row (time period) can be viewed from **DetailView**.
7. The time-dependent offset profile for the selected (checked) signals can be viewed from the **Signal Timing-Adjusted** chart.
8. Users can check how the best-matching timing plan was selected by clicking the **Detail** (…) button.
9. The **Speed Viewer** dialog will pop up and show the predicted link speeds for a given time interval.



Time Settings
Current time: 18:30, 3/10/2014 (Mountain Daylight Time)
Simulation start time: 18:00, 3/10/2014
Planning time horizon: From 18:30, 3/10/2014 To 06:00, 3/11/2014 (total 11 h 30 m)
(simulation clock time: 30 minutes - 720 minutes)

☑ Scenarios
☑ Weather
☑ Signal Contro
☑ Incident

Settings for: Adjusted Signal Timing
Time Interval: 60 minutes

[SummaryView] Timing plans:

PlanSet	StartTime	EndTime	PlanID		Detail
19_TOD	3/10/2014 6:30 PM	3/10/2014 7:30 PM	19	19	...
69_Wth_5	3/10/2014 7:30 PM	3/10/2014 8:30 PM	69	19	...
19_TOD	3/10/2014 8:30 PM	3/10/2014 9:30 PM	19	19	...
Actuated	3/10/2014 9:30 PM	3/10/2014 10:30 PM	AC	AC	...
Actuated	3/10/2014 10:30 PM	3/10/2014 11:30 PM	AC	C	...
Actuated	3/10/2014 11:30 PM	3/11/2014 12:30 AM	AC		...

[DetailView] Signal coordination:

Plot	SignalID	Offset	LinkSpeed	PlanID
☑	5004	50	45	19
☑	5003	60	45	19
☑	5002	75	45	19
☐	5001	65	45	19
☐	5000	0	45	19
☐	5020	95	45	19

Retrieve

Generate Scenario Files
● For on-line simulation (DYNASMART-X)
☑ Prediction under current condition (P0)
☐ Prediction with intervention (P1)
Export

Ready

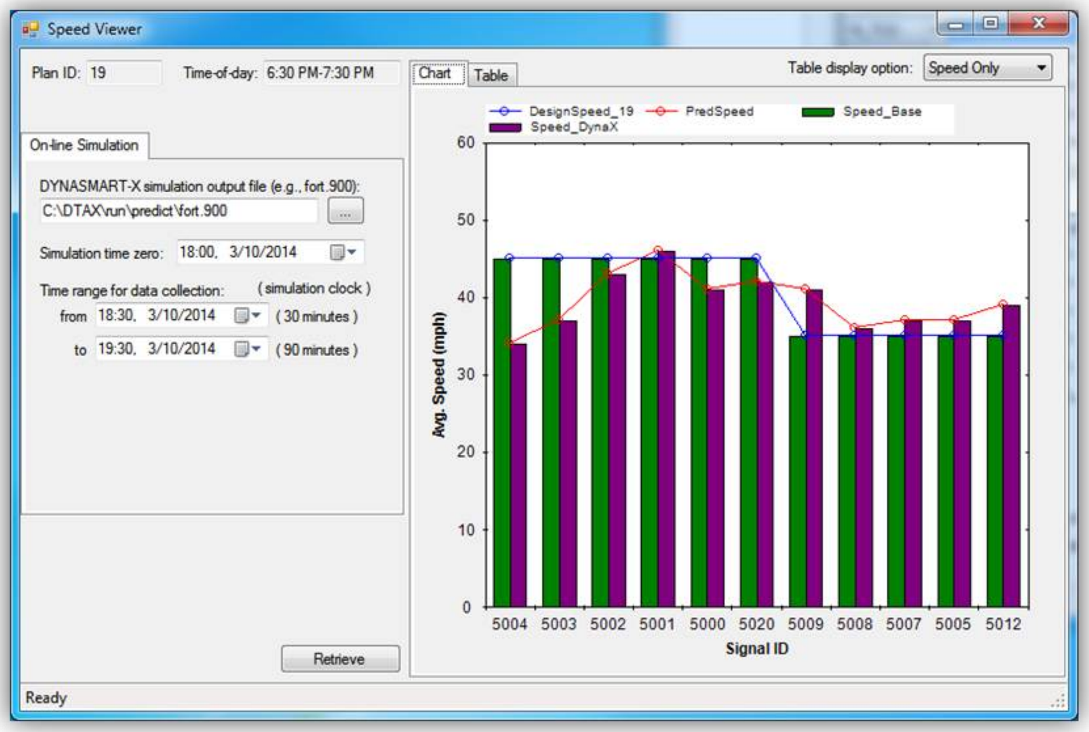
Figure B-10. Select Alternative Signal Timing Plans

Speed Viewer Dialog

The Speed Viewer Dialog allows users to monitor the predicted link speeds on Riverdale Road, and compare them with the design speed of coordinated signal plans. The quantities plotted in the Speed Viewer Dialog include the followings:

- **DesignSpeed_Y**: the assumed link speed for timing plan Y (e.g., Y϶ {19, 69, 67,70})
- **PredSpeed** : the final predicted link speed
- **Speed_Base**: the base speed (e.g., posted speed limit) used in Time-of-Day plans

- **Speed_DynaX**: the predicted link speed obtained from DYNASMART-X simulation results



Plan ID: 19

Time-of-day: 6:30 PM-7:30 PM

Table display option: Speed Only

DYNASMART-X simulation output file (e.g., fort.900): C:\DTAX\run\predict\fort.900

Simulation time zero: 18:00, 3/10/2014

Time range for data collection: (simulation clock)

from 18:30, 3/10/2014 (30 minutes)

to 19:30, 3/10/2014 (90 minutes)

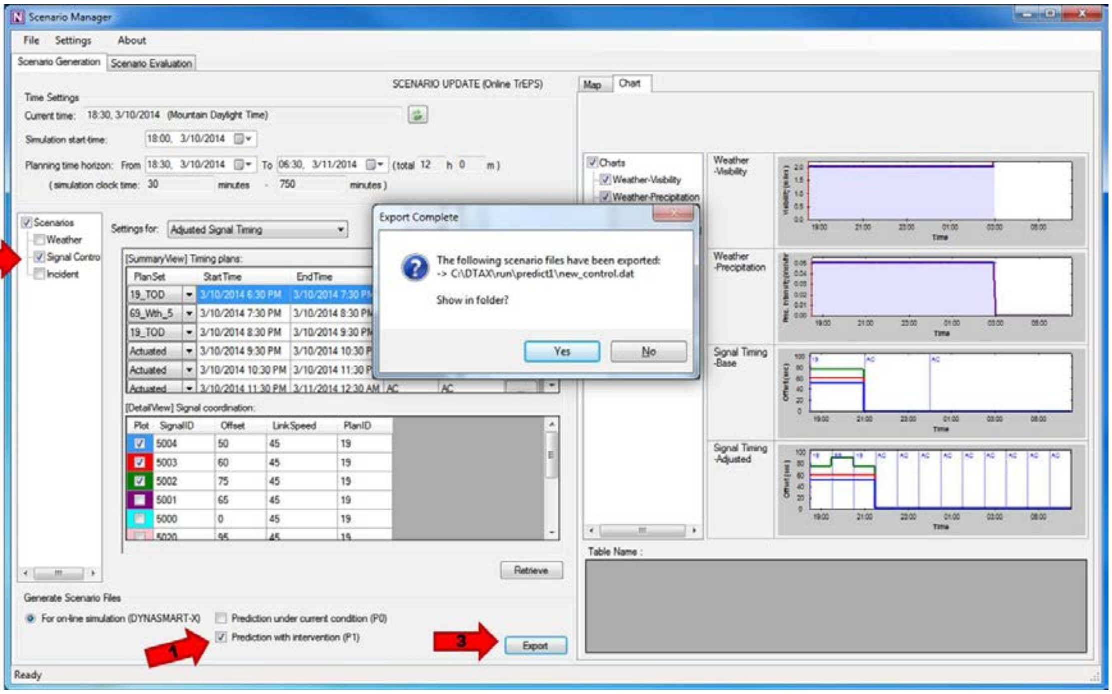
Ready

Figure B-11. Speed Viewer Dialog

Export New Control Scenario to DYNASMART-X for Testing

During the simulation, if the user would like to switch to a new signal plan, please follow the procedures below to export the new control scenario to DYNASMART-X for testing:

1. Check **Prediction with intervention (P1)** and uncheck **Prediction under current condition (P0)** to export the new control scenario only to the testing module (P1) for comparison.
2. Check **Signal Control** node and leave other scenarios unchecked to export the Signal Control scenario only.
3. Click **Export** to export the new adjusted signal timing scenario (new_control.dat).



SCENARIO UPDATE (Online TrEPS)

Time Settings

Current time: 18:30, 3/10/2014 (Mountain Daylight Time)

Simulation start-time: 18:00, 3/10/2014

Planning time horizon: From 18:30, 3/10/2014 To 06:30, 3/11/2014 (total 12 h 0 m)

(simulation clock time: 30 minutes - 750 minutes)

☑ Scenarios
  ☐ Weather
  ☑ Signal Contro
  ☐ Incident

Settings for: Adjusted Signal Timing

[SummaryView] Timing plans:

PlanSet	StartTime	EndTime
19_TOD	3/10/2014 6:30 PM	3/10/2014 7:30 P
69_Wth_5	3/10/2014 7:30 PM	3/10/2014 8:30 P
19_TOD	3/10/2014 8:30 PM	3/10/2014 9:30 P
Actuated	3/10/2014 9:30 PM	3/10/2014 10:30 P
Actuated	3/10/2014 10:30 PM	3/10/2014 11:30 P
Actuated	3/10/2014 11:30 PM	3/11/2014 12:30 AM

[DetailView] Signal coordination:

Plot	SignalID	Offset	LinkSpeed	PlanID
☑	5004	50	45	19
☑	5003	60	45	19
☑	5002	75	45	19
☐	5001	65	45	19
☐	5000	0	45	19
☐	5020	95	45	19

Export Complete

The following scenario files have been exported:
-> C:\DTAX\run\predict1\new_control.dat

Show in folder?

Generate Scenario Files

● For on-line simulation (DYNASMART-X)

☐ Prediction under current condition (P0)

☑ Prediction with intervention (P1)

Ready

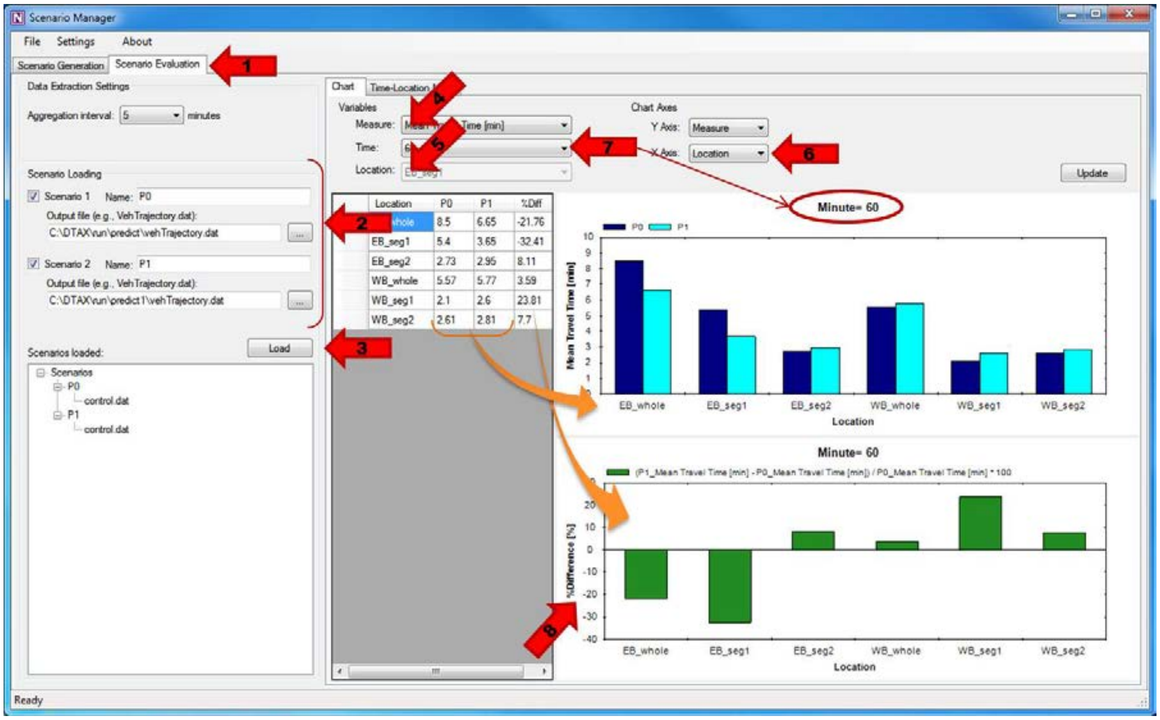
Figure B-12. Export New Control Input Files to DYNASMART-X

Evaluate Alternative Signal Timing Plan

After exporting the new signal control scenario, wait approximately 5 minutes until DYNASMART-X completes the prediction with the new scenario. Next, load the simulation outputs from P0 and P1 to evaluate the scenario performances.

1. Click **Scenario Evaluation** tab.
2. Ensure that (i) both Scenario 1 and 2 are checked and (ii) scenario names and output paths are specified.
3. Click **Load** to load the simulated vehicle trajectories for the current prediction interval (i.e., next 1 hour)
4. Several different performance measures can be evaluated, which include total travel time, mean travel time, 25 percentage of travel time, 80 percentage of travel time, 95 percentage of travel time, standard deviation of travel time, buffer index, mean stop time, percentage of stopped vehicles.
5. Users can choose the locations or segments from which output performance measures will be extracted.
6. Can select X-Axis between **Location** and **Time**.
7. Depending on the type of X-Axis, the chart series are available for different time intervals or locations.

8. The **percentage difference** between P0 and P1 is displayed on the bottom chart. Note: always the first tree node is used as the "*reference scenario"* and the second tree node is used as the "*compared scenario*."



Aggregation interval: 5 minutes

Scenario Loading

☑ Scenario 1 Name: P0

Output file (e.g., VehTrajectory.dat):

C:\DTAX\run\predict\vehTrajectory.dat

☑ Scenario 2 Name: P1

Output file (e.g., VehTrajectory.dat):

C:\DTAX\run\predict1\vehTrajectory.dat

Scenarios loaded:

Measure: Mean Tr… Time [min]

Time: 6…

Location: EB_seg1

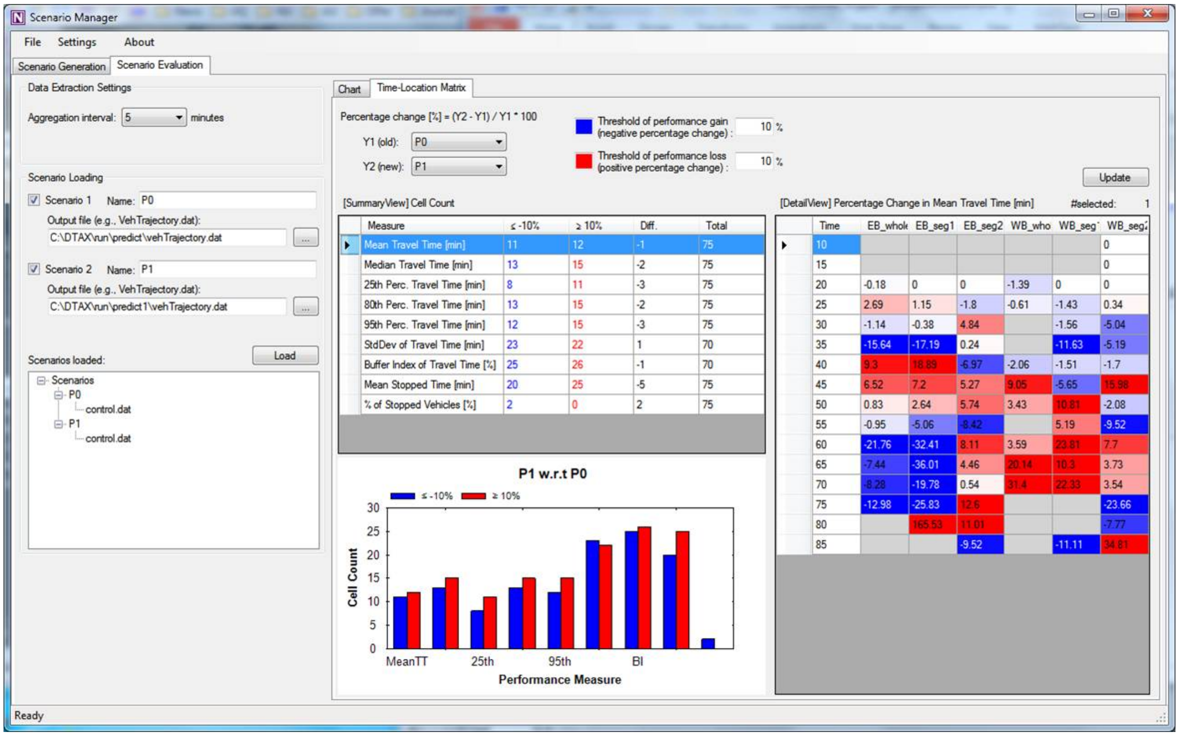
Y Axis: Measure

X Axis: Location

Location	P0	P1	%Diff
whole	8.5	6.65	-21.76
EB_seg1	5.4	3.65	-32.41
EB_seg2	2.73	2.95	8.11
WB_whole	5.57	5.77	3.59
WB_seg1	2.1	2.6	23.81
WB_seg2	2.61	2.81	7.7

Figure B-13. Evaluate Alternative Signal Timing Plans

Users can also evaluate the performance gain (or loss) due to P1 with respect to P0 for all time intervals and all locations via **Time-Location Matrix** view. To view the results, click the '**Time-Location Matrix**' tab on Scenario Manager interface. The blue colored cells represent the performance measures where P1 is superior to P0, and the red colored cells represent the performance measures where P1 is not as good as P0. The more blue cells you can see, the more confident you are with the alternative signal plan.



Data Extraction Settings

Aggregation interval: 5 minutes

Scenario Loading

☑ Scenario 1 Name: P0

Output file (e.g., VehTrajectory.dat): C:\DTAX\run\predict\vehTrajectory.dat

☑ Scenario 2 Name: P1

Output file (e.g., VehTrajectory.dat): C:\DTAX\run\predict1\vehTrajectory.dat

Scenarios loaded:

- Scenarios
  - P0
    - control.dat
  - P1
    - control.dat

Percentage change [%] = (Y2 - Y1) / Y1 * 100

Y1 (old): P0

Y2 (new): P1

🟦 Threshold of performance gain (negative percentage change) : 10 %

🟥 Threshold of performance loss (positive percentage change) : 10 %

[SummaryView] Cell Count

Measure	≤ -10%	≥ 10%	Diff.	Total
Mean Travel Time [min]	11	12	-1	75
Median Travel Time [min]	13	15	-2	75
25th Perc. Travel Time [min]	8	11	-3	75
80th Perc. Travel Time [min]	13	15	-2	75
95th Perc. Travel Time [min]	12	15	-3	75
StdDev of Travel Time [min]	23	22	1	70
Buffer Index of Travel Time [%]	25	26	-1	70
Mean Stopped Time [min]	20	25	-5	75
% of Stopped Vehicles [%]	2	0	2	75

[DetailView] Percentage Change in Mean Travel Time [min] #selected: 1

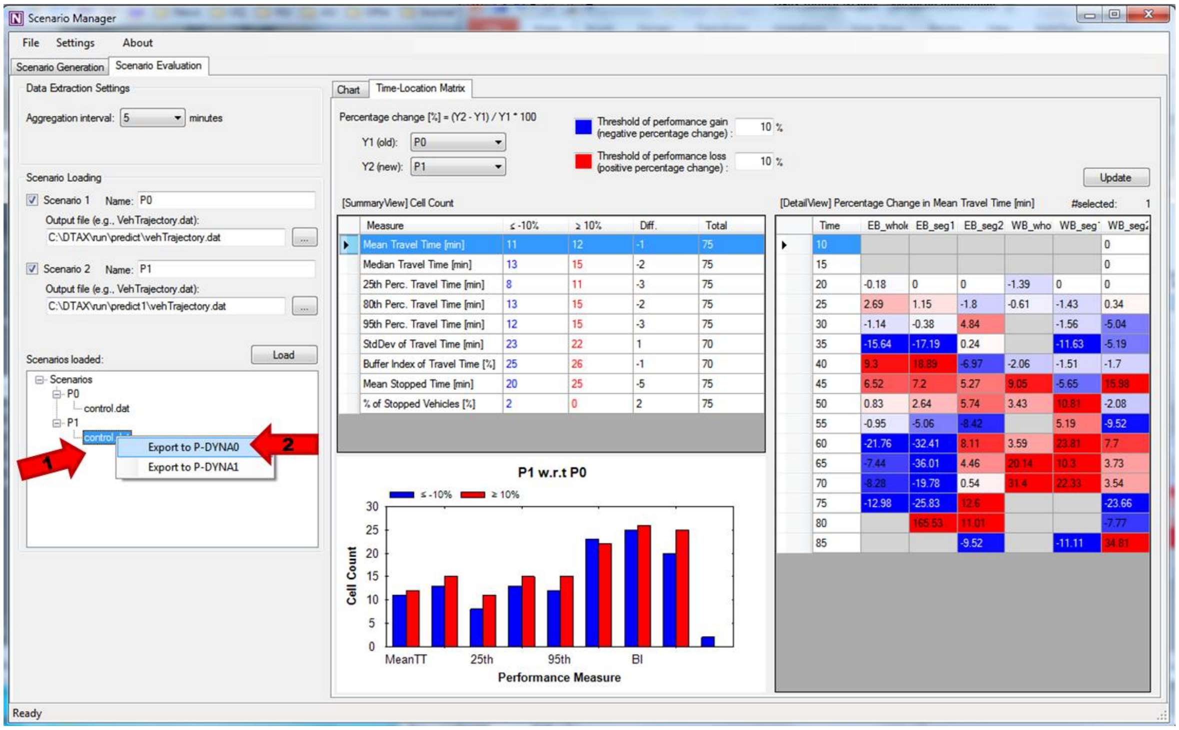
Time	EB_whol	EB_seg1	EB_seg2	WB_who	WB_seg	WB_seg
10						0
15						0
20	-0.18	0	0	-1.39	0	0
25	2.69	1.15	-1.8	-0.61	-1.43	0.34
30	-1.14	-0.38	4.84		-1.56	-5.04
35	-15.64	-17.19	0.24		-11.63	-5.19
40	9.3	18.89	-6.97	-2.06	-1.51	-1.7
45	6.52	7.2	5.27	9.05	-5.65	15.98
50	0.83	2.64	5.74	3.43	10.81	-2.08
55	-0.95	-5.06	-8.42		5.19	-9.52
60	-21.76	-32.41	8.11	3.59	23.81	7.7
65	-7.44	-36.01	4.46	20.14	10.3	3.73
70	-8.28	-19.78	0.54	31.4	22.33	3.54
75	-12.98	-25.83	12.6			-23.66
80		165.53	11.01			-7.77
85			-9.52		-11.11	34.81

Figure B-14. Time-location Matrix

Update Signal Scenario after Deploying New Signal Plan in Real Wrold

If we decide to implement P1 and deploy the associated plan to the real-network, we need to reflect this in the simulation world as well. After deploying the new signal plan on the field, export the tested control scenario (P1) to actual implementation (P0) following the procedures:

1. Right-click on **control.dat** of P1.
2. Click **Export to P-DYNA0** to export ***control.dat*** residing in "..\run\predict" to "..\run\predict1" folder. This will allow the new control strategy tested in P1 to be actually implemented in P0 in DYNASMART-X.



Aggregation interval: 5 minutes

☑ Scenario 1 Name: P0
Output file (e.g., VehTrajectory.dat): C:\DTAX\run\predict\vehTrajectory.dat

☑ Scenario 2 Name: P1
Output file (e.g., VehTrajectory.dat): C:\DTAX\run\predict1\vehTrajectory.dat

Percentage change [%] = (Y2 - Y1) / Y1 * 100

Y1 (old): P0

Y2 (new): P1

🟦 Threshold of performance gain (negative percentage change) : 10 %

🟥 Threshold of performance loss (positive percentage change) : 10 %

[SummaryView] Cell Count

Measure	≤ -10%	≥ 10%	Diff.	Total
Mean Travel Time [min]	11	12	-1	75
Median Travel Time [min]	13	15	-2	75
25th Perc. Travel Time [min]	8	11	-3	75
80th Perc. Travel Time [min]	13	15	-2	75
95th Perc. Travel Time [min]	12	15	-3	75
StdDev of Travel Time [min]	23	22	1	70
Buffer Index of Travel Time [%]	25	26	-1	70
Mean Stopped Time [min]	20	25	-5	75
% of Stopped Vehicles [%]	2	0	2	75

[DetailView] Percentage Change in Mean Travel Time [min] #selected: 1

Time	EB_whol	EB_seg1	EB_seg2	WB_who	WB_seg	WB_seg
10						0
15						0
20	-0.18	0	0	-1.39	0	0
25	2.69	1.15	-1.8	-0.61	-1.43	0.34
30	-1.14	-0.38	4.84		-1.56	-5.04
35	-15.64	-17.19	0.24		-11.63	-5.19
40	9.3	18.89	-6.97	-2.06	-1.51	-1.7
45	6.52	7.2	5.27	9.05	-5.65	15.98
50	0.83	2.64	5.74	3.43	10.81	-2.08
55	-0.95	-5.06	-8.42		5.19	-9.52
60	-21.76	-32.41	8.11	3.59	23.81	7.7
65	-7.44	-36.01	4.46	20.14	10.3	3.73
70	-8.28	-19.78	0.54	31.4	22.33	3.54
75	-12.98	-25.83	12.6			-23.66
80		165.53	11.01			-7.77
85			-9.52		-11.11	34.81

Figure B-15. Update Scenario after Deploying Alternative Signal Plan in Real World

Quitting the Software

When quitting the software, it is recommended to quit DYNASMART-X first and then quit Scenario Manager.

1. To quit DYNASMART-X, click **File → Close DYNASMART-X Components** and then click **File → Exit**. Close any associated console windows if they are still open.
2. To quit Scenario Manger, simply close the Scenario Manager window (click on the cross in the red box at the top right corner of the window).

Appendix C. Scenario Manager’s Input Data

Scenario Manager requires two classes of input files: input for scenario generation and input for scenario evaluation. All the input files must be present in the Scenario Manager working directory (e.g., C:\ScenarioManager\SMwd). **Table C-1** provides a brief description of what each input file is used for. The input files have different file extensions. For example, input files specifically designed for the Scenario Manager program use the CSV (comma-separated values) file format with the “.csv” extension, whereas files from the DYNASMART program have the “.dat” extension. In the CSV files, the first row represents a header containing a list of column names. The column names are **case-sensitive** and must be specified as presented in the associated format descriptions. The order of columns does not matter and the columns can be in any order.

Table C-7. Summary of Scenario Manager Input Files

Category		Input File	Description
Scenario Generation	Signal Control Scenario	**corridor.csv**	Information regarding signalized intersections selected for the weather-responsive traffic signal control; mapping between signal ID and DYNASMART nodes
		planDetail.csv	Signal control parameters for each signal and timing plan
		planSet.csv	Signal timing library; available timing plans and base plan for each time-of-day and day-of-week combination
		control_X.dat	[DYNASMART input file] signal control input for the entire network with signal timing plan **X** for the Riverdale Rd corridor
	Demand Scenario	**demand.dat**	[DYNASMART input file] 24-hr historical demand starting at 6AM
	Incident Scenario	**network.dat**	[DYNASMART input file] Information regarding network links; needed to specify incident location
		dyna_slc_riverdale.shp (.dbf, .prj, .shx)	Shapefile representing the DYNASMART Riverdale Rd network; needed to select incident link using the map selection tool
Scenario Evaluation		**routes.csv**	User-defined target locations for scenario evaluation; route performance measures are extracted from VehTrajectory.dat

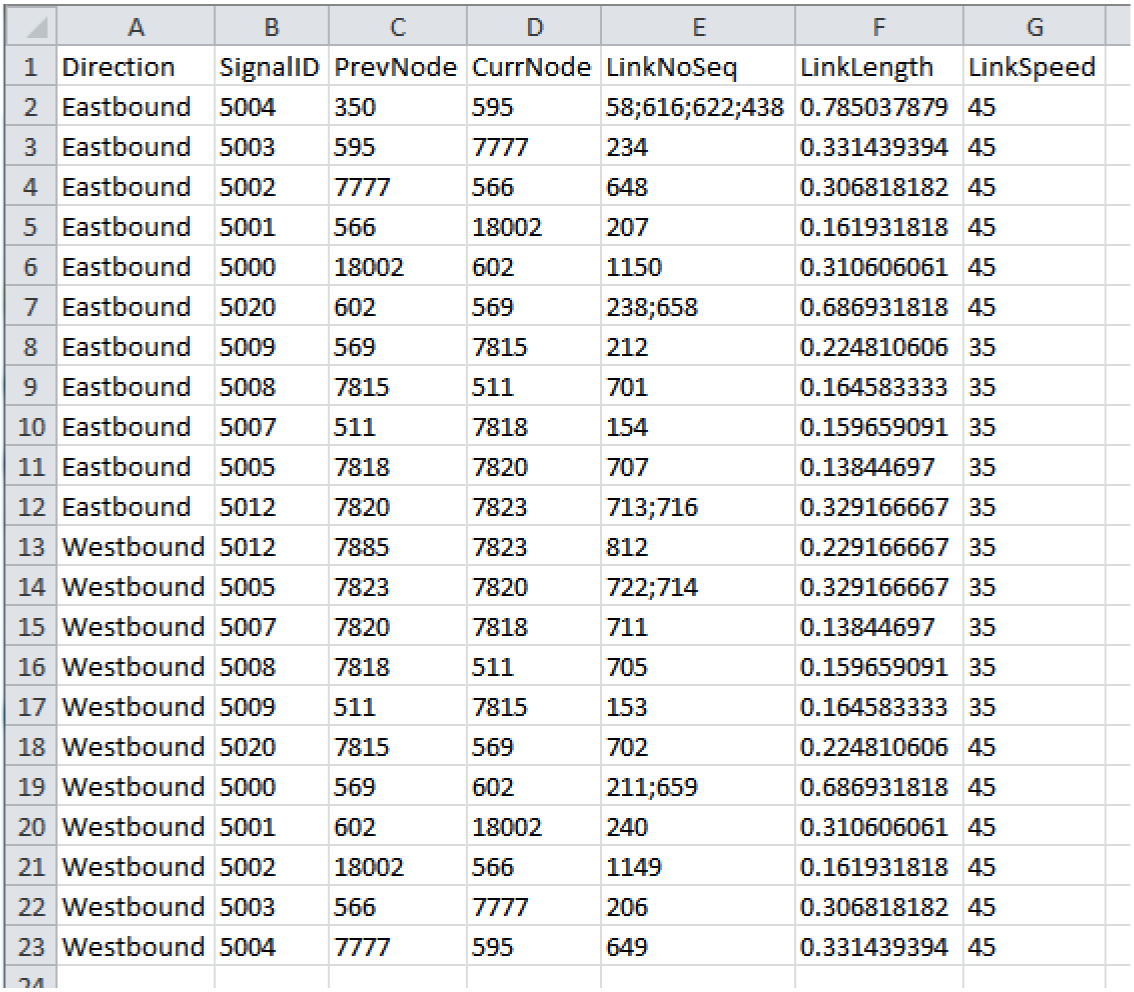
Traffic Signal Information (corridor.csv)

This file describes signalized intersections considered for the TrEPS-based weather-responsive traffic signal control. **Table C-2** presents required format and descriptions for each column of the **corridor.csv** input file and **Figure C-1** shows a sample file for the Riverdale Rd network.

The study corridor may be specified in terms of both directions of the major street. For a given direction, starting from the first signalized intersection, all downstream intersections should be exhausted (from upstream to downstream) before representing a new direction. Whenever a sequence of signal IDs is needed (for a purpose of displaying tables or charts), the list of signal IDs specified for the first **Direction** group is used in Scenario Manager. For instance, by using the input shown in **Figure C-1**, tables and charts in Scenario Manager will display signal IDs based on the order of SignalIDs for Eastbound (i.e., 5004, 5003, … , 5012).

Table C-8. Description of the “corridor.csv” Input File

Column Name	Value Format	Description
Direction (required)	String	Name of the corridor direction (e.g., Westbound, Eastbound, Northbound and Southbound).
SignalID (required)	Integer	ID of a signal device representing a single signalized intersection (or node in a simulation network)
PrevNode (optional)	Integer	DYNASMART node ID corresponding to the upstream signal in a given direction
CurrNode (required)	Integer	DYNASMART node ID corresponding to **SignalID**, the current signal
LinkNoSeq (required)	String or String array; Format: X1 or X1;X2;…;XN	Sequence of DYNASMART link IDs associated with links composing the segment between **PrevNode** (upstream signal) and **CurrNode** (current signal)
LinkLength (optional)	Double	Length of the segment between **PrevNode** and **CurrNode** [miles]
LinkSpeed (required)	Integer	Post speed limit of the incoming link in a given direction [mph] This is the design speed used in deriving offsets for the base-case (Time-of-day) signal timing plans and should be consistent with **LinkSpeed** records for Base PlanID in **planDetail.csv**.



	A	B	C	D	E	F	G
1	Direction	SignalID	PrevNode	CurrNode	LinkNoSeq	LinkLength	LinkSpeed
2	Eastbound	5004	350	595	58;616;622;438	0.785037879	45
3	Eastbound	5003	595	7777	234	0.331439394	45
4	Eastbound	5002	7777	566	648	0.306818182	45
5	Eastbound	5001	566	18002	207	0.161931818	45
6	Eastbound	5000	18002	602	1150	0.310606061	45
7	Eastbound	5020	602	569	238;658	0.686931818	45
8	Eastbound	5009	569	7815	212	0.224810606	35
9	Eastbound	5008	7815	511	701	0.164583333	35
10	Eastbound	5007	511	7818	154	0.159659091	35
11	Eastbound	5005	7818	7820	707	0.13844697	35
12	Eastbound	5012	7820	7823	713;716	0.329166667	35
13	Westbound	5012	7885	7823	812	0.229166667	35
14	Westbound	5005	7823	7820	722;714	0.329166667	35
15	Westbound	5007	7820	7818	711	0.13844697	35
16	Westbound	5008	7818	511	705	0.159659091	35
17	Westbound	5009	511	7815	153	0.164583333	35
18	Westbound	5020	7815	569	702	0.224810606	45
19	Westbound	5000	569	602	211;659	0.686931818	45
20	Westbound	5001	602	18002	240	0.310606061	45
21	Westbound	5002	18002	566	1149	0.161931818	45
22	Westbound	5003	566	7777	206	0.306818182	45
23	Westbound	5004	7777	595	649	0.331439394	45

Figure C-16. General Format of the <corridor.csv> Input File

Signal Timing Plan Library (planSet.csv)

This file describes a set of signal timing plans for each of the possible combinations of day-of-week, time-of-day and weather conditions. **Figure C-2** shows a tree structure defining a list of plans for each case. For instance, the day-of-week variable can have three states: weekday, Saturday and Sunday. For a given weekday, four different time-of-day states are defined: AM peak (6:30-9:00), AM off-peak (9:00-13:00), PM off-peak (13:00-18:60) and PM peak (18:30-21:00). For a given weekday and time-of-day, four different weather conditions are considered in terms of their impacts on link speeds: 0mph, 5mph, 10mph and 15mph reductions in normal link speeds (e.g., posted speed limits) and the associated signal timing plan is specified : Plan 1, 58, 57 and 56, respectively. The plan for the normal condition (e.g., Plan 1 for - 0mph) is considered as a base plan indicating that all other three plans follow the same parameters (e.g., cycle length and splits) specified in this base plan and only offsets are adjusted to reflect the assumed speed reductions due to weather.

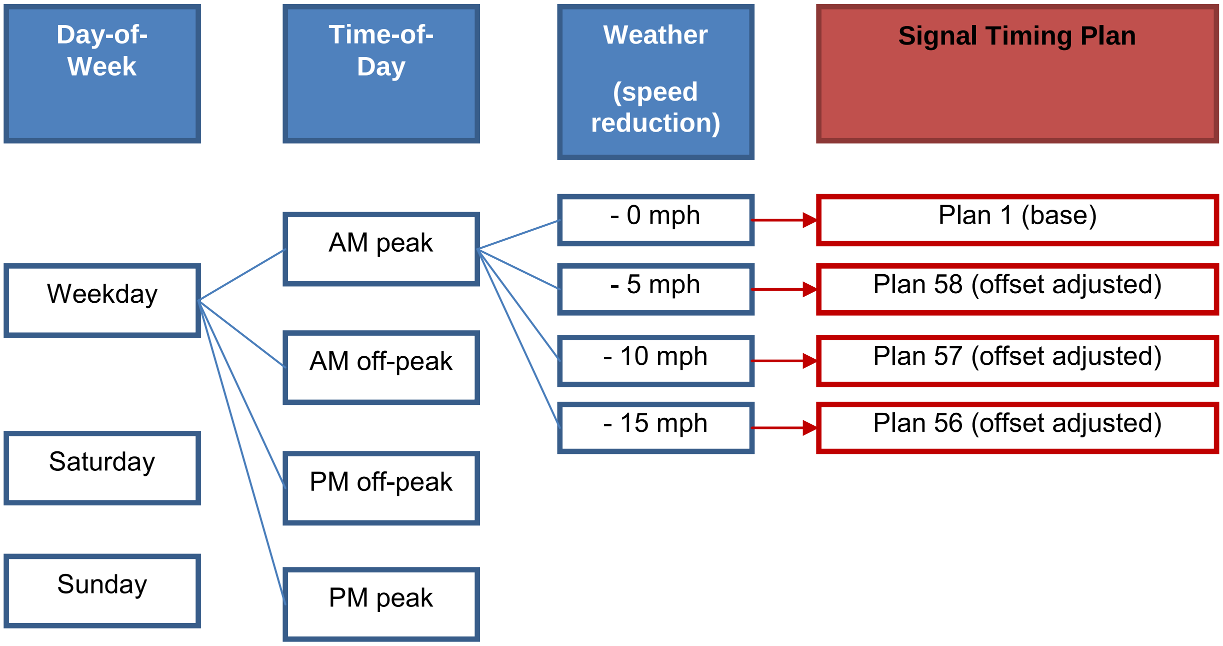


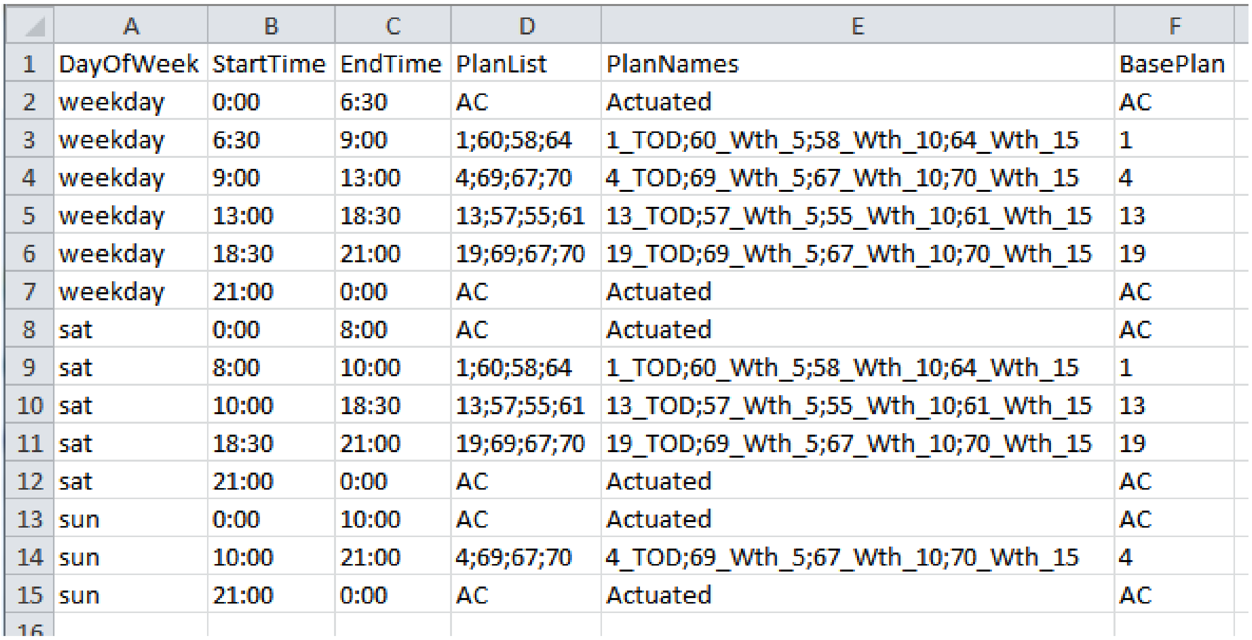
Figure C-17. Structure of Signal Timing Plan Action Set

Table C-3 presents required format and descriptions for each column of the **planSet.csv** input file and **Figure C-3** shows a sample file. The first row represents a header containing a list of column names. The column names are case-sensitive and must be specified as presented in **Table C-3**. The order of columns does not matter and the columns can be in any order.

Table C-9. Description of the "planSet.csv" Input File

Column Name	Value Format	Description
DayOfWeek (required)	String; should be one of the following values: {weekday, weekend, Mon, Tue, Wed, Thu, Fri, Sat, Sun}	The day-of-week condition for defining a signal timing plan set The value string is case-insensitive.
StartTime (required)	DateTime; Format: "HH:mm" (24hr format)	Start-time of the time-of-day condition for defining a signal timing plan set
EndTime (required)	DateTime; Format: "HH:mm" (24hr format)	End-time of the time-of-day condition for defining a signal timing plan set
PlanList (required)	String or String array; Format: X1 or X1;X2;…;XN	Signal timing plan set, i.e., a set of available timing plan IDs for the given day-of-week and time-of-day combination. When more than one plan is available, the plan IDs should be

Column Name	Value Format	Description
		separated by semicolons (;) as a delimiter. The plans must include both Base and Adjusted plans. For the actuated plan, enter "AC"
PlanNames (required)	String or String array; Format: X1 or X1;X2;…;XN	User-friendly names for the plans defined in "PlanList" column.
BasePlan (required)	String	Base plan ID. This value must be one of the elements in the PlanList array. For the actuated plan, enter "AC"



	A	B	C	D	E	F
1	DayOfWeek	StartTime	EndTime	PlanList	PlanNames	BasePlan
2	weekday	0:00	6:30	AC	Actuated	AC
3	weekday	6:30	9:00	1;60;58;64	1_TOD;60_Wth_5;58_Wth_10;64_Wth_15	1
4	weekday	9:00	13:00	4;69;67;70	4_TOD;69_Wth_5;67_Wth_10;70_Wth_15	4
5	weekday	13:00	18:30	13;57;55;61	13_TOD;57_Wth_5;55_Wth_10;61_Wth_15	13
6	weekday	18:30	21:00	19;69;67;70	19_TOD;69_Wth_5;67_Wth_10;70_Wth_15	19
7	weekday	21:00	0:00	AC	Actuated	AC
8	sat	0:00	8:00	AC	Actuated	AC
9	sat	8:00	10:00	1;60;58;64	1_TOD;60_Wth_5;58_Wth_10;64_Wth_15	1
10	sat	10:00	18:30	13;57;55;61	13_TOD;57_Wth_5;55_Wth_10;61_Wth_15	13
11	sat	18:30	21:00	19;69;67;70	19_TOD;69_Wth_5;67_Wth_10;70_Wth_15	19
12	sat	21:00	0:00	AC	Actuated	AC
13	sun	0:00	10:00	AC	Actuated	AC
14	sun	10:00	21:00	4;69;67;70	4_TOD;69_Wth_5;67_Wth_10;70_Wth_15	4
15	sun	21:00	0:00	AC	Actuated	AC
16						

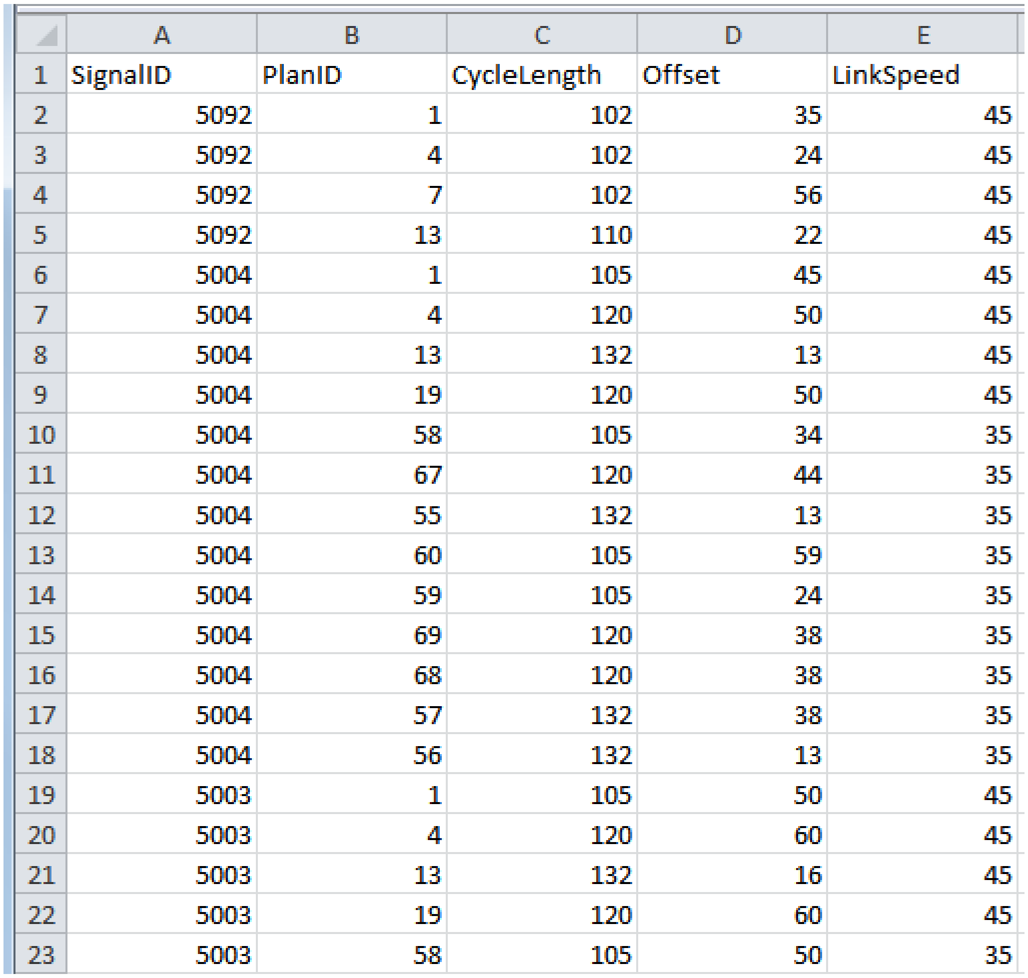
Figure C-18. General Format of the "platSet.csv" Input File

Detailed Signal Offset Data (planDetail.csv)

This file describes detailed offset values for the plans specified in the **planSet.csv** input file. For every **SignalID** in **corridor.csv** and every **PlanID** shown in **PlanList** of **planSet.csv**, the offset and the underlying design speed must be specified. **Table C-4** presents required format and descriptions for each column of the **planDetail.csv** input file and **Figure C-4** shows a sample file. The first row represents a header containing a list of column names. The column names are case-sensitive and must be specified as presented in **Table C-4**. The order of columns does not matter and the columns can be in any order.

Table C-10. Description of the "planDetail.csv" Input File

Column Name	Value Format	Description
SignalID (required)	Integer	ID of a signal device representing a single signalized intersection; all of the unique **SignalIDs** appearing in corridor.csv must be specified here for each planID.
PlanID (required)	String	ID of a signal timing plan; all of the plan IDs in the **PlanList** column of **planSet.csv** must be specified here for each signal.
CycleLength (optional)	Integer	Cycle length of a given signal timing plan
Offset (required)	Integer	Offset value at this intersection used for **PlanID**
LinkSpeed (required)	Integer	Design speed (i.e., assumed link speed) used in obtaining the **Offset** value of a given timing plan. This is the speed of incoming links of the given intersection for both directions.



	A	B	C	D	E
1	SignalID	PlanID	CycleLength	Offset	LinkSpeed
2	5092	1	102	35	45
3	5092	4	102	24	45
4	5092	7	102	56	45
5	5092	13	110	22	45
6	5004	1	105	45	45
7	5004	4	120	50	45
8	5004	13	132	13	45
9	5004	19	120	50	45
10	5004	58	105	34	35
11	5004	67	120	44	35
12	5004	55	132	13	35
13	5004	60	105	59	35
14	5004	59	105	24	35
15	5004	69	120	38	35
16	5004	68	120	38	35
17	5004	57	132	38	35
18	5004	56	132	13	35
19	5003	1	105	50	45
20	5003	4	120	60	45
21	5003	13	132	16	45
22	5003	19	120	60	45
23	5003	58	105	50	35

Figure C-19. General Format of the "planDetail.csv" Input File

DYNASMART Signal Control Data for Base-case Plan (control_X.dat)

This is a DYNASMART signal control input file (*control.dat*) for the entire Riverdale Road simulation network with a timing plan-specific data for the signals along the Riverdale Rd corridor. Scenario Manager requires this file to be prepared for each of the base plans defined in column **BasePlan** in **planSet.csv**. The name of each file should be "control_X.dat" where X is replaced with the associated plan ID. For instance, in Figure C-3, five base plans are defined with plan ID of AC, 1, 4, 13 and 19, respectively. In this case, five *control.dat* files must be present in the Scenario Manager working directory with the following names: *control_AC.dat*, *control_1.dat*, *control_4.dat*, *control_13.dat* and *control_19.dat*, respectively. Scenario Manager uses these files to create DYNASMART signal input files for offset-adjusted timing plans. Since offset-adjusted plans and their associated base-case plan differ only in offset values (with all other parameters identical across plans within each plan set), Scenario Manager takes the contents of the base-case control.dat first and then update necessary offset values to create a new control.dat for a given offset-adjusted timing plan.

In control_X.dat, only one signal timing plan may be specified such that the number of signal timing plans defined at the first line of control.dat becomes 1. The start time of the signal timing plan defined at the 2nd line of control.dat is not used in Scenario Manager. Detailed descriptions for control.dat can be found in DYNASMART-P User's Guide.

DYNASMART Demand Data for 24 hr-Historical Demand (demand.dat)

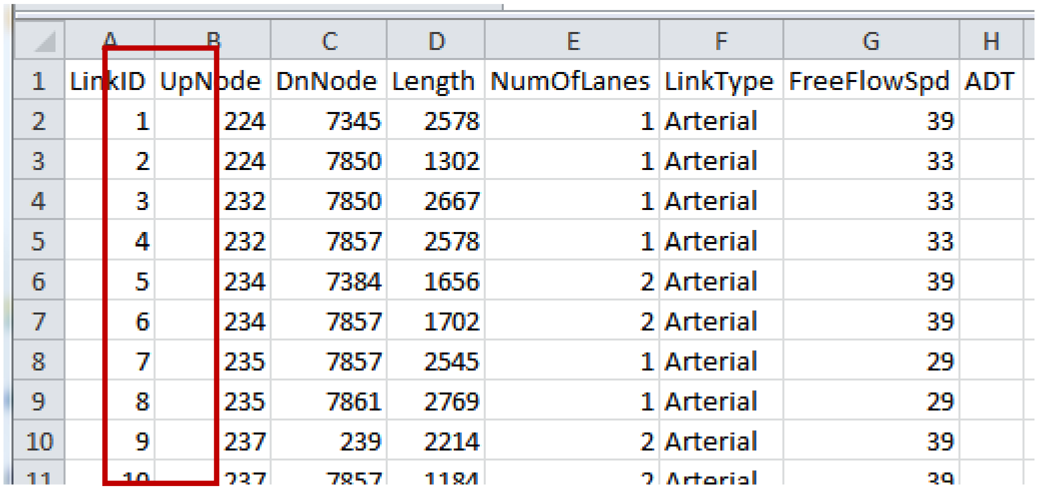
This is a DYNASMART demand input file (demand.dat) representing historical time-dependent OD demand for a 24-hour period. Scenario Manager uses this file to prepare a new demand file starting from any particular point in time during the day. For instance, the historical demand is specified from 6AM to 6AM and a user wants to run DYNASMART-X at 9am, Scenario Manager uses the historical demand file to create a new 24-hr demand representing the period between 9am to 9am and export it to DYNASMART-X input folders. Detailed descriptions for demand.dat can be found in DYNASMART-P User's Guide.

DYNASMART Network Data (network.dat)

This is a DYNASMART network input file (network.dat) representing the Riverdale Road network. Scenario Manager uses this file to load link information that is used in specifying the incident scenario. Detailed descriptions for network.dat can be found in DYNASMART-P User's Guide.

Shapefile for Study Network (.shp, *.dbf, *.prj, *.shx)*

You can display the DYNASMART simulation network for the study network on the map view by adding the associated shapefile as a map layer. If a shapefile is loaded on the map and it contains the attribute "LinkID" representing DYNASMART Link ID in its "dbf" file (as shown in **Figure C-5**), users can select an incident location by clicking links on the map view. The attribute LinkID in the dbf file represents to the order of links in network.dat. For example, LinkID=1 represents the first link appearing in network.dat. Currently, selecting incident links via the map selection tool is only available for the shapefile named "dyna_slc_riverdale."



	A	B	C	D	E	F	G	H
1	LinkID	UpNode	DnNode	Length	NumOfLanes	LinkType	FreeFlowSpd	ADT
2	1	224	7345	2578	1	Arterial	39	
3	2	224	7850	1302	1	Arterial	33	
4	3	232	7850	2667	1	Arterial	33	
5	4	232	7857	2578	1	Arterial	33	
6	5	234	7384	1656	2	Arterial	39	
7	6	234	7857	1702	2	Arterial	39	
8	7	235	7857	2545	1	Arterial	29	
9	8	235	7861	2769	1	Arterial	29	
10	9	237	239	2214	2	Arterial	39	
11	10	237	7857	1184	2	Arterial	39	

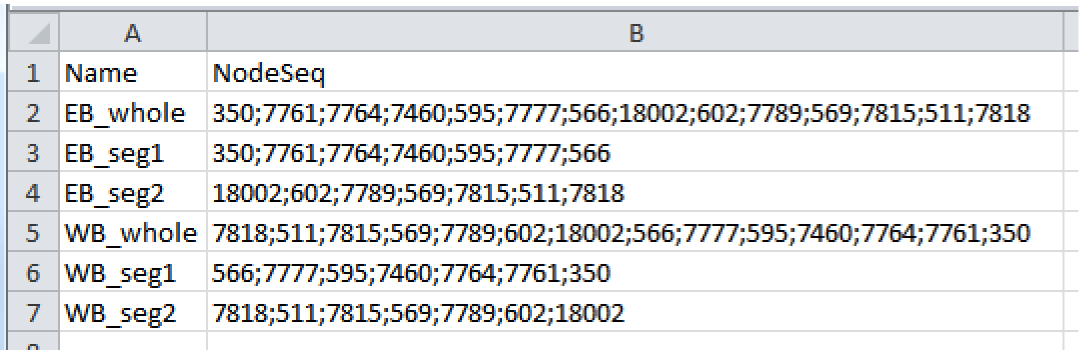
Figure C-20. General Format of the "dyna_slc_riverdale.dbf" Input File

Target Locations for Scenario Evaluation (routes.csv)

This file describes a set of corridors or segments for which output performance measures will be extracted and is used in the Scenario Evaluation tab. Users can specify either a single link or a link sequence to perform a comparative analysis at various levels, i.e., link- and path-levels. **Table C-5** presents required format and descriptions for each column of the **routes.csv** input file and **Figure C-6** shows a sample file. The first row represents a header containing a list of column names. The column names are case-sensitive and must be specified as presented in **Table C-5**. The order of columns does not matter and the columns can be in any order.

Table C-11. Description of the “routes.csv” Input File

Column Name	Value Format	Description
Name (required)	String	User-defined name of a selected corridor
NodeSeq (required)	String array	String representing a sequence of DYNASMART node IDs for a target corridor. The node IDs should be separated by semicolons (;) as a delimiter.



	A	B
1	Name	NodeSeq
2	EB_whole	350;7761;7764;7460;595;7777;566;18002;602;7789;569;7815;511;7818
3	EB_seg1	350;7761;7764;7460;595;7777;566
4	EB_seg2	18002;602;7789;569;7815;511;7818
5	WB_whole	7818;511;7815;569;7789;602;18002;566;7777;595;7460;7764;7761;350
6	WB_seg1	566;7777;595;7460;7764;7761;350
7	WB_seg2	7818;511;7815;569;7789;602;18002

Figure C-21. General Format of the “routes.csv” Input File

Appendix D. Scenario Library: Weather-responsive Signal Timing Plan

Deploying a particular signal plan involves setting a large number of control parameters for individual traffic signals. From a practical point of view, it is often not feasible for TMC operators to create a new plan whenever parameter adjustments are needed. As such, it is a common practice that TMC operators maintain a manageable number of pre-defined “canned” action sets, each of which defines all the parameters and coordination settings for the entire corridor associated with each timing plan, and simply switch between these existing plans during the operation. The Scenario Library approach is introduced to aid this type of operation.

Table D-1 shows an example of the signal timing plan deployment rules defined in Scenario Library. UDOT implements four TOD plans (Plan ID=1, 4, 13, 19) during weekdays under normal conditions. Each plan specifies cycle length, split and offset for each of the 13 signals in Riverdale Rd. The offset value of each signal is determined based on the posted link speed for the incoming links of the intersection. For each TOD plan, UDOT has developed three weather plans, where only offset values are adjusted based on assumed speed drops in the link speeds—5, 10 and 15 mph, respectively—and all other parameters are unchanged from its base-case TOD plan. For instance, between 6:30 and 9:00, Plan 1 is deployed when there is no weather. When the overall link speeds along the corridor decreases by 5 mph (with respect to their associated posted speeds) due to a weather event, Plan 60 is deployed instead. Plan 58 and 64 are deployed when speed drops are 10 mph and 15 mph, respectively.

Table D-12. Scenario Library Defining Deployment Rules for Normal and Weather-Responsive Signal Timing Plans (Weekdays)

STime period	**Signal Timing Plan ID**			
	Time-of-day plan	***Weather plans***		
		Speed reduction level[a]		
		-5 mph	***-10 mph***	***-15 mph***
6:30-9:00	1	60	58	64
9:00-13:00	4	69	67	70
13:00-18:30	13	57	55	61
18:30-21:00	19	69	67	70

a. Assumed speed reduction in link speed with respect to the posted speed

U.S. Department of Transportation
ITS Joint Program Office-HOIT
1200 New Jersey Avenue, SE
Washington, DC 20590

Toll-Free “Help Line” 866-367-7487
www.its.dot.gov

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