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# Utah DOT Weather Responsive Traffic Signal Timing

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**Final Report — September 13, 2013**

**FHWA-JPO-13-088**


U.S. Department of Transportation

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## Notice

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16. Abstract

Over the past decade, Federal Highway Administration's (FHWA) Road Weather Management Program (RWMP) has championed the cause of improving traffic operations and safety during weather events. The program's current emphasis is to encourage agencies to be more proactive in the way that they manage traffic operations during weather events. Weather Responsive Traffic Management (WRTM) is the central component of the program's efforts. WRTM involves the implementation of traffic advisory, control, and treatment strategies in direct response to or in anticipation of developing roadway and visibility issues that result from deteriorating or forecasted weather conditions. WRTM also includes using weather forecasting to provide proactive advisories, control, and maintenance strategies In 2011, the RWMP initiated a project to document recent developments in WRTM, identify improvements to the strategies, and develop implementable Concepts of Operations. As a follow-on task, three concepts were selected for further implementation and real-world deployment. This report describes the implementation of one particular concept relating to weather responsive traffic signal management by Utah DOT. The report contains the system design, operation, evaluation approach, findings and lessons learned from the implementation.


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# Table of Contents

## List of Appendices

## List of Tables



## List of Figures

# Executive Summary

## Introduction and Background

Weather Responsive Traffic Management (WRTM) involves the implementation of traffic advisory, control, and treatment strategies in direct response to or in anticipation of developing roadway and visibility issues that result from deteriorating or forecasted weather conditions. WRTM also includes using weather forecasting to provide proactive advisories and control strategies based on forecasts of weather conditions, and not just the results of those conditions. The Federal Highway Administration's (FHWA) Road Weather Management Program (RWMP) has, as one of its primary focus areas, been encouraging the development and implementation of WRTM strategies. This report specifically addresses a recent implementation of a WRTM strategy in Utah: Weather Responsive Traffic Signal Timing.

In 2011, the RWMP initiated a project to document existing strategies for WRTM, identify improvements to the strategies, and develop implementable Concepts of Operations for the improved strategies. A ConOps was developed for several different WRTM strategies, including weather responsive traffic signal timing. Several States expressed interest in participating in this project, and Utah DOT (UDOT) was the partner selected to implement a traffic signal timing strategy.

In this deployment, UDOT developed and tested an advanced concept for expanding operations of weather responsive signal operations to corridors outside of the Salt Lake City area. The intent of the project was to make UDOT's traffic signal systems more responsive to changes in traffic demands and travel speeds during severe winter conditions.

Recently, UDOT installed a new traffic signal performance monitoring system developed by Purdue University that collects cycle-by-cycle statistics for each intersection in the Riverdale Road corridor in Ogden, Utah. UDOT plans to use this system throughout the entire State to assess the performance and effectiveness of traffic signal operations at the intersections in the State-supported corridors. Through this project, UDOT is examining how this system, coupled with additional detection technology, can be used to better monitor and operate traffic signals during significant weather events in the corridor.

UDOT's goal for implementing weather responsive signal timing strategy along the Riverdale Road corridor is to allow traffic signal operators to anticipate when weather conditions deteriorate to the point of impacting travel speeds in the corridor. Once aware of the impending deterioration, the system allows the operators to deploy traffic signal timing plans that best match the prevailing travel conditions in the corridor.

# Implementation Details

Riverdale Road is a northeast-southwest oriented road that carries traffic between I-84 and US-89 in Ogden, Utah. This segment is primarily a 6-lane road with 11 traffic signals. It carries about 30,000 vehicles on an average weekday. Signal spacing ranges from 700 feet to over 3,000 feet.

As part of the project, UDOT implemented a system to operate the corridor traffic signals in a weather responsive mode. During weather events, operators in the TMC were able to monitor both weather conditions and traffic performance in the corridor. As corridor travel speeds began to drop and the percentage of vehicle arriving on the green phase began to decrease, operators in the TMC implemented new coordination timing plans that were designed specifically to address the deteriorating roadway and weather conditions.

The system uses information about travel speed in the corridor coupled with road condition information from roadway weather information system (RWIS) stations, meteorological forecasts, and signal performance data from UDOT's traffic signal monitoring system to decide when different weather-responsive traffic signal timing plans should be implemented by the TMC operators. Components of the system included:

- Weather Monitoring Station
- Advance Detection Systems
- UDOT's Signal Performance Metrics System which provided the Purdue Coordination Diagrams, Approach Volumes Profiles and Corridor Travel Speeds.
- Traffic Estimation and Prediction System (TrEPS) Decision Support System

UDOT weather responsive traffic signal timing plans were deployed only when weather events were expected to have a significant impact on traffic operations for a substantial duration. The protocols that UDOT used to determine when to deploy the timing plans were as follows:

- During the weather months, UDOT Meteorologists continuously monitor approaching weather systems and provide forecasts of changing weather conditions.
- Approximately 24-hours before the anticipated arrival time of a significant weather event, UDOT Meteorologists hold a weather briefing at which they provide UDOT personnel the following information:
  - The start time and duration of the impending weather event.
  - An assessment of the severity of the storm, including the type and anticipated amount of precipitation, estimated wind and visibility conditions, expected temperatures, etc.
  - An assessment of the extent to which the weather conditions will impact traffic operations (anticipated impact on speed or anticipated accumulations and pavement surface conditions, etc.).
- Using the forecasts provided by UDOT Meteorologists, the Traffic Signal Manager would select the timing plan to be used in the initial deployment and schedule the time to activate the timing plan in the corridor based on the estimated arrival time of the weather event using UDOT's traffic signal management software system.

- As the weather event unfolds, the UDOT Traffic Signal Manager would monitor weather and operating conditions as well as reports from Traffic Signal Maintenance personnel to determine if, different plans were needed based on conditions in the field. The operator would also use the surveillance camera on the corridor to confirm field operations.
- Traffic signal operations would revert back to normal control at the next time-of-day plan change time, unless the weather plan was extended by the Traffic Signal Manager. The Traffic Signal Manager can also issue a command through the traffic signal management software system to deactivate the snow plan and return the controller to normal operation prior to the normal time-of-day timing plan change.
- After each weather event, the UDOT Traffic Signal Manager assessed the effectiveness of the timing plan to determine if modifications were needed.

Appendix A – Concepts of Operations provides the operational procedures and guidelines developed by UDOT for implementing adverse weather timing plans in the Riverdale Rd. corridor. A formal evaluation was also carried out using observed and modeled conditions on the corridor. The evaluation consisted of field data collection, operator assessments, and mesoscopic modeling to conduct an off-line evaluation of the weather-responsive timing plans deployed in the corridor.

# Evaluation Results

The results of the operator assessments and modeling show that UDOT was able to maintain a high level of progression in the Riverdale Rd during inclement weather events by implementing weather responsive traffic signal timings. UDOT' s high resolution performance monitoring system in the corridor showed that UDOT was able to maintain at least the same (or higher) level of arrival on green and platoon ratios with weather responsive timing planes during implement weather conditions as normal, time-of-day operations in the corridor. The evaluation showed that total travel times and corridor-level travel times were less when the weather responsive timing plans were deployed in the corridor when inclement weather existed compared to normal time-of-day timing plans under the same weather and traffic conditions. Table ES-1 summarizes the results for each of the four hypotheses described in the evaluation plan (Appendix B).

**Table ES-1. Evaluation Hypotheses and Summary of Results.**

| Hypothesis | Evaluation Results |
|---|---|
| How did the weather-responsive traffic signal system in the Riverdale corridor improve UDOT's ability to respond to different inclement weather conditions? | • Of the thirteen events where weather responsive signal timing plans were implemented, the UDOT Traffic Signal Manager rated the overall operation of the deployed plans during the events to be average or above average in eight of those events.<br>• DOT operators commented that the system reduced the number of "stuck intersections" during adverse weather as maintenance personnel did not have to respond to malfunctioning detectors not detecting vehicles. |
| By using the system, was UDOT able to maintain a high quality of progression on Riverdale Road during inclement weather? | • When aggregated over all the intersections, implementing a weather responsive timing plan where recalls were not used provided the main-street the same level of performance (if not slightly better) as the normal, time-of-day control during non-weather events.<br>• Except in a few situations, the quality of progression provided by the weather responsive timing plans was similar or better than that provided by the normal (non-weather) traffic signal timing plans |
| Was UDOT able to maximize performance of the signal system during different types of weather conditions in the corridor? | • **4.3 percent reduction in cumulative travel time by deploying the weather responsive timing plans.**<br>• **11.2 percent reduction in cumulative stop time over using the current time-of-day plans during the snow event**<br>• UDOT's weather-responsive signal plans help reduce travel time unreliability for three of the four sections analyzed in the study<br>• During the a.m. peak, deploying the weather responsive timing plans during the snow event (as opposed to keeping the normal time-of-day timing plans active) resulted in a reduction in average stopped time on the eastbound approach of Riverdale Road at seven of the eleven intersections where the snow plans were deployed.<br>• Likewise, deploying the weather responsive timing plans during the snow event resulted in a reduction in average stopped time on seven of the eleven westbound approaches (although not necessarily the same intersections).<br>• The reductions in average stopped times were more substantial for the westbound approaches of Riverdale Rd, compared to the eastbound direction.<br>• In the off-peak, average stopped time declined at six of the eleven intersections for the eastbound direction of travel on Riverdale Rd and seven of the eleven intersections in the westbound direction. |
| Was UDOT able to maintain equitable service to the cross-streets during different weather conditions in the corridor? | • Modeled results continued to show improvements for all impacted vehicles including cross-street traffic. Cumulative ravel times improved by 3 percent and overall stopped times by 14.45 percent.<br>• Cross-street data was not collected as part of the observed data. |

Source: Battelle/TTI

# Conclusions

UDOT's implementation of Wx-SIG concepts has resulted in a truly weather-responsive approach to traffic signal management. Starting with the role of the meteorologist, UDOT monitored Riverdale Corridor conditions to identify the best time to implement weather-based signal plans. Using forecast information, UDOT engineers were able to time the deployment of weather-related plans better for a majority of the weather events encountered in 2013.

By using the signal performance management system, UDOT was able to actively adjust signal timing plans during weather events to match observed conditions (primarily link speeds). Using the PCDs as the performance indicator, UDOT signal engineers were able to maintain comparable levels of progression to non-weather conditions as measured by the Arrivals on Green and the Platoon Ratios across the corridor.

The past winter was a learning experience for UDOT as they figured out the right operating approach to maintain a true weather responsive traffic control system in a corridor. The implementation allowed UDOT to understand the level of effort required to monitor the corridor during weather events, the nature and the frequency of adjustments to signal plans, and the required performance measurement tools to manage the system. UDOT is committed to continue these operations on the Riverdale Corridor as well as expanding the use of weather-responsive signal management to other appropriate corridors.

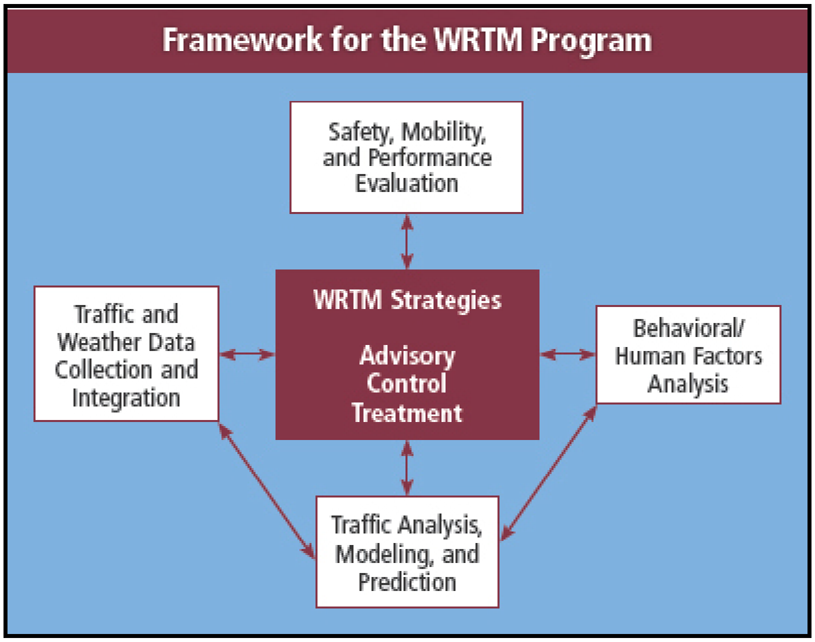
# Chapter 1 Introduction

The impacts of weather on traffic operations are well-documented in the literature. Over the past decade, the Federal Highway Administration's (FHWA) Road Weather Management Program (RWMP) has championed the cause of improving traffic operations and safety during weather events. The program's current emphasis is to encourage agencies to be more proactive in the way that they manage traffic operations during weather events. Weather Responsive Traffic Management (WRTM) is the central component of the program's efforts. WRTM involves the implementation of traffic advisory, control, and treatment strategies in direct response to or in anticipation of developing roadway and visibility issues that result from deteriorating or forecasted weather conditions. WRTM also includes using weather forecasting to provide proactive advisories, control and maintenance strategies.

WRTM also brings together into a logical framework (Figure 1-1) the various other activities (such as weather information integration, traffic analysis, performance measurement, etc.) that the RWMP has been supporting. WRTM at the core includes a set of actionable strategies that a transportation operator can implement, covering advisory, control and treatment. Supporting the ability to implement these strategies are various important elements of WRTM. These elements include:

- Traffic and Weather Data Collection and Integration – focusing on the integration of appropriate weather and traffic information to enable an agency to make decisions in a more proactive manner.
- Traffic Analysis, Modeling and Simulation – providing the modeling and simulation capabilities to assess impacts of weather events on traffic operations, and the tools necessary for a traffic manager to make informed decisions, including information from the other elements.
- Human Factors – addressing the appropriateness of the strategies for message dissemination as well as issues relating to driver behavior in various weather conditions (such as lane changing, gap acceptance and car following).
- Performance Evaluation – determining the effectiveness and benefits of implementing WRTM strategies.

While each of these areas in Figure 1-1 is not new to a transportation agency, the umbrella framework of WRTM brings together all these interlinked pieces to achieve coordinated, proactive, and effective responses to weather events.




FHWA

**Figure 1-1. Framework for the WRTM Program.**

Consistent with the above framework, the RWMP has initiated and completed several activities that research, document and develop tools for WRTM. The RWMP has developed several guidance documents, tools, and research reports that agencies can use to better integrate weather information in their traffic operations, analyze the relationships between weather conditions (e.g. precipitation, visibility and wind speed) and traffic parameters (e.g. volume, speed, density, driver behavior including lane changing, car-following and gap acceptance), and evaluate the effectiveness of road weather advisory and information messages.

In 2011, the RWMP initiated a project to collate recent developments in WRTM, identify improvements to the strategies, and develop implementable Concepts of Operations[1]. Based on the input from an expert panel assembled for this task and the list of improvements identified, five strategy areas were prioritized for Concept of Operations development:

- Weather Responsive Active Traffic Management – includes vehicle, facility and route restrictions (Wx-ATM)
- Weather Responsive Traffic Signal Management (Wx-SIG)
- Weather Responsive Traveler Information – includes both pre-trip and en-route traveler information (Wx-TINFO)
- Seasonal Weight Restrictions
- Intra- and Inter-agency Coordination.

[1] FHWA, Developments in Weather Responsive Traffic Management Strategies, June 2011, FHWA-JPO-11-086, available at ntl.bts.gov/lib/42000/42900/42965/wrtm_final_report_06302011.pdfShare

## Overall Project Objectives

The previous study in 2011 identified several WRTM strategies being implemented by State DOTs, in many cases but it did not represent the full extent of the WRTM framework as defined in Figure 1-1. The main objective of the study was to help implement a WRTM operational capability within the agency that includes all the elements of WRTM framework.

This follow-up project focused on helping State DOTs implement WRTM strategies based on the Concepts of Operations. Of the five concepts listed, the first three were chosen as candidates to move towards implementation. These three strategies, Wx-ATM, Wx-SIG, Wx-TINFO, represent concepts with highest readiness levels and interest from the Stakeholders.

Not intended as a research effort, the Concepts of Operations were the starting point to help the partner agencies implement a capability that would continue to be used in day-to-day operations. Each implemented concept was intended to achieve the following objectives:

- Use full extent of weather and traffic data available to support decision-making during adverse weather
- Provide improved advisories, notifications and control capabilities to the implementing agency
- Result in improved performance outcomes relating to safety and mobility during adverse weather

## Implementation Approach

Using the concepts selected for implementation, a rigorous stakeholder engagement approach helped identify potential State DOT partners for implementation. Working within limited budget and tight schedule, structured interviews were conducted with several State DOTs to ascertain their interest in partnering with RWMP in this project. Partnering implied the following commitments by the agency:

- Implementing a project consistent with the guidelines set forth by the WRTM Concepts of Operations
- Deploying or accomplishing the major milestones of the project by the winter of 2013
- Committing to operate and use the results of the projects as part of daily operations
- Providing a minimum of 20 percent of the overall cost as local matching funds and internal resources

Multiple agencies expressed interest in various concepts and ultimately, two States were identified to partner with RWMP to implement the three concepts. This identification was based on the assessment of readiness of the partners to move ahead with these concepts immediately after the agreement. Oregon DOT was the partner to implement a Weather Responsive Active Traffic Management system and Utah DOT was the partner to implement the other two concepts. Both agencies committed more than the required share of funds necessary to implement this project.

Each of these implementations is described in a separate report. This report documents the implementation of the Weather-Responsive Traffic Signal Management by Utah DOT (UDOT).

## Implementation Overview

Weather can have a significant impact on traffic signal operations in Utah. For years, UDOT has implemented special traffic signal timing plans on one arterial to assist with plowing operations during severe winter weather events; however, these special timing plans have been used only in one corridor in the Salt Lake area. Under this project, UDOT is looking to expand their abilities to better manage traffic signal operations during severe winter weather conditions. In this deployment, UDOT developed and tested an advanced concept for expanding operations of weather responsive signal operations to corridors outside of the Salt Lake City area. The intent of the project was to make UDOT's traffic signal systems more responsive to changes in traffic demands and travel speeds during severe winter conditions.

Recently, UDOT installed a new traffic signal performance monitoring system developed by Purdue University that collects cycle-by-cycle statistics for each intersection in the Riverdale Road corridor in Ogden, Utah. UDOT plans to use this system throughout the entire State to assess the performance and effectiveness of traffic signal operations at the intersections in the State-supported corridors. Through this project, UDOT is examining how this system, coupled with additional detection technology, can be used to better monitor and operate traffic signals during significant weather events in the corridor.

UDOT's goal for implementing Wx-SIG along the Riverdale Road corridor is to allow traffic signal operators to anticipate when weather conditions deteriorate to the point of impacting travel speeds in the corridor. Once aware of the impending deterioration, the system allows the operators to deploy traffic signal timing plans that best match the prevailing travel conditions in the corridor. UDOT intended to achieve the following operational objectives as part of this deployment:

- Maintain a high level of progression on the main-street approaches throughout the duration of the weather event.
- Maintain an acceptable level of the throughput of traffic for the conditions of the roadway.
- Maintain equitable service to cross-street traffic during inclement weather events.

## Organization of the Report

The rest of the report describes the Utah DOT implementation in detail describing the corridor, details of implemented system, system operations during winter of 2013 and the evaluation conducted as part of this effort. The report is organized as follows:

- Section 2 describes the details of UDOT's implementation including defining the corridor and the system components
- Section 3 describes the evaluation approach established for the implementation
- Section 4 provides the results of the evaluation
- Section 5 summarizes the findings and lessons learned
- Appendix A includes the full concept of operations developed for this project
- Appendix B includes the evaluation plan for this project as well.

# Chapter 2 Implementation Details

UDOT's initial deployment of Wx-SIG involved the Riverdale Road corridor in Ogden, Utah. UDOT selected this corridor because of its high degree of detection instrumentation. There are also existing snow plans that are being implemented during storms for the corridor. The snow plans have recalls for phases with video detection, and offsets have been adjusted to account for a 30 percent reduction in speed. The effectiveness of these plans has not been evaluated and UDOT field engineers noted that significant improvements are possible in determining the right time to implement the snow plans as well as improving the snow plans themselves. UDOT engineers also noted the challenges with video detection during storm events.

This interest spurred UDOT's participation in the FHWA Wx-SIG implementation project. While heavily instrumented, additional equipment (i.e., additional detection as well as a road weather information sensors) were installed to acquire more data on the corridor during inclement weather conditions. The following sections describe the corridor and the implementation approach used by UDOT.

## Description of Corridor

Riverdale Road is a northeast-southwest oriented road that carries traffic between I-84 and US-89 in Ogden, Utah. This segment is primarily a 6-lane road with 11 traffic signals. It carries about 30,000 vehicles on an average weekday. Signal spacing ranges from 700 feet to over 3,000 feet. Much of the existing detection on the corridor is video detection, which does not perform well during snow events. Figure 2-1 provides a general overview of the location of the corridor while Figure 2-2 shows the traffic signals that are included as part of this implementation. Commercial activity in the corridor is significant with shopping areas on both sides of the road for large portions of the corridor, especially on the western side, gradually reducing in density west to east.

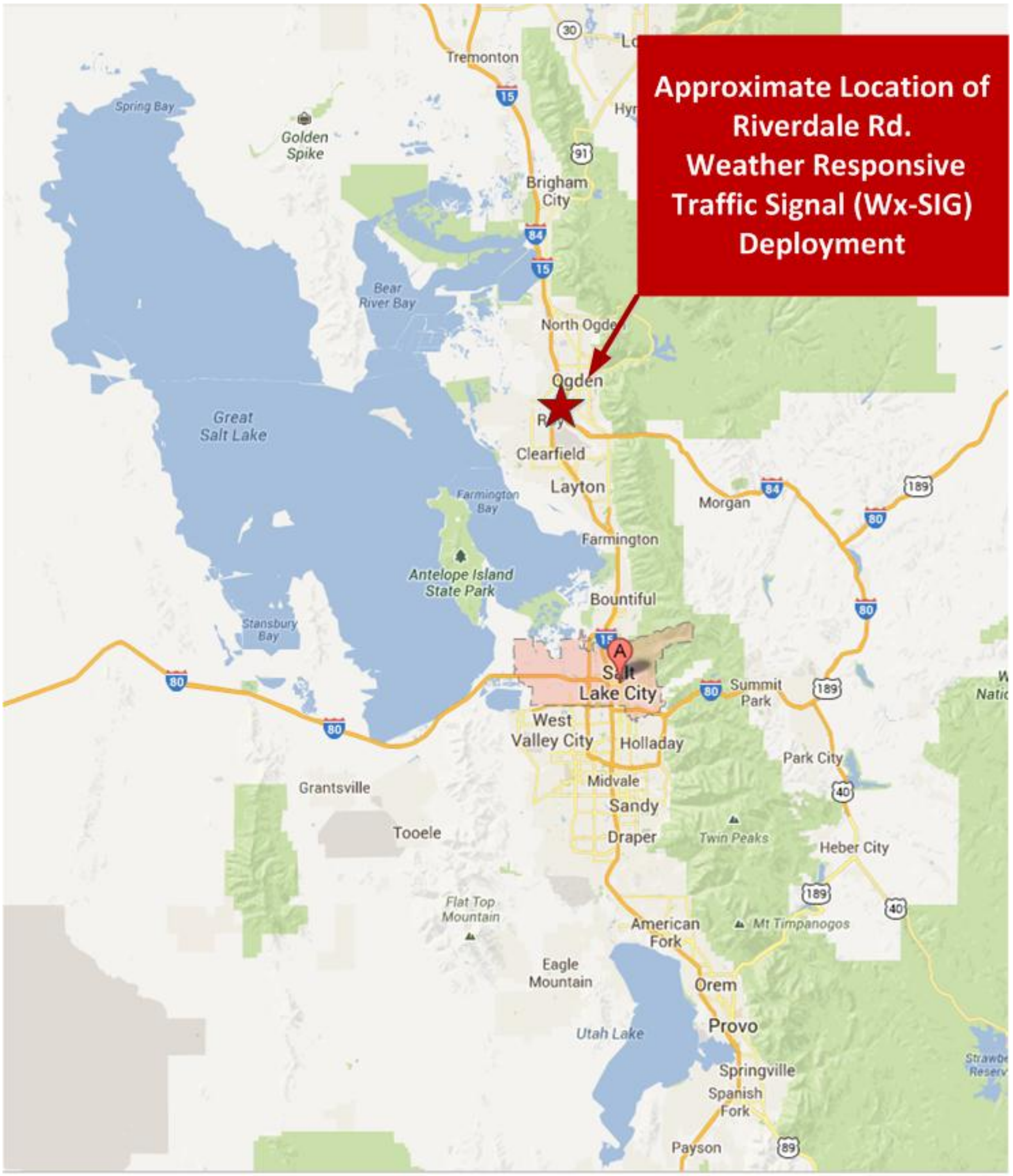


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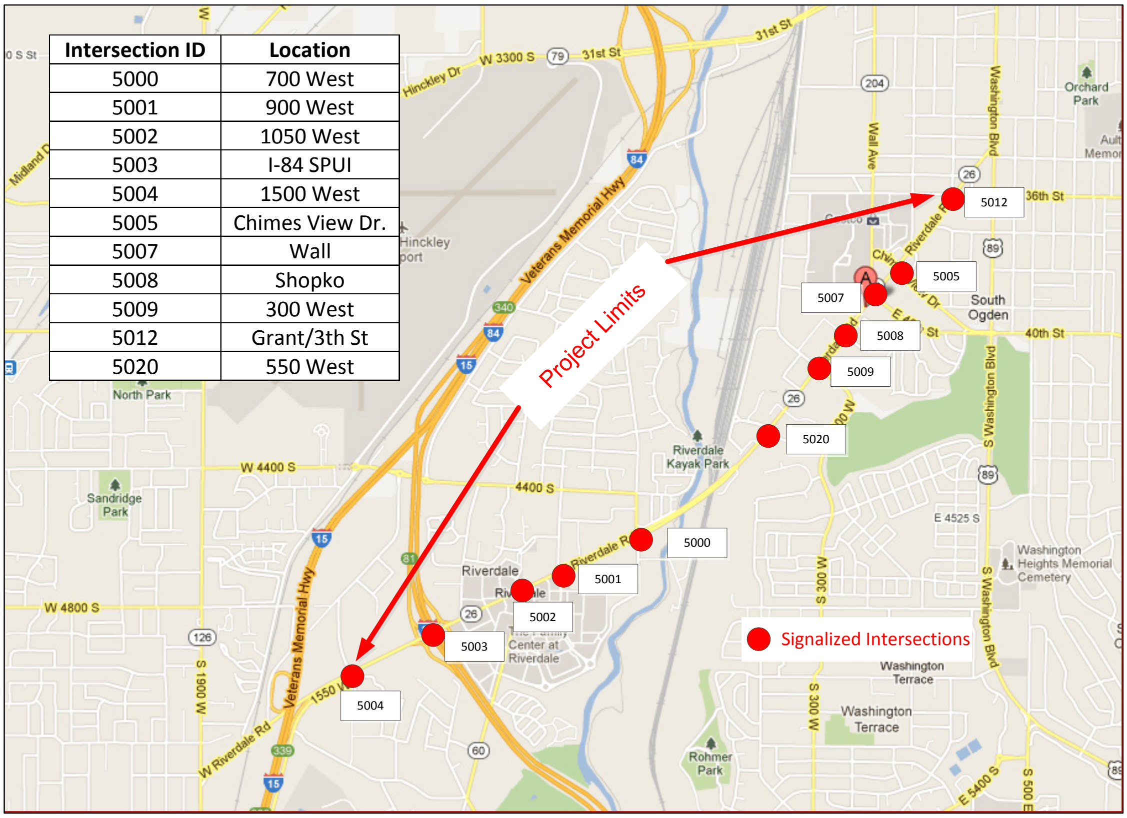
**Figure 2-1. General Location of UDOT Wx-SIG Deployment.**




| Intersection ID | Location |
|---|---|
| 5000 | 700 West |
| 5001 | 900 West |
| 5002 | 1050 West |
| 5003 | I-84 SPUI |
| 5004 | 1500 West |
| 5005 | Chimes View Dr. |
| 5007 | Wall |
| 5008 | Shopko |
| 5009 | 300 West |
| 5012 | Grant/3th St |
| 5020 | 550 West |

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**Figure 2-2. Site Map of Riverdale Road Wx-SIG Implementation.**

# Components of the System

As part of the Wx-SIG project, UDOT implemented a system to operate the corridor traffic signals in a weather responsive mode. During weather events, operators in the TMC were able to monitor both weather conditions and traffic performance in the corridor. As corridor travel speeds began to drop and the percentage of vehicle arriving on the green phase began to decrease, operators in the TMC implemented new coordination timing plans that were designed specifically to address the deteriorating roadway and weather conditions.

The system uses information about travel speed in the corridor coupled with road condition information from roadway weather information system (RWIS) stations, meteorological forecasts, and signal performance data from UDOT's traffic signal monitoring system to decide when different weather-responsive traffic signal timing plans should be implemented by the TMC operators. The following sections describe the elements of the system:

## Weather Monitoring Station

UDOT procured, installed and integrated an RWIS station directly in the corridor. This station provided UDOT meteorologists and TMC operators with information on road temperature, road surface condition, precipitation type and rate, depth accumulation on the road, wind speed, and air temperature. The RWIS installation helped UDOT in two main ways. First, it served as an additional data point for UDOT meteorologists to customize forecasts for the Riverdale corridor. Second, it allowed UDOT signal engineers to view current weather and road weather conditions in the corridor before implementing signal plans.

## Advance Detection Systems

As part of the project, UDOT also installed additional advanced traffic sensors in the corridor. The technology deployed through the project was the Wavetronix Smartsensor® Advance. These sensors were installed to provide advance detection upstream of the stop bar along Riverdale Road at critical locations in the corridor. UDOT selected these sensors to provide greater detection capabilities over the previously deployed video detection systems. Because the sensors monitor individual vehicles as they approach the intersection, they are able to provide increased dilemma zone protection as well as increase intersection efficiency.

Data from these sensors supported performance measurement and signal operations by capturing approach volumes and speeds throughout the corridor. Table 2-1 below shows the upgrades that were made as part of this project.

**Table 2-1. Upgrades to Riverdale Road Detection Systems.**

| Cross Street | City | Detection Removed | Detection Installed | Notes |
|---|---|---|---|---|
| 1500 West | Roy | E/W advance radar and reuse it 36th St | – | – |
| I-84 SPUI | Riverdale | E/W thru video | – | – |
| 1050 West | Riverdale | E/W thru video | WB radar advance | EB radar advance already deployed |
| 900 West | Riverdale | – | WB & EB radar advance | – |
| 700 West | Riverdale | E/W thru video | EB radar advance | WB Radar advance already deployed |
| 550 West | Riverdale | – | – | WB & EB advance already deployed |
| 300 West | Riverdale | N/S thru video | WB & EB radar advance | – |
| Shopko | Riverdale | N/S thru video | WB & EB radar advance | – |
| Wall/40th | Riverdale | N/S thru video | WB & EB radar advance | – |
| Chimes View | Riverdale | SB thru video | WB & EB radar advance | – |
| 36th Street | Riverdale | N/S Matrix radar | WB & EB radar advance | – |

Source: Utah Department of Transportation

## UDOT's Signal Performance Metrics System

In conjunction with this deployment, UDOT continues to independently develop and deploy their Signal Performance Metrics System. The system uses high-resolution detector data to automatically generate performance metrics that operators at the Traffic Signal Operations Desk can use to assess, both in real-time and post-event, the effectiveness of different traffic signal timing plans, and to identify necessary changes in traffic signal timing plans for future events. Through a web interface, operators are able to access the following tools and data to assist them in making their evaluations:

(Need to include the web address of the signal performance website)

- Purdue Coordination Diagrams
- Approach Volumes Profiles
- Corridor Travel Speeds.

Each of these is discussed in detail below.

***Purdue Coordination Diagrams***

The Purdue Coordination Diagram (PCD) is a tool for visualizing and quantitatively evaluating signal performance and identifying opportunities for improvements. Developed by researchers at Purdue University, the PCD plots the arrival time of each vehicle at an intersection using input from setback detectors, in combination with information about the phase state (red and green intervals). The diagrams allow UDOT Signal Systems Operators to review the arrival of each platoon relative to the start and end of green on a cycle-by-cycle basis. At a higher level, the performance of the green band can be qualitatively evaluated through visual inspection of the concurrence (or lack thereof) of vehicle platoons within the green bands. Quantitative measures such as the percent of vehicles arriving on green can be extracted from aggregation of the data. The PCDs allow UDOT Signal Systems Operators to predict and fine tune the impact of offset adjustments for an arterial corridor.

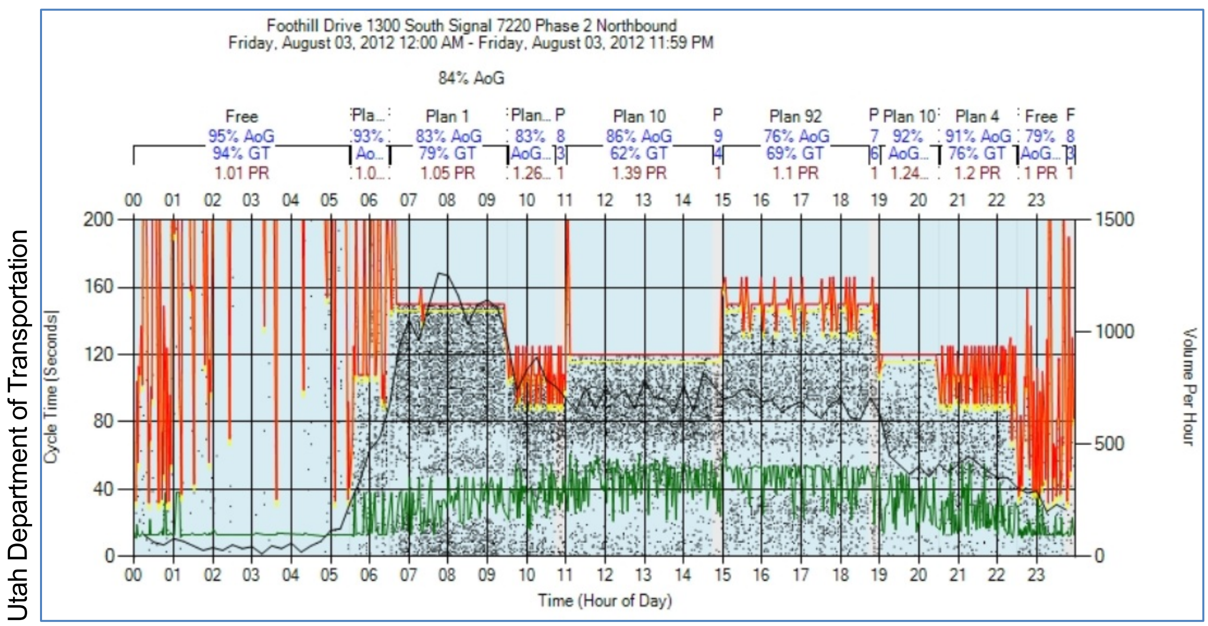


**Figure 2-3. Example of a Purdue Coordination Diagram produced by UDOT's Signal Performance Metric System.**

Periodically throughout the course of the winter, UDOT Signal System Operators reviewed the PCDs from each of the eleven intersections in the Riverdale Road Traffic Signal System. The PCDs helped UDOT evaluate the progression quality characteristics as follows:

- Vehicles arriving at intersection – at what point in the cycle are vehicles arriving?
- Green time split allocation – Is there enough green time for the phase?
- Time-of-day schedule change – what effect does changing plans have on the operations?
- Early return to green on main line – what effect does this have on the reduced speeds?
- Impact of queuing – the shock wave associated with queues over the advanced detector

### *Approach Volumes Profiles*

UDOT Signal System Operators also used approach volumes to determine not only when to activate and deactivate the inclement weather traffic signal timing plans but also to fine-tune the traffic signal timing parameters as part of a post-event evaluation. These profiles reflect how traffic demands change in the corridor during weather events. An example of an Approach Volume profile produced by UDOT's Signal Performance Metrics System is shown in Figure 2-4.

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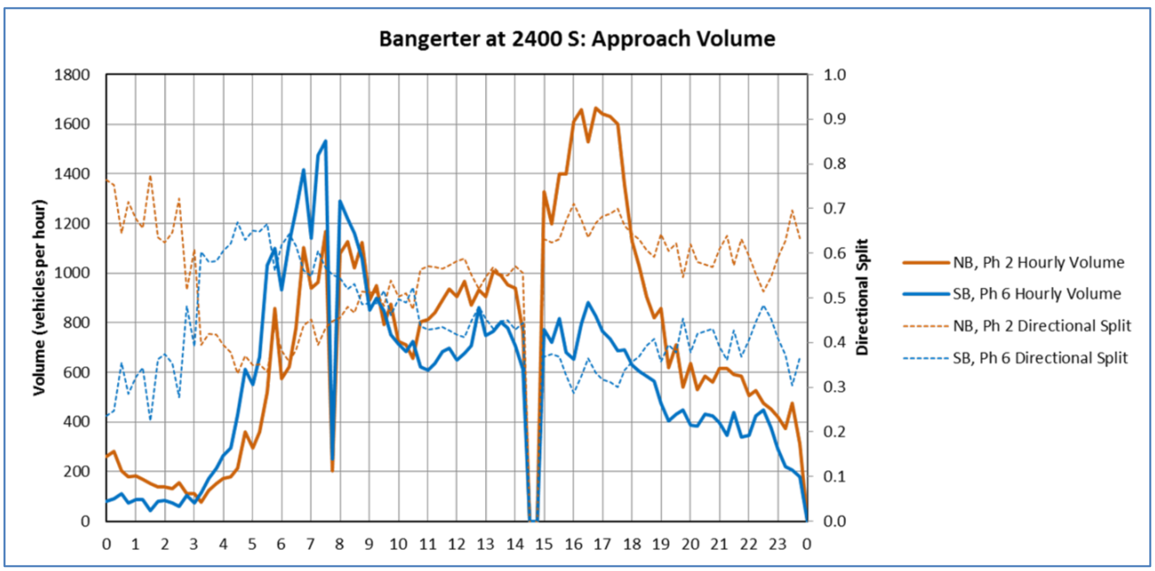



**Figure 2-4. Example of an Approach Volume Profile produced by UDOT's Signal Performance Metric System.**

The approach volumes are already being displayed on the secondary Y axis of the PCD's (See Figure 2-3). As part of this deployment, UDOT modified the reporting to create a separate link volume profile metric on the website. The approach volumes come from the Econolite ASC3 controllers deployed in the field. Because of communications latencies, approach volumes may be delayed in real-time by as much as 45 minutes although improvements made post the project have got the time down to seconds. UDOT used the approach volumes to provide the following information:

- Count data to help for modeling purposes
- Volume trends with adverse weather – should smaller cycle lengths be run along the corridor? Could the volume trends be a trigger when to run adverse weather plans?
- Directional splits – should offset progression favor certain directions

***Link Speeds***

Primarily, link speeds were used by the UDOT Signal System Operators to determine when to activate and deactivate the inclement weather traffic signal timing plans. The link speeds were gathered by graphing the approach speed at UDOT's website. An example of a link speed graph is shown in Figure 2-5 showing both the average speed and the 85$^{th}$ Percentile speeds. This graph is produced by pulling the time-stamped raw speeds from the radar sensors. Only the speeds that cross the count detector (350-400 feet) from the intersection and that arrive 20 seconds after the start of the green to the start of the yellow are included in the graphs.

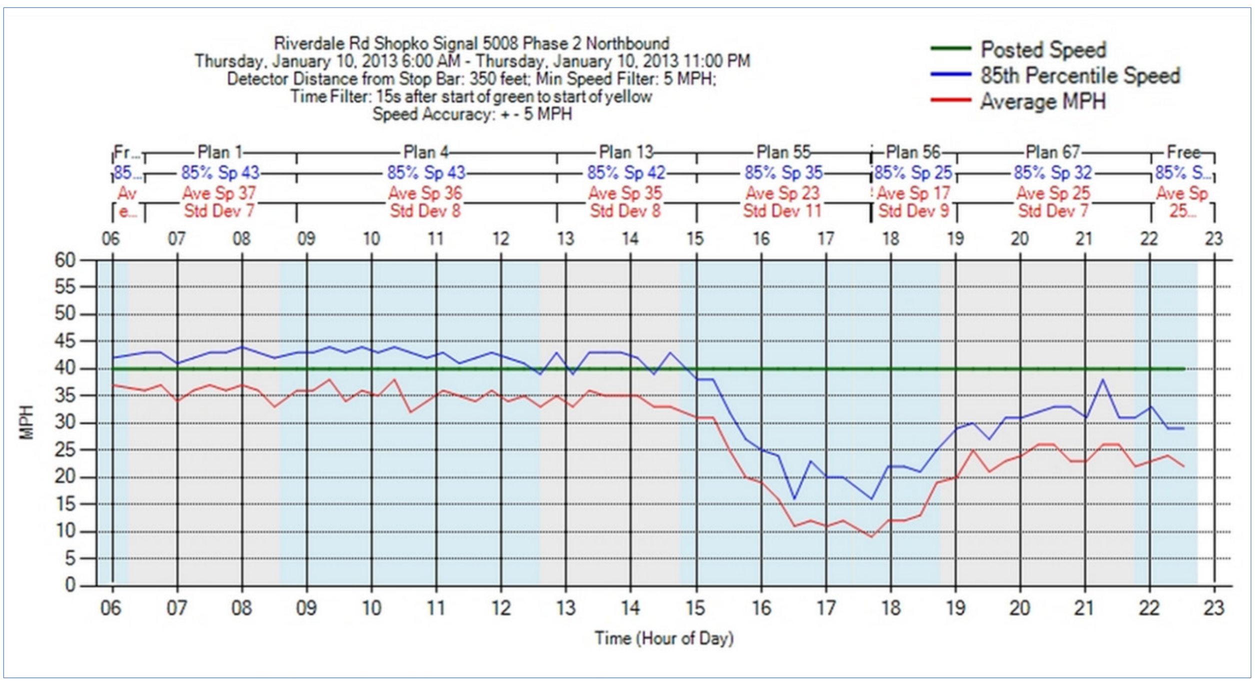



**Figure 2-5. Example of an Link Speed Profile Produced by by UDOT's Signal Performance Metric System Showing Average and 85$^{th}$-percentile Speeds.**

The approach speed (both the average speed and 85 percentile speed) were added to the automatic performance measure website as part of this project. Note that the accuracy of the speed reading is ±5 mph.

### Traffic Estimation and Prediction System (TrEPS) Decision Support System

UDOT is also implementing and integrating a Traffic Estimation and Prediction System (TrEPS) in the traffic signal system. TrEPS is a decision support system that can assist UDOT Signal Systems operators with decisions regarding when and what traffic management strategies to use in a corridor during inclement weather events. Designed to run in both off-line and on-line modes, TrEPS is intended to forecast future traffic conditions utilizing existing traffic and weather conditions and evaluate a variety of what-if scenarios. Using TrEPS, UDOT traffic signal operators can assess the impacts of different traffic signal and other management strategies before they are deployed in the field. This can help UDOT determine 1) the degree to which weather conditions will impact traffic operations, and 2) the appropriate time and locations for deploying various traffic signal timing strategies based on anticipated travel conditions in the corridor.

## Weather Responsive Traffic Signal Operations

The following section describes the weather responsive signal timing plans developed as part of this project and the protocols and conditions under which the weather plans were deployed in the corridor during winter 2013.

### Weather Responsive Signal Timing Plans

For the purposes of this deployment, UDOT created three special traffic signal timing plans that were implemented during significant weather events. The timing plans were patterned after the time-of-day (TOD) signal timing deployed in the corridor. UDOT developed a set of weather responsive timing plans for each of the A.M., Off-Peak, and P.M. base timing plan:

- A "light" snow plan was developed that used the same cycle lengths and split times as the normal, time-of-day plans. This timing plan was intended to be used when snow conditions in the corridor were assumed to impact travel speeds, but where the weather conditions were not expected to impede the performance of the traffic sensors. For this timing plan, the offsets were adjusted to accommodate an assumed 30 percent speed reduction in travel speeds for Riverdale Rd. Normal detector operation was used to activate the non-coordinated phases.
- Two "heavy" snow plans were also developed. These plans were intended to be used when snow conditions impacted BOTH travel speeds and the performance of the traffic sensors. With these timing plans, the offsets were designed to accommodate an assumed 30 percent speed reductions. Automatic recalls were used for the non-coordinated phases to ensure that all phases are serviced when either a) weather impacts to the vehicle detectors caused them to malfunction or b) the lane marking become obscured because of snow accumulation. Each timing plan used different automatic recall features on the controller: one which utilized a maximum recall to ensure that all non-coordinated phase (regardless of demand) were activated to the maximum extent each cycle, and one which utilized a minimum recall to ensure that all non-coordinated phases were activated received at their minimum program duration, regardless of demand. The recall features caused the

signal phases to be serviced every cycle, regardless of whether a vehicle was present to use the phase. This was done to keep malfunctioning detector from skipping cross-street phases in case traffic was present on the side-street approaches.

These weather responsive timing plans were deployed in UDOT Traffic Signal Management System as special timing plans, and downloaded to each of the 11 signalized intersections in the corridor. Table 2-2 provides a summary of the timing plans used in this deployment.

**Table 2-2. UDOT's Weather Responsive Timing Plans for Riverdale Road.**

| Siemens i2 Action Sets & Plans | | | Recommended Time-of-Day Schedule | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Sunday | | Monday - Friday | | Saturday | |
| **Set** | **Title** | **Plan #** | **To** | **From** | **To** | **From** | **To** | **From** |
| 154 | Riverdale AM Snow No RCL | 58 | - | - | 630 | 900 | 800 | 1000 |
| 155 | Riverdale Off Snow No RCL | 67 | 1000 | 2000 | 900/ 1830 | 1300/ 2100 | 1830 | 2100 |
| 195 | Riverdale PM Snow No RCL | 55 | - | - | 1300 | 1830 | 1000 | 1830 |
| 196 | Riverdale AM Snow Max RCL | 59 | Only run with permission from Mark Taylor | | | | | |
| 197 | Riverdale OffP Snow Max RCL | 68 | | | | | | |
| 198 | Riverdale PM Snow Max RCL | 56 | | | | | | |
| 199 | Riverdale AM Snow Min RCL | 60 | Only run on request of Region 1 traffic – 300 W & 900 W on Max RCL | | | | | |
| 200 | Riverdale OffP Snow Min RCL | 69 | | | | | | |
| 201 | Riverdale PM Snow Min RCL | 57 | | | | | | |

Source: Utah Department of Transportation

## Deployment Protocols

UDOT weather responsive traffic signal timing plans were deployed only when weather events were expected to have a significant impact on traffic operations for a substantial duration. The protocols that UDOT used to determine when to deploy the timing plans were as follows:

- During the weather months, UDOT Meteorologists continuously monitor approaching weather systems and provide forecasts of changing weather conditions.
- Approximately 24-hours before the anticipated arrival time of a significant weather event, UDOT Meteorologists hold a weather briefing at which they provide UDOT personnel the following information:
  - The start time and duration of the impending weather event.
  - An assessment of the severity of the storm, including the type and anticipated amount of precipitation, estimated wind and visibility conditions, expected temperatures, etc.

  - An assessment of the extent to which the weather conditions will impact traffic operations (anticipated impact on speed or anticipated accumulations and pavement surface conditions, etc.).

- Using the forecasts provided by UDOT Meteorologists, the Traffic Signal Manager would select the timing plan to be used in the initial deployment and schedule the time to activate the timing plan in the corridor based on the estimated arrival time of the weather event using UDOT's traffic signal management software system. Generally, the UDOT Traffic Signal Manager would implement the "Light" snow plan to be activated initially.
- As the weather event unfolds, the UDOT Traffic Signal Manager would monitor weather and operating conditions as well as reports from Traffic Signal Maintenance personnel to determine if, a "Heavy" snow plan was needed, and which of the two, based on conditions in the field. The operator would also use the surveillance camera on the corridor to confirm field operations.
- Traffic signal operations would revert back to normal control at the next time-of-day plan change time, unless the weather plan was extended by the Traffic Signal Manager. The Traffic Signal Manager can also issue a command through the traffic signal management software system to deactivate the snow plan and return the controller to normal operation prior to the normal time-of-day timing plan change.
- After each weather event, the UDOT Traffic Signal Manager assessed the effectiveness of the timing plan to determine if modifications were needed.

Appendix A – Concepts of Operations provides the operational procedures and guidelines developed by UDOT for implementing adverse weather timing plans in the Riverdale Rd. corridor.

# Chapter 3 Evaluation

The scope of work for this project includes an evaluation of the weather responsive traffic signal system. The purpose of the evaluation is to assess the effectiveness of the system to allow UDOT to better manage traffic signal operations in the corridor during weather events. By collecting data on how UDOT operators used the system during multiple weather events, UDOT plans to demonstrate how the system was used to proactively manage traffic signal operations during inclement weather conditions, with the goal of achieving the best level of performance during inclement weather conditions as conditions permit. The evaluation was structured to answer the following evaluation questions:

- How did the weather-responsive traffic signal system in the Riverdale corridor improve UDOT’s ability to respond to different inclement weather conditions?
- By using the system, was UDOT able to maintain a high quality of progression on Riverdale Road during inclement weather?
- Was UDOT able to maintain throughput and reduce delays on the corridor during different types of weather conditions?
- Was UDOT able to maintain equitable service to the cross-streets during different weather conditions on the corridor?

Table 3-1 identifies the operational objectives and evaluation questions that were examined during the project evaluation. Table 3-1 also identifies the measures of effectiveness (MOEs), analysis methods, and data that were used to perform the evaluation. Note that equitable service to the cross-streets is included as an objective but was not evaluated as part of this project because traffic and performance data on the cross-streets were not available.

**Table 3-1. Evaluation Approach.**

| Operational Objective | Evaluation Question | Measures of Effectiveness (MOE) | Evaluation Method | Data Source |
|---|---|---|---|---|
| 1. Improve UDOT's ability to manage traffic signal operations during inclement weather | 1.1. How did the weather-responsive traffic signal system in the Riverdale corridor improve UDOT's ability to respond to different inclement weather conditions? | Are the timing plans sensible and workable from the operator's perspective? | Operator Assessments/ Interview | UDOT Signal Desk Operator |
| | | Are the timing plans responsive to various weather events observed in the corridor? | Operator Assessments/ Interview | UDOT Signal Desk Operator |
| | | Did the implementation of the system reduce agency resource requirements? (e.g. staff hours to view cameras or check field conditions) | Operator Assessments/ Interview | UDOT Signal Desk Operator |
| | | Rating of operations during weather event | Operator Assessments | UDOT Signal Desk Operator |
| 2. Maintain Quality of Progression | 2.1 By using the system, was UDOT able to maintain a high quality of progression on Riverdale Road during inclement weather? | Percentage of Vehicles Arriving on Green (AoG) | Calculate AoG for each intersection and compare with threshold | Purdue Coordination Diagram |
| | | Platoon Ratio | Calculate Platoon ratio for each intersection and compare with HCM thresholds | Purdue Coordination Diagram |
| | | Average Link speed during inclement weather / Standard Deviation of Link Speed | Compare link speed averages and standard deviations with and without weather events. | Wavetronix sensors |
| 3. Maintain Throughput and Reduce Delay | 3.1 Was UDOT able to maximize performance of the signal system during different types of weather conditions in the corridor? | System Delay | Compare System delay with and without WRTM Timing plans | TrEPS Model |
| | | System Throughput | Compare system throughput with and without WRTM timing plans | TrEPS Model |

| Operational Objective | Evaluation Question | Measures of Effectiveness (MOE) | Evaluation Method | Data Source |
|---|---|---|---|---|
| 4. Maintain Equitable Service | 4.1 Was UDOT able to maintain equitable service to the cross-streets during different weather conditions in the corridor? | Not Evaluated in this Deployment<br>(See Note below) | Not Evaluated in this Deployment | Not Evaluated in this Deployment |

Note: As part of this deployment the cycle length, splits and timing parameters (i.e. min green, passage, yellow, red, max green) were left the same for both normal and weather conditions. UDOT believes that equitable service is being maintained as a result of these constraints.

Source: Battelle/TTI

# Evaluation Approach

The evaluation can be broken down into three elements discussed below.

## Operator Assessments

One reason for evaluating this deployment is to assess the degree with which the weather responsive system can assist UDOT in making better, more informed decisions about how to manage and operate their traffic signal systems during weather events. The system provides feedback to TMC and traffic signal system operators that lets them identify, through post-event evaluation and in real-time, improvements to deployed traffic management strategies. UDOT plans to use information obtained from the system to continuously improve and fine-tune their traffic signal timing responses to different weather events.

UDOT's approach for evaluating the benefits of the system on improving their ability to better manage traffic signal operations is largely subjective. At the conclusion of the winter season, UDOT Signal System operators were interviewed to obtain their opinions on the extent to which the deployed system allowed UDOT to better operate the traffic signals in the corridor. The intent of this assessment was to document 1) how UDOT utilized the system in making/modifying signal timing plan changes in the corridor throughout the course of the evaluation period, and 2) the opinions of system operators as to the general effectiveness of the weather responsive traffic signal timing plans to improve operations in the corridor.

Operator logs were used to examine how UDOT used the systems deployed as part of this project to better manage the traffic signal systems. The operator logs were examined to determine what type of changes UDOT made to the traffic signal timing plans and why these changes were made. UDOT signal system operators were asked to describe the processes and reasoning associated with making these changes and to describe how their weather responsive operating goals and objectives changed as a result of having the deployed technologies in the corridor.

## Automated Signal Performance Data

As part of the deployment, UDOT implemented technology that automatically generates two performance measures via Purdue Coordination Diagrams (PCD) – Arrivals on Green (AoG) and Platoon Ratio. Both measures are used by traffic signal engineers to assess the effectiveness of coordination signal timing plans. The PCDs were produced for each of the 11 intersections on the corridor during each major event.

After each weather event, a PCD was generated for each intersection for the duration of the event. The AoG and $R_P$ associated with each weather responsive timing plan deployed during the event were then extracted from the diagrams for the duration of the event. These values were then compared to AoG and $R_P$ values produced by timing plans deployed during typical, non-inclement weather timing plan for a similar duration. In addition, UDOT computed an aggregate, corridor-wide AoG and $R_P$ for the duration of the event by combining individual AoG and $R_P$ values from each intersection. Similar corridor-wide values were produced for non-inclement weather conditions.

## Modeling

Because of the limited sample size of weather events and because of the deployment schedule, it was not possible for UDOT to perform an extensive before-and –after comparison using field data. The Traffic Estimation and Prediction System (TrEPS) was used to compare the effectiveness of the weather responsive traffic signal timing plans during weather events. Using a limited number of weather events, traffic volume and speed data collected by the systems were used to compare the travel times and delays in the Riverdale corridor with and without the weather responsive traffic signal timing plans in place. In this analysis, corridor travel time and delays with the weather responsive timing plans in place were compared with the corridor that results when the normal, time-of-day traffic signal timing plan is used in place of the weather responsive one.

Because the traffic signal timing plans were the only variable between the two cases, the difference in the corridor throughput and delays was directly attributable to the use of the different timing plans. UDOT expected the corridor travel times and delays to be at least the same (if not lower) using the weather responsive timing plans compared to corridor throughput/delays achieved under the deteriorated weather conditions using normal traffic signal timing plans designed assuming ideal weather conditions albeit with better progression and fewer stops.

# Chapter 4 Evaluation Results

The results of the evaluation analysis are presented in the following sections.

## Descriptive Statistics

Throughout the duration of the evaluation period, UDOT kept a log of events related to the use of the system during events. This log included information about the event (e.g., type of event, magnitude of the event, impact of the event on operations, duration of the event, etc.) and the traffic management decisions made during the event (i.e., the different timing plans deployed during the event, the duration the plans were in effect, etc.).

Table 4-1 shows the type and duration of events that occurred during evaluation period. The table also shows the weather traffic management strategies that were deployed during each weather event. Table 4-2 shows the number of times and average duration over which each weather responsive timing strategy was deployed during the evaluation period.

### Operator Assessments

Figure 4-1 provides a summary of the operator assessment on the overall operational improvement resulting from deployment of weather responsive signal timing strategies on the Riverdale Corridor. Of the thirteen events where weather responsive signal timing plans were implemented, the UDOT Traffic Signal Manager rated the overall operation of the deployed plans during the events to be average or above average in eight of those events. For all the events where the Traffic Signal Manager indicated the weather responsive timing plans had an average or above average improvement on operational performance, significant reductions in corridor travel speeds were noted to have occurred sometime during the event initiating the deployment of the plans. In the five events where the Traffic Signal Manager rated the timing plans as not having an impact of operations, the severity of the events was judged by the Traffic Signal Manager to be relatively minor compared to their forecasted conditions.

UDOT operators were also asked to provide their general opinion on the overall effectiveness of the weather responsive signal timing plans to improve operations in the corridor. They thought the plans were effective in improving operations along the corridor when the minimum recall or no recall plans were used. They felt less comfortable deploying the maximum recall plans as they were judged to have a detrimental effect on performance, due to the extra stops and additional delays incurred along the main street. The UDOT operators felt that having the ability to fine-tune the timing plans by using the PCDs was a major benefit to the study. Prior to this study, UDOT did not have the ability to do an assessment of the performance of their weather responsive signal strategies. UDOT operators commented that the system reduced the number of “stuck intersections” during adverse weather as maintenance personnel did not have to respond to malfunctioning detectors not detecting vehicles. UDOT also thought leaving the cycle length and splits the same as the normal time-of-day plans was also beneficial and expect to continue this practice in other weather responsive deployments.

Table 4-3 provides an overview of the operator assessments associated with each event.

**Table 4-1. Dates, Types and Durations of Weather Events during the Evaluation Period and Timing Plans Deployed.**

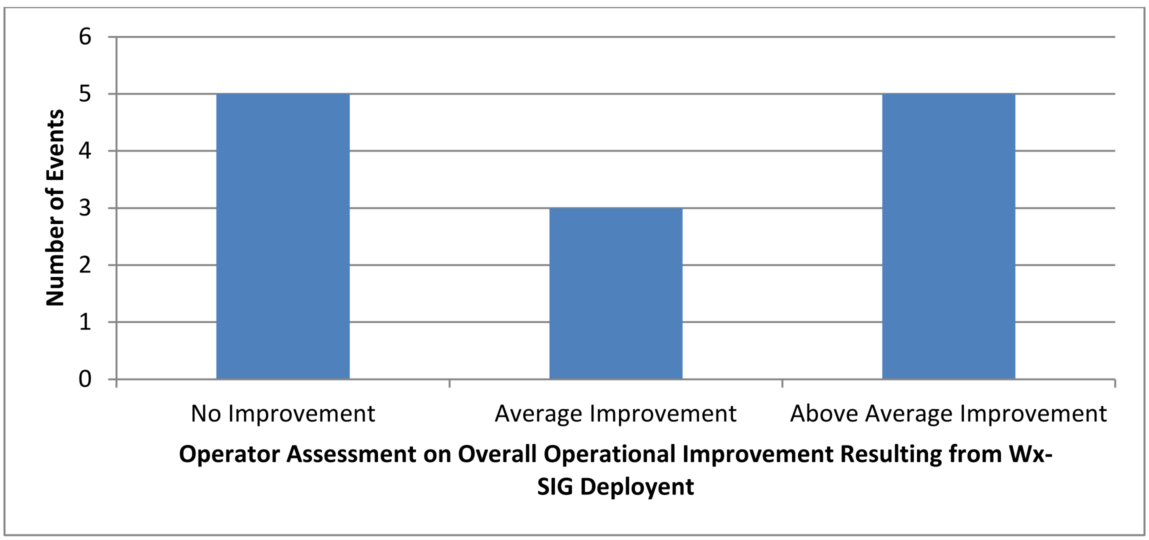
| Event Date | Event Type | Weather Event | | | Timing Plans Deployed |
|---|---|---|---|---|---|
| | | Start Time | End Time | Duration | |
| January 10, 2013 | Road Snow, Low Visibility , Bridge Ice | 15:00 | 22:00 | 7 hrs. | 55,56,57 |
| January 11, 2013 | Road Snow, Low Visibility , Bridge Ice | 5:45 | 21:10 | 15 hrs. 25 min | 68,59,68,55,56,68 |
| January 12, 2013 | Road Snow | 11:00 | 18:30 | 7 hrs. 30 min | 55 |
| January 24, 2013 | Freezing Rain | 6:30<br>14:00 | 13:00<br>18:30 | 6 hrs. 30 min<br>4 hrs. 30 min | 58,57<br>55 |
| January 25, 2013 | | 6:30 | 9:30 | 3 hrs. | 58 |
| January 26, 2013 | Fog | 18:45 | 22:00 | 3 hrs. 15 min | 69 |
| January 28, 2013 | Moderate to Heavy Snow | 7:15<br>9:30 | 9:00<br>11:00 | 1 hr. 45 min<br>1 hr. 30 min | 57<br>69 |
| January 29, 2013 | Light to Moderate Snow | 6:00 | 18:30 | 12 hrs. 30 min | 58,67,69,57 |
| February 4, 2013 | Fog | 6:30 | 9:00 | 2 hrs. 30 min | 58 |
| February 7, 2013 | Light Snow | 6:30 | 9:00 | 2 hrs. 30 min | 58 |
| February 8, 2013 | Light to Moderate Snow | 15:00 | 18:30 | 3 hrs. 30 min | 57 |
| February 21, 2013 | Light Snow | 7:30 | 9:00 | 1 hr. 30 min | 60 |
| February 22, 2013 | Light Snow | 7:00 | 9:00 | 2 hrs. | 60 |
| February 23, 2013 | Moderate to Briefly Heavy Snow | 6:30<br>10:00 | 8:00<br>18:30 | 8 hrs. 30 min | 57,69 |

Source: Battelle/TTI

**Table 4-2. Number of Times and Average Duration that Each Traffic Signal Timing Plan was Deployed.**

| Weather Responsive Timing Plan Number | Number of Times Plan was Deployed | Average Duration of Deployment (minutes) |
|---:|---:|---:|
| 55 | 4 | 225 |
| 56 | 2 | 195 |
| 57 | 4 | 288.75 |
| 58 | 5 | 156 |
| 59 | 1 | 120 |
| 60 | 3 | 100 |
| 67 | 3 | 180 |
| 68 | 3 | 158.33 |
| 69 | 4 | 138.75 |

Source: Battelle/TTI




Battelle/TTI

**Figure 4-1. Operator Assessments of the Overall Operational Improvement Resulting from Deployment of Weather Responsive Signal Timing Strategies.**

**Table 4-3. Operator Assessments for Each Weather Event included in the Evaluation Period.**

| Event Date | Event Type | Significant Speed Reduction? | Event Justify Implementation of Weather Plan? | Rating of Overall Operational Improvement |
|---|---|---|---|---|
| January 10, 2013 | Road Snow, Low Visibility , Bridge Ice | Yes | Yes | Average |
| January 11, 2013 | Road Snow, Low Visibility , Bridge Ice | Yes | Yes | Average |
| January 12, 2013 | Road Snow | Yes | Yes | Above Average |
| January 24, 2013 | Freezing Rain | Yes | Yes | Above Average |
| January 26, 2013 | Fog | No | No | None |
| January 28, 2013 | Moderate to Heavy Snow | Yes | Yes | Above Average |
| January 29, 2013 | Light to Moderate Snow | Yes | Yes | Above Average |
| February 4, 2013 | Fog | No | No | None |
| February 7, 2013 | Light Snow | No | No | None |
| February 8, 2013 | Light to Moderate Snow | Yes | Yes | Above Average |
| February 21, 2013 | Light Snow | No | No | None |
| February 22, 2013 | Light Snow | No | No | None |
| February 23, 2013 | Moderate to Briefly Heavy Snow | Yes | Yes | Above Average |

Source: Battelle/TTI

## Arrivals on Green

Table 4-4 through Table 4-6 shows the percentage of the main-street vehicles arriving during the green interval for the “a.m. peak”, “off-peak”, and “p.m. peak” periods respectively. Each table shows a typical percent arrival that would be generated during normal (or non-weather) conditions and the percent arrival for each of the three weather responsive timing plans developed off of that base timing plan. The table also shows the number of times each specific weather timing plan was deployed during the evaluation period. Percent arrivals on green are reported for each intersection by direction. A corridor average representing the average percent arrival from all intersection in the corridor is also provided for each direction of travel.

**Table 4-4. Percent Arrival on Green – A.M. Peak Timing Plans.**

| Arrivals on Green (Percent) | | | | |
|---|---|---|---|---|
| **Timing Plan Number** | **Non-Weather** | **Weather Timing Plans** | | |
| | **1** | **58** | **59** | **60** |
| **Recall Active** | **None** | **None** | **Maximum** | **Minimum** |
| **Sample Size** | **5** | **5** | **1** | **3** |
| **Northbound/Westbound** | | | | |
| Chimes View Dr | 82.0 | 81.9 | 75.0 | 77.9 |
| Wall | 72.8 | 60.7 | 65.0 | 75.1 |
| Shopko | 84.8 | 95.8 | 73.0 | 80.8 |
| 300 West | 33.6 | 52.8 | 62.0 | 28.5 |
| 550 West | 96.0 | 78.3 | 45.0 | 97.0 |
| 700 West | 67.0 | 54.0 | 44.0 | 76.1 |
| 900 West | 76.2 | 73.7 | 89.0 | 69.0 |
| 1050 West | 74.4 | 85.3 | 52.0 | 72.6 |
| I-84 SPUI | 73.2 | 53.0 | 77.0 | 51.9 |
| 1500 West | 72.8 | 65.1 | 46.0 | 53.8 |
| **Corridor Average** | **73.3** | **74.4** | **62.8** | **65.7** |
| **Southbound/Eastbound** | | | | |
| Chimes View Dr | 77.4 | 66.9 | 47.0 | 62.8 |
| Wall | 29.4 | 35.5 | 40.0 | 48.2 |
| Shopko | 96.6 | 90.9 | 80.0 | 76.1 |
| 300 West | 22.4 | 74.4 | 78.0 | 37.1 |
| 550 West | 97.4 | 77.0 | 58.0 | 96.0 |
| 700 West | 61.0 | 57.0 | 76.0 | 75.3 |
| 900 West | 69.4 | 85.0 | 55.0 | 72.0 |
| 1050 West | 79.8 | 69.7 | 65.0 | 64.5 |
| I-84 SPUI | 74.6 | 61.9 | 71.0 | 68.5 |
| 1500 West | 73.6 | 68.2 | 51.0 | 66.0 |
| **Corridor Average** | **68.2** | **72.8** | **62.1** | **63.8** |

Source: Battelle/TTI

**Table 4-5. Percent Arrival on Green – Off-Peak Timing Plans.**

| Arrivals on Green (Percent) | | | | |
|---|---|---|---|---|
| Timing Plan Number | Normal | Weather Timing Plans | | |
| | 4 | 67 | 68 | 69 |
| **Recall Active** | **None** | **None** | **Maximum** | **Minimum** |
| **Sample Size** | **5** | **3** | **3** | **4** |
| **Northbound/Westbound** | | | | |
| Chimes View Dr | 75.6 | 66.0 | 66.4 | 72.9 |
| Wall | 61.0 | 88.2 | 81.1 | 81.4 |
| Shopko | 70.6 | 95.2 | 80.9 | 86.4 |
| 300 West | 55.8 | 61.8 | 51.4 | 17.1 |
| 550 West | 92.2 | 94.4 | 69.9 | 82.2 |
| 700 West | 64.0 | 52.2 | 76.0 | 68.6 |
| 900 West | 57.4 | 95.0 | 82.3 | 44.5 |
| 1050 West | 76.8 | 74.2 | 71.4 | 81.8 |
| I-84 SPUI | 72.4 | 61.9 | 50.0 | 47.7 |
| 1500 West | 69.4 | 80.6 | 32.5 | 72.9 |
| **Corridor Average** | **69.5** | **77.0** | **66.2** | **65.5** |
| **Southbound/Eastbound** | | | | |
| Chimes View Dr | 70.4 | 66.0 | 50.4 | 55.4 |
| Wall | 32.2 | 37.0 | 25.9 | 33.8 |
| Shopko | 84.0 | 95.2 | 73.2 | 77.7 |
| 300 West | 37.2 | 61.8 | 70.6 | 64.2 |
| 550 West | 85.0 | 92.6 | 62.7 | 88.0 |
| 700 West | 54.2 | 56.9 | 74.4 | 72.5 |
| 900 West | 72.2 | 87.2 | 78.2 | 70.8 |
| 1050 West | 66.2 | 57.8 | 36.7 | 62.4 |
| I-84 SPUI | 72.6 | 75.3 | 74.4 | 76.8 |
| 1500 West | 75.0 | 75.7 | 57.5 | 68.1 |
| **Corridor Average** | **64.9** | **72.1** | **60.4** | **67.0** |

Source: Battelle/TTI

**Table 4-6. Percent Arrival on Green – P.M. Peak Timing Plans.**

| Arrivals on Green (Percent) | | | | |
|---|---|---|---|---|
| **Timing Plan Number** | **Normal** | **Weather Timing Plans** | | |
| | **13** | **55** | **56** | **57** |
| **Recall Active** | **None** | **None** | **Maximum** | **Minimum** |
| **Sample Size** | **5** | **4** | **2** | **4** |
| **Northbound/Westbound** | | | | |
| Chimes View Dr | 80.0 | 82.1 | 77.7 | 77.7 |
| Wall | 59.4 | 70.7 | 54.2 | 71.4 |
| Shopko | 67.6 | 75.1 | 60.2 | 74.9 |
| 300 West | 60.0 | 59.8 | 58.3 | 40.6 |
| 550 West | 84.6 | 86.3 | 66.1 | 78.1 |
| 700 West | 60.2 | 67.5 | 61.3 | 56.2 |
| 900 West | 80.8 | 83.9 | 74.0 | 60.6 |
| 1050 West | 71.2 | 71.7 | 64.0 | 78.7 |
| I-84 SPUI | 64.4 | 62.8 | 46.5 | 57.7 |
| 1500 West | 75.8 | 77.9 | 62.5 | 72.9 |
| **Corridor Average** | **70.4** | **73.6** | **62.5** | **67.7** |
| **Southbound/Eastbound** | | | | |
| Chimes View Dr | 72.2 | 70.6 | 52.4 | 66.9 |
| Wall | 44.4 | 45.2 | 46.6 | 35.5 |
| Shopko | 83.6 | 77.0 | 71.5 | 90.9 |
| 300 West | 47.8 | 61.2 | 49.3 | 74.4 |
| 550 West | 84.6 | 80.0 | 49.8 | 77.0 |
| 700 West | 60.2 | 59.8 | 60.7 | 57.0 |
| 900 West | 69.2 | 72.8 | 61.5 | 85.0 |
| 1050 West | 61.8 | 54.0 | 35.1 | 69.7 |
| I-84 SPUI | 67.2 | 66.3 | 58.2 | 61.9 |
| 1500 West | 73.8 | 74.8 | 61.6 | 68.2 |
| **Corridor Average** | **66.5** | **67.3** | **54.7** | **63.8** |

Source: Battelle/TTI

Figure 4-2 and Figure 4-3 show the overall percent arrival on green for main-street traffic accumulated over all the intersections resulting from deployment of the different weather responsive signal timing strategies. These figures show that when aggregated over all the intersections, implementing a weather responsive timing plan where recalls were not used provided the main-street the same level of performance (if not slightly better) as the normal, time-of-day control during non-weather events. Some other general observations about the percentage of vehicle arriving on green include the following:

- The percent arrival of vehicles varies considerably from intersection to intersection. At most of the intersections, a large proportion of the main-street vehicles arrive during the green portion of the phase. However, at a few intersections (such as 300 West and maybe Wall St.), the number of main-street vehicles arriving on green is less than 50 percent. This suggests the need to tune offsets at these intersections.
- At almost every intersection, the percent main-street traffic arriving on green was less when the recalls were used to guarantee service to the cross-street phase. This is to be expected because when a recall is used, it forces the signal to remain green in the cross-streets for a fixed duration, even if no demand is present to utilize the green. This essentially takes time away from main-street phases that are used to favor the main-street movements. It also prevents the traffic signal controller from taking any unused green time and allocating it back to the main-street phases.

The percent arrival on greens was lower when the maximum recall was used compared to when the minimum recall was used. This is to be expected because it forces the traffic signal controller to stay in the cross-street phase for a maximum time interval regardless of demand (but not during the off-peak period shown in Fig 4-2).

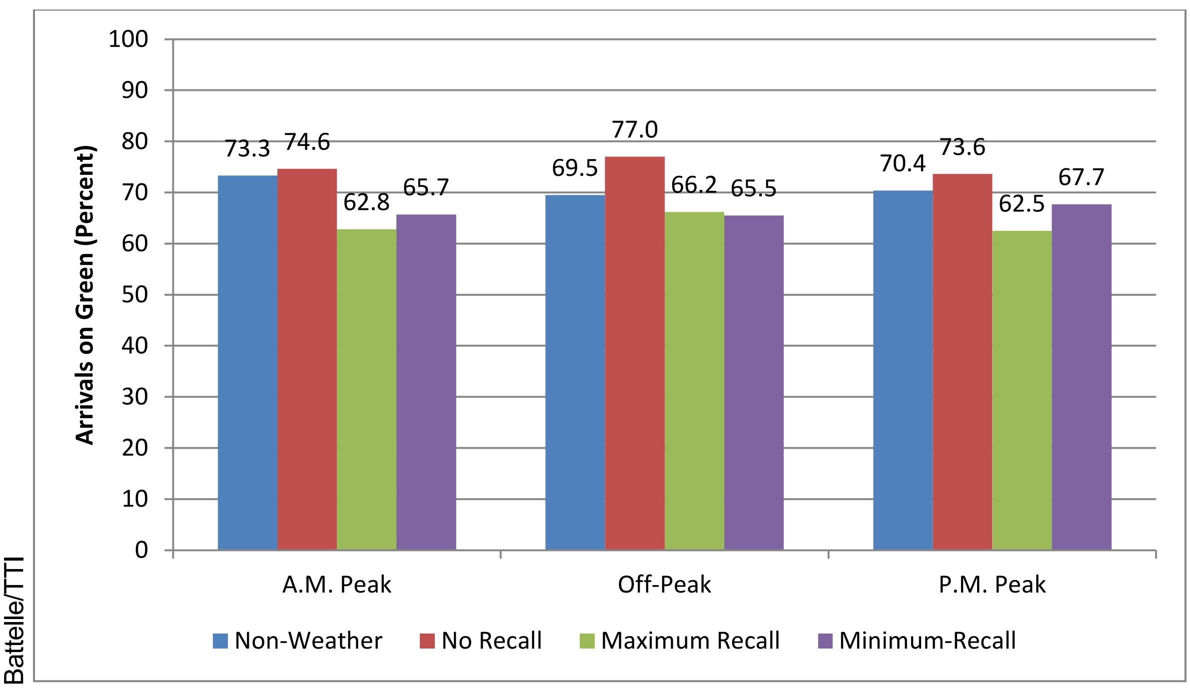



**Figure 4-2. Average Percent Arrival on Green for Corridor – Northbound/Westbound.**

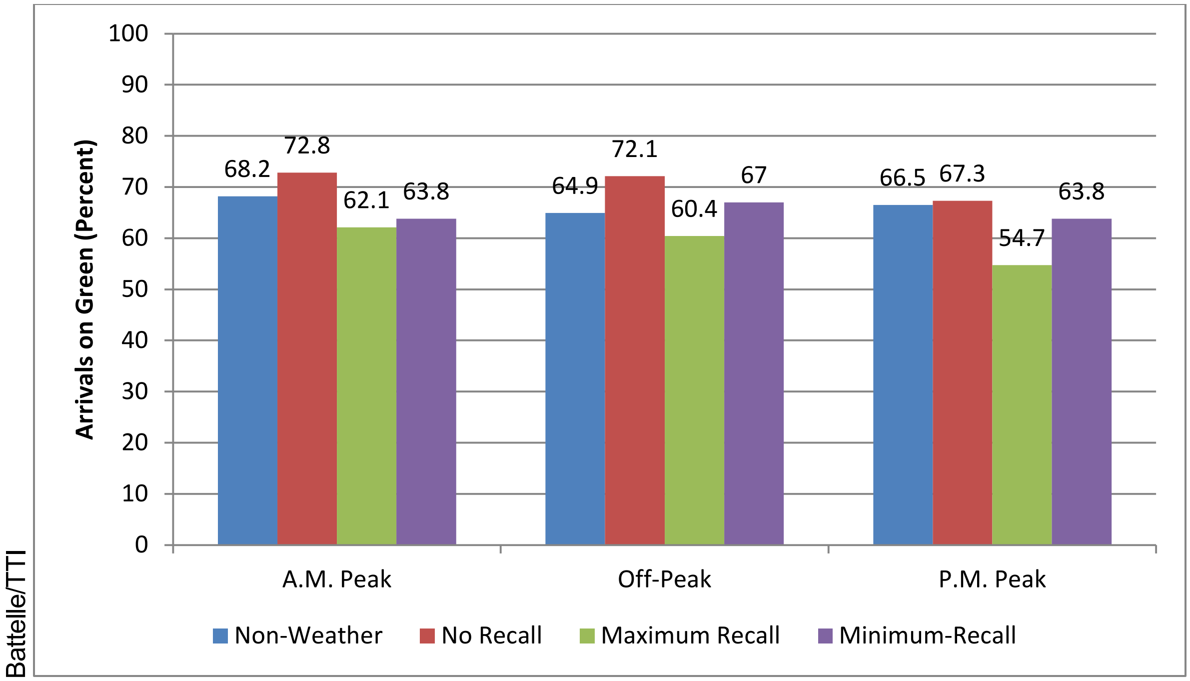



**Figure 4-3. Average Percent Arrival on Green for Corridor – Southbound/Eastbound.**

## Platoon Ratio

Platoon Ratio ($R_p$) as a measure of the quality of progression provided by the coordinated phases on the main-street. $R_p$ is defined as the ratio of percentage of vehicles arriving on green to the green split allocated to that phase. The 2000 *Highway Capacity Manual* [2] uses the following table to rate the quality of progression using computed $R_P$ values:

**Table 4-7. Quality of Progression Rating Based on Platoon Ratio.**

| Range of Platoon Ratio ($R_P$) | Progression Quality |
|---|---|
| ≤ 0.50 | Very Poor |
| > 0.50 – 0.85 | Unfavorable |
| > 0.85 – 1.15 | Random Arrivals |
| > 1.15 – 1.50 | Favorable |
| > 1.50 – 2.00 | Highly Favorable |
| > 2.00 | Exceptional |

Source: 2000 Highway Capacity Manual

[2] Highway Capacity Manual

Table 4-8 through Table 4-10 show the average platoon ratios produced at each intersection when the different weather-responsive timing plans were deployed. The cells in the table are color coded to correspond with appropriate quality of progression rating. The tables show that except in a few situations, the quality of progression provided by the weather responsive timing plans was similar or better than that provided by the normal (non-weather) traffic signal timing plan. One of those exceptions is Plan 69 at 300 West during the off-peak period. Notice that the quality of progression is rated as “Very Poor” in the northbound/westbound direction and “Highly Favorable” in the southbound/eastbound direction. This does not mean that the timing plan is inappropriate. What this does mean, however, is that the adjustment is needed to the offsets so as to better balance traffic flow in both directions. At this particular intersection, only 17 percent of the southbound vehicles arrived during the green interval. By adjusting the offset, UDOT should be able to better fine-tune how the intersection operates during inclement weather conditions. Similar fine-tuning adjustment of the offsets associated with other plans (i.e., Plan 58) might also be needed in order improve the effectiveness of these timing plans.

The overall average platoon ratio associated with each timing plan is shown in Figure 4-4 and Figure 4-5 for the northbound and southbound directions respectively. These figures show that overall the quality of progression was not severely degraded as a result of implementing the different weather responsive timing plan strategies and UDOT was able to maintain traffic conditions similar to non-weather levels.

**Table 4-8. Average Platoon Ratios – A.M. Peak Timing Plans.**

| Platoon Ratio | | | | |
|---|---|---|---|---|
| **Timing Plan Number** | **Non-Weather** | **Weather Timing Plans** | | |
| | **1** | **58** | **59** | **60** |
| **Recall Active** | **None** | **None** | **Maximum** | **Minimum** |
| **Sample Size** | **5** | **5** | **1** | **3** |
| **Northbound/Westbound** | | | | |
| Chimes View Dr | 1.09 | 1.13 | 1.21 | 1.08 |
| Wall | 1.00 | 0.87 | 1.27 | 1.20 |
| Shopko | 0.90 | 1.04 | 1.46 | 1.10 |
| 300 West | 0.83 | 0.86 | 1.77 | 0.75 |
| 550 West | 0.99 | 0.82 | 1.12 | 1.01 |
| 700 West | 0.99 | 0.79 | 1.07 | 1.35 |
| 900 West | 0.98 | 1.02 | 1.78 | 1.25 |
| 1050 West | 0.97 | 1.22 | 1.27 | 1.23 |
| I-84 SPUI | 1.19 | 0.85 | 1.48 | 0.92 |
| 1500 West | 0.95 | 0.88 | 0.90 | 0.81 |
| **Corridor Average** | **0.99** | **1.01** | **1.33** | **1.06** |
| **Southbound/Eastbound** | | | | |
| Chimes View Dr | 1.03 | 0.93 | 1.09 | 1.00 |
| Wall | 0.66 | 0.63 | 1.29 | 0.81 |
| Shopko | 1.04 | 0.99 | 1.60 | 1.04 |
| 300 West | 0.52 | 1.16 | 2.11 | 0.98 |
| 550 West | 1.01 | 0.80 | 1.45 | 1.00 |
| 700 West | 0.94 | 0.91 | 1.90 | 1.45 |
| 900 West | 0.88 | 1.21 | 1.20 | 1.47 |
| 1050 West | 1.11 | 1.12 | 1.59 | 1.15 |
| I-84 SPUI | 1.18 | 0.94 | 1.37 | 1.22 |
| 1500 West | 1.00 | 1.00 | 1.00 | 1.03 |
| **Corridor Average** | **0.94** | **1.03** | **1.46** | **1.10** |

Source: Battelle/TTI

| Range of Platoon Ratio | Progression Quality |
|---|---|
| ≤ 0.50 | Very Poor |
| > 0.5 - 0.85 | Unfavorable |
| > 0.85 - 1.15 | Random |
| >1.15 - 1.50 | Favorable |
| > 1.50 - 2.00 | Highly Favorable |
| > 2.00 | Exceptional |

**Table 4-9. Average Platoon Ratios – Off- Peak Timing Plans.**

| Platoon Ratio | | | | |
|---|---|---|---|---|
| **Timing Plan Number** | **Non-Weather** | **Weather Timing Plans** | | |
| | **4** | **67** | **68** | **69** |
| **Recall Active** | **None** | **None** | **Maximum** | **Minimum** |
| **Sample Size** | **5** | **3** | **3** | **4** |
| **Northbound/Westbound** | | | | |
| Chimes View Dr | 1.08 | 0.93 | 1.01 | 1.02 |
| Wall | 0.88 | 1.19 | 1.42 | 1.17 |
| Shopko | 0.86 | 1.10 | 1.43 | 1.29 |
| 300 West | 1.28 | 1.02 | 1.32 | 0.43 |
| 550 West | 1.06 | 1.06 | 1.49 | 1.13 |
| 700 West | 1.00 | 1.06 | 1.73 | 1.14 |
| 900 West | 0.83 | 1.23 | 1.71 | 0.84 |
| 1050 West | 1.24 | 1.34 | 1.73 | 1.44 |
| I-84 SPUI | 1.13 | 0.88 | 0.93 | 0.76 |
| 1500 West | 0.88 | 1.05 | 0.61 | 1.04 |
| **Corridor Average** | **1.02** | **1.08** | **1.34** | **1.03** |
| **Southbound/Eastbound** | | | | |
| Chimes View Dr | 1.01 | 0.95 | 1.03 | 0.88 |
| Wall | 0.74 | 0.64 | 0.72 | 0.74 |
| Shopko | 1.06 | 1.11 | 1.30 | 1.16 |
| 300 West | 0.85 | 0.98 | 1.77 | 1.61 |
| 550 West | 0.99 | 1.02 | 1.50 | 1.21 |
| 700 West | 0.92 | 1.06 | 1.93 | 1.40 |
| 900 West | 1.15 | 1.14 | 1.84 | 1.49 |
| 1050 West | 1.14 | 1.30 | 1.04 | 1.29 |
| I-84 SPUI | 1.18 | 1.11 | 1.38 | 1.25 |
| 1500 West | 0.99 | 0.99 | 1.01 | 0.99 |
| **Corridor Average** | **1.00** | **1.08** | **1.35** | **1.20** |

Source: Battelle/TTI

| Range of Platoon Ratio | Progression Quality |
|---|---|
| ≤ 0.50 | Very Poor |
| > 0.5 - 0.85 | Unfavorable |
| > 0.85 - 1.15 | Random |
| >1.15 - 1.50 | Favorable |
| > 1.50 - 2.00 | Highly Favorable |
| > 2.00 | Exceptional |

**Table 4-10. Average Platoon Ratios – P.M. Peak Timing Plans.**

| Platoon Ratio | | | | |
|---|---|---|---|---|
| **Timing Plan Number** | **Non-Weather** | **Weather Timing Plans** | | |
| | **13** | **55** | **56** | **57** |
| **Recall Active** | **None** | **None** | **Maximum** | **Minimum** |
| **Sample Size** | **5** | **4** | **2** | **4** |
| **Northbound/Westbound** | | | | |
| Chimes View Dr | 1.18 | 1.19 | 1.18 | 1.12 |
| Wall | 0.89 | 1.05 | 0.90 | 1.10 |
| Shopko | 0.86 | 0.99 | 0.98 | 1.03 |
| 300 West | 1.38 | 1.25 | 1.42 | 0.98 |
| 550 West | 1.03 | 1.07 | 1.32 | 1.08 |
| 700 West | 1.05 | 1.10 | 1.33 | 0.98 |
| 900 West | 1.25 | 1.26 | 1.58 | 1.15 |
| 1050 West | 1.25 | 1.29 | 1.53 | 1.46 |
| I-84 SPUI | 1.04 | 0.99 | 0.89 | 0.96 |
| 1500 West | 1.02 | 1.02 | 1.08 | 1.05 |
| **Corridor Average** | **1.10** | **1.11** | **1.22** | **1.10** |
| **Southbound/Eastbound** | | | | |
| Chimes View Dr | 1.07 | 1.03 | 1.03 | 1.10 |
| Wall | 0.90 | 0.86 | 1.01 | 1.00 |
| Shopko | 1.11 | 1.07 | 1.18 | 0.97 |
| 300 West | 1.03 | 1.26 | 1.23 | 1.43 |
| 550 West | 1.04 | 1.00 | 1.04 | 0.99 |
| 700 West | 1.09 | 1.15 | 1.48 | 1.19 |
| 900 West | 1.28 | 1.31 | 1.67 | 1.52 |
| 1050 West | 1.20 | 1.05 | 0.90 | 1.09 |
| I-84 SPUI | 1.14 | 1.14 | 1.11 | 1.09 |
| 1500 West | 1.00 | 1.00 | 1.01 | 1.00 |
| **Corridor Average** | **1.09** | **1.09** | **1.17** | **1.13** |

Source: Battelle/TTI

| Range of Platoon Ratio | Progression Quality |
|---|---|
| ≤ 0.50 | Very Poor |
| > 0.5 - 0.85 | Unfavorable |
| > 0.85 - 1.15 | Random |
| >1.15 - 1.50 | Favorable |
| > 1.50 - 2.00 | Highly Favorable |
| > 2.00 | Exceptional |

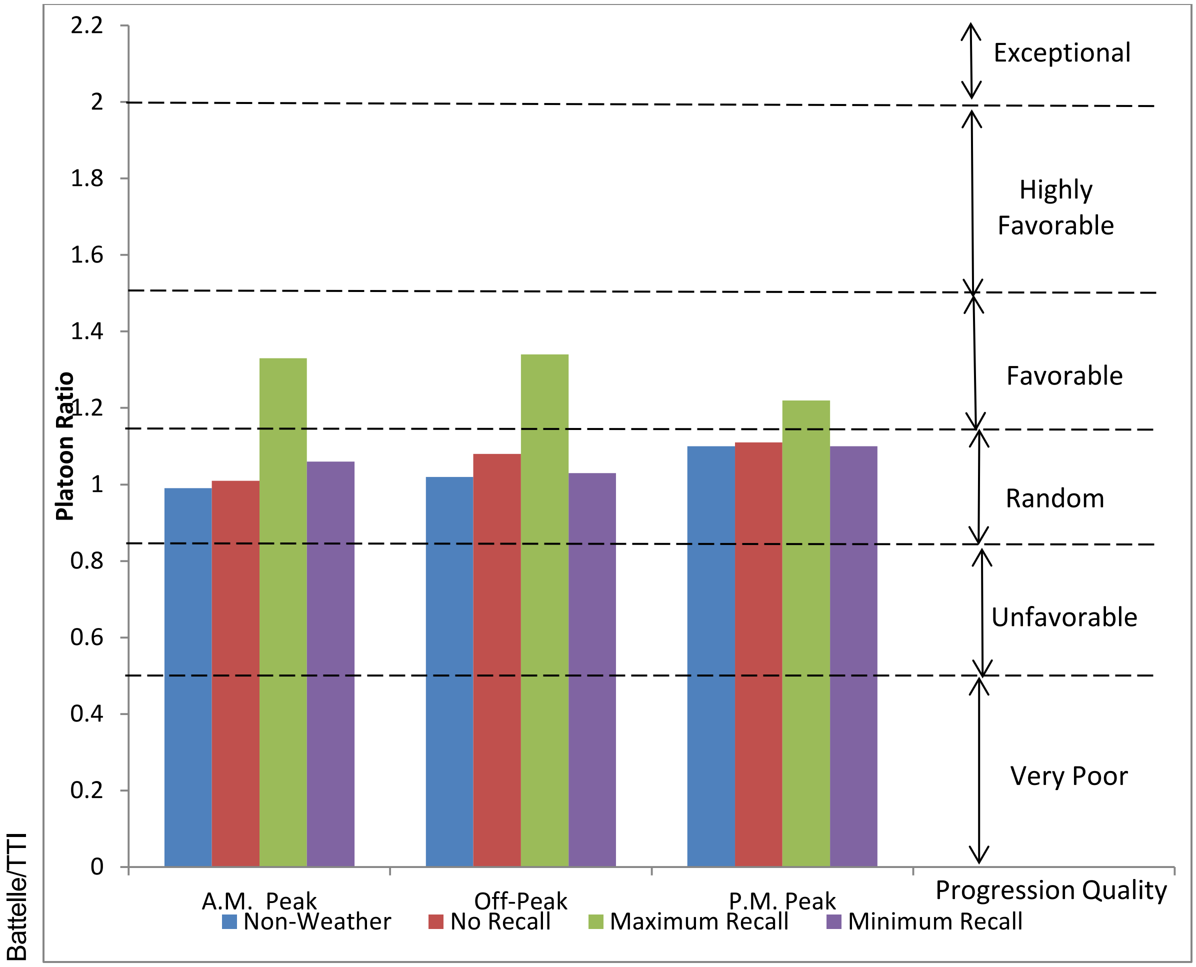



**Figure 4-4. Overall Quality of Progression Achieved in the Northbound/Westbound Direction by the Different Weather Responsive Timing Plans in the Riverdale Road Corridor.**

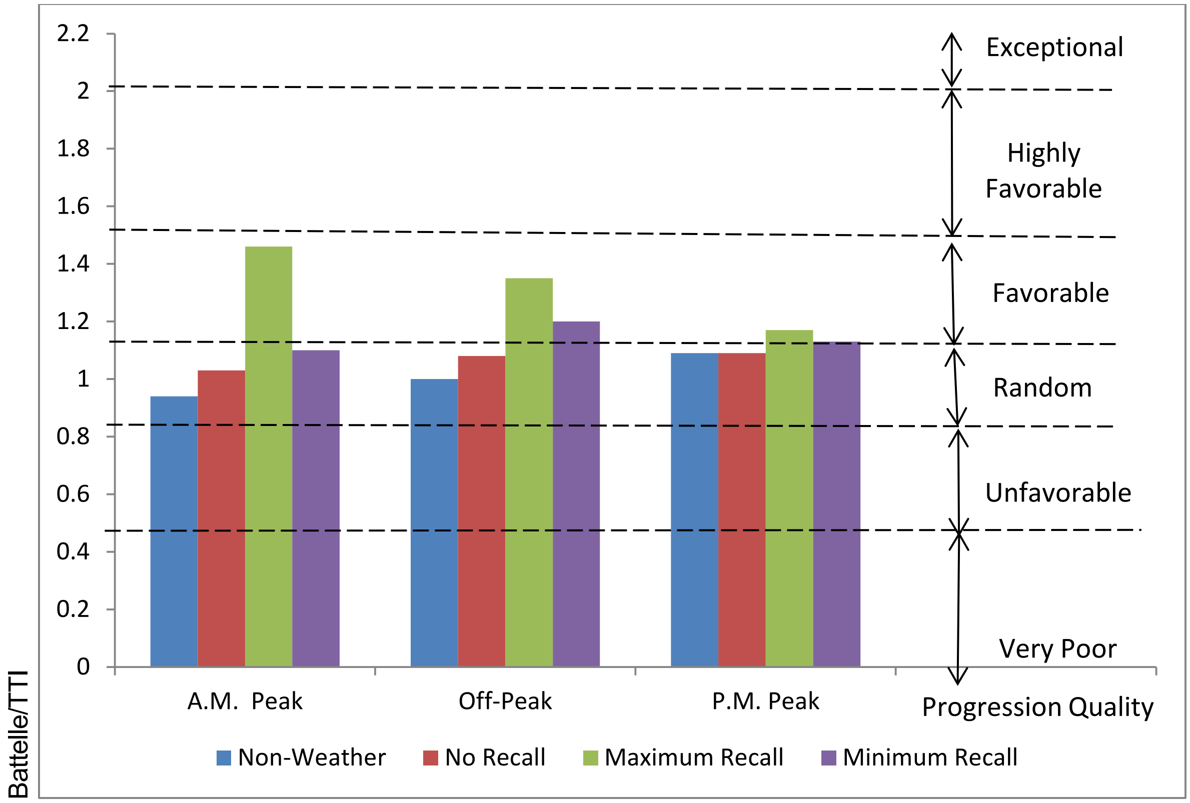



**Figure 4-5. Overall Quality of Progression Achieved in the Southbound/Eastbound Direction by the Different Weather Responsive Timing Plans in the Riverdale Road Corridor.**

# TrEPS Evaluation Results

Recently, a parallel project was initiated by FHWA to integrate and operationalize a weather-sensitive Traffic Estimation and Prediction System (TrEPS) model calibrated for the Salt Lake City area. The system is being installed as a decision-support tool to support evaluation of different weather-responsive signal timing strategies as well as for determining when to deploy such timing strategies in the corridor.

As part of their initial calibration and evaluation steps, FHWA's contractor Northwestern University used the DYNASMART-P portion of TrEPS to conduct an off-line evaluation of the weather-responsive timing plans deployed in the Riverdale Road corridor. This section provides a summary of the results of the evaluation effort. A comprehensive reporting the results of the analysis can be found in the Task 2 technical memorandum created for "Development of Weather-Responsive Traffic Estimation and Prediction (TrEPS) project in Utah."

Specifically, this portion of the evaluation focused on answering the following questions for UDOT:

- What was the cumulative effect of implementing different weather responsive signal timing strategies on overall corridor performance throughout the entire duration of the weather event?
- What effect did implementing the different weather responsive signal timing plans have on mainline traffic performance? How did they compare to normal time-of-day operations during the weather event?
- What effect did implementing the different weather responsive traffic signal timing plans have on cross-street traffic performance? Did cross-street delays increase as a result of deploying the different weather responsive signal timing plans?

Therefore, three-levels of analysis were performed using the vehicle trajectory data from DYNASMART-P:

- Aggregate-level
- Corridor-level
- Intersection-level

Table 4-11 below shows the performance measures used to perform each of these analysis levels.

**Table 4-11. Measures Used to Assess WRTM Performance in Riverdale Corridor.**

| Level of Analysis | Performance Measures |
|---|---|
| Aggregate-Level | Cumulative travel time (minutes)<br>Cumulative stopped time (minutes)<br>Proportion of vehicles required to stop |
| Corridor-Level | Average travel time (minutes)<br>Average stopped time per vehicle (seconds) |
| Intersection-Level | Throughput (number of vehicles/5-min)<br>Average intersection stopped time (seconds) |

Source: Northwestern University

In addition, various travel time reliability measures were extracted from trajectories to evaluate the effectiveness of a given signal strategy in reducing travel time variability and improving travel time 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 )

The evaluation approach consisted of conducting a simulation analysis of the different signal timing strategies of a particular weather event: a snow storm on January 29, 2012, a significant mid-winter storm that affected the corridor.

Figure 4-6 shows the variation of visibility and snow intensity between 6 a.m. and 9 p.m. on January 29th. 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 before stopping after 1:00 pm.

The signal timing plans implemented during this snow event were obtained from UDOT (Table 4-12), and coded into DYNASMART. Three sets of traffic simulation experiments were conducted under the same traffic demand:

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



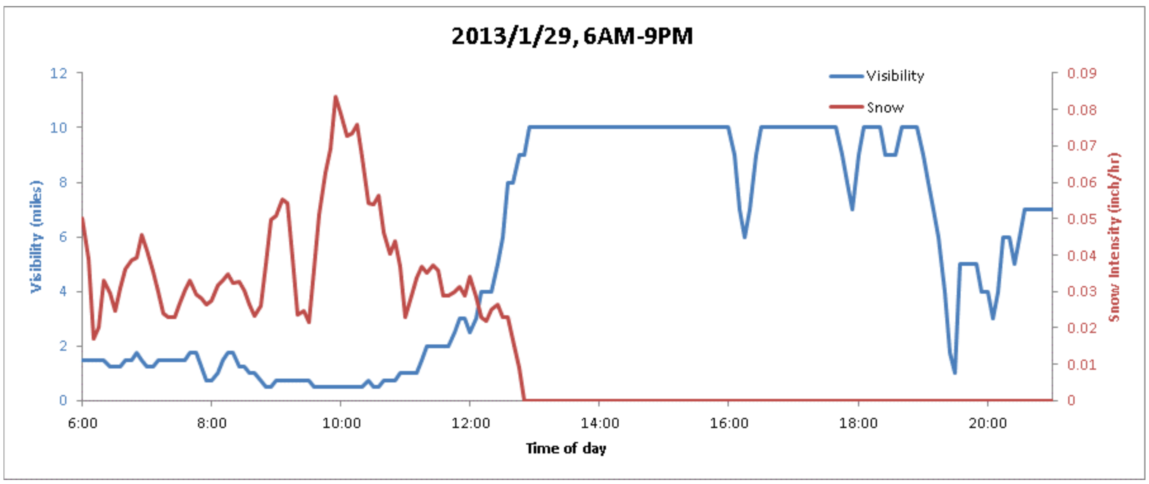



**Figure 4-6. Snow Intensity and Visibility during the January 29th Snow Event.**

**Table 4-12. UDOT's Signal Plan Normal Timing of Day and Weather-Numbers Implemented for January 29th Storm.**

| Time of Day | Time of Day Plan Number | Weather Responsive Timing Plan Number | Description of Weather Responsive Timing Plan |
|---|---|---|---|
| 6:00 – 6:30 | fully actuated | fully actuated | Responds directly to traffic demands |
| 6:30 – 9:00 | 1 | 58 | A.M. peak period plan with actuated cross-streets |
| 9:00 – 11:00 | 4 | 67 | Off-peak plan with actuated cross-streets |
| 11:00 – 13:00 | 4 | 69 | Off-peak plan with cross-streets on maximum recall |
| 13:00 – 18:30 | 13 | 57 | P.M. peak plan with actuated cross-streets |
| 18:30 – 21:00 | 19 | 19 | |

Source: Northwestern University

Traffic performance data were generated from the output of DYNASMART-P simulations. DYNASMART-P outputs consist 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. Using detailed vehicle trajectories, the evaluation was able to develop the following MOE's for use in evaluating the performance under different weather responsive signal timing strategies.

## Aggregate-Level Analysis

Figure 4-7 shows a comparison of the modeled cumulative travel times of all vehicles traveling through the Riverdale Road under different weather and traffic signal timing scenarios. If normal timing plans were deployed during the snow event in January 29th, the cumulative travel time in the corridor would increase by 18.6 percent compared to normal travel conditions (i.e., normal TOD timing plans with non-inclement weather conditions). This is the difference between the first two bars in the figure below. When UDOT used their weather responsive timing plans during the snow storm, cumulative travel time increased by only 14.3 percent. This is equates to a 4.3 percent reduction in cumulative travel time by deploying the weather responsive timing plans.

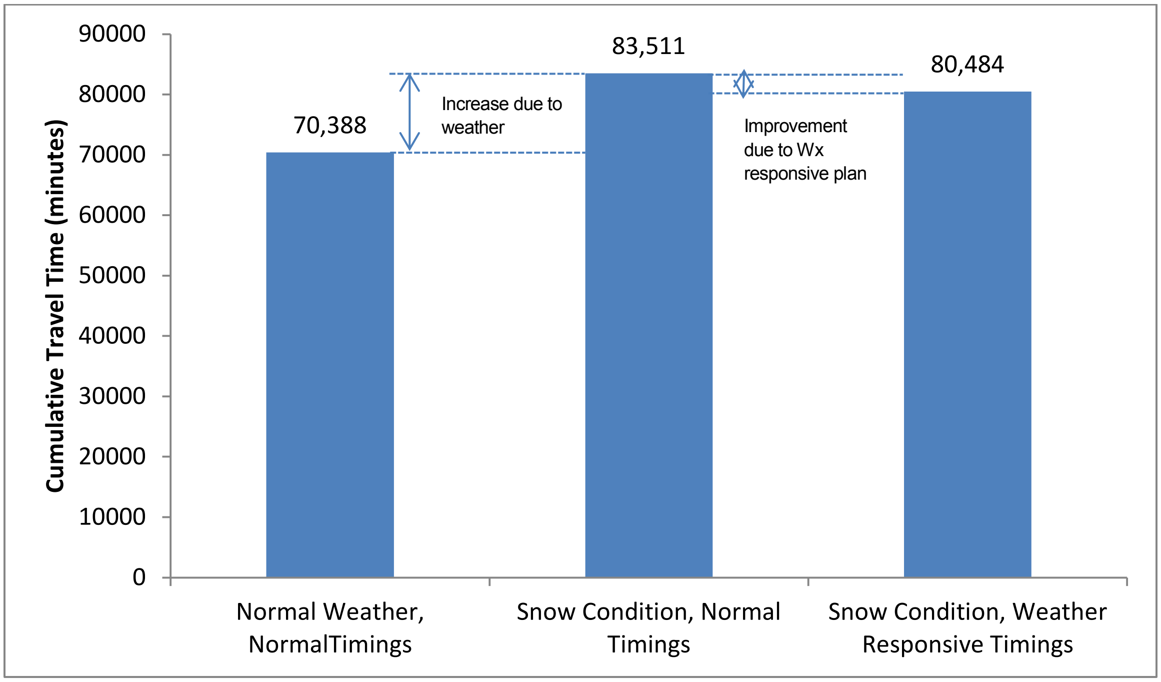





**Figure 4-7. Modeled Total Travel Time Associated Different Weather and Traffic Signal Timing Strategies for the Riverdale Road Corridor.**

Figure 4-8 shows the cumulative stopped time estimated by TrEPS to be experienced by travelers in the Riverdale Road corridor under different weather conditions and traffic signal timing plans. The model estimates that on a typical day with no inclement weather, using the current time-of-day traffic signal timings would results in an estimated 15,920 minutes of cumulative stopped time. Under snow conditions, the cumulative stopped time would increase to 25,281 minutes if the current time of day timing plans were deployed. However, when the weather responsive timing plans were used, cumulative stopped time decreased to 22,434 minutes, an 11.2 percent reduction in cumulative stop time over using the current time-of-day plans during the snow event.

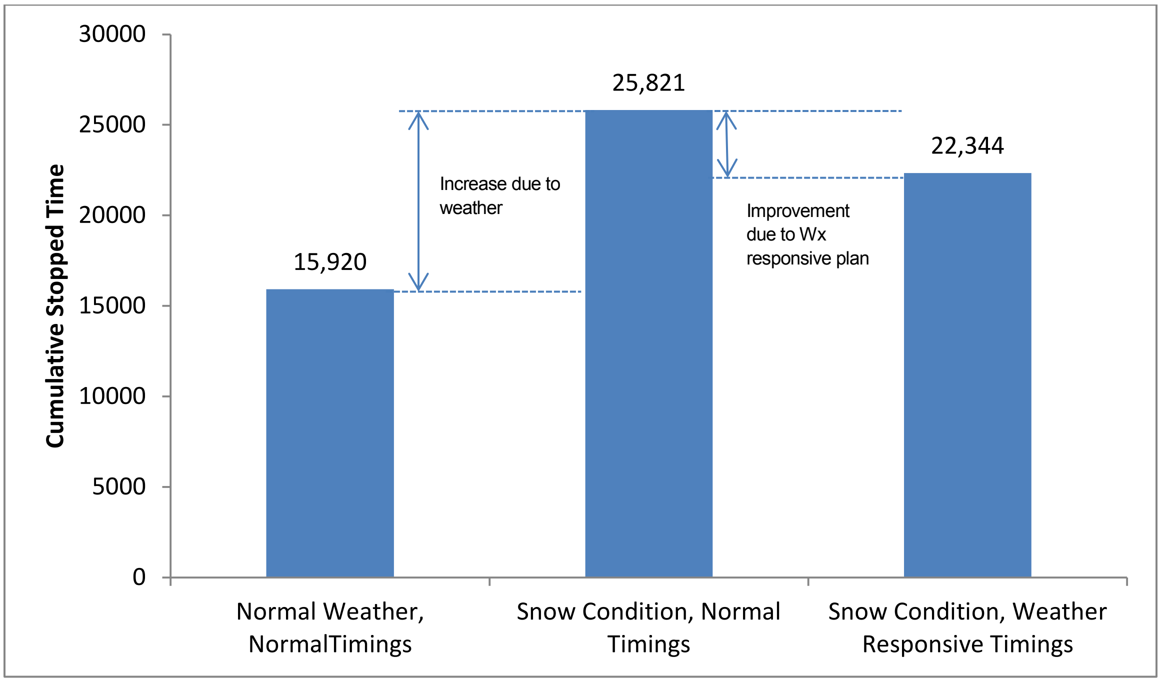



**Figure 4-8. Modeled Total Stopped Time Under Different Weather and Traffic Signal Timing Strategies for the Riverdale Road Corridor.**

### *Travel on Riverdale Rd.*

For this analysis, the evaluation considered only those vehicles that travel on Riverdale Road. 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 4-9 shows the bar charts for total travel time, total stopped time, and total fraction of stopped vehicles under the three simulation scenarios.

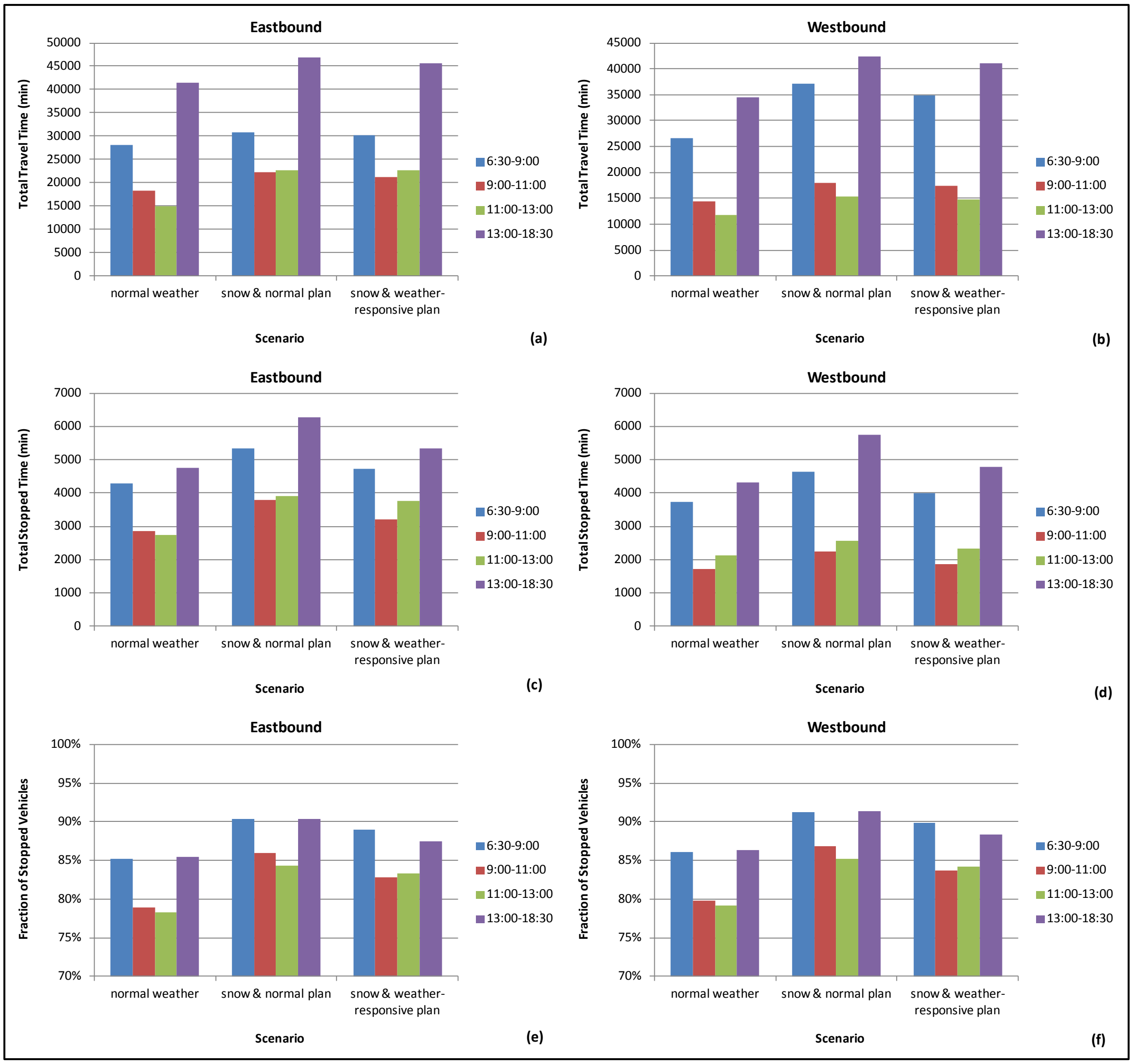



**Figure 4-9. Aggregated (a,b) Total Travel Time (c,d) Total Stopped Time (e,f) Total Fraction of Stopped Vehicles for Vehicles Traversing the Entire Corridor.**

Summarizing the findings from the figure, 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 performs 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 4-13. The savings are computed by comparing the results between snow under the normal plan and snow under the weather-responsive plan scenarios.

**Table 4-13. 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% |

Source: Northwestern University

### *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 4-10 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 4-14 lists the savings due to the weather-responsive signal plans.

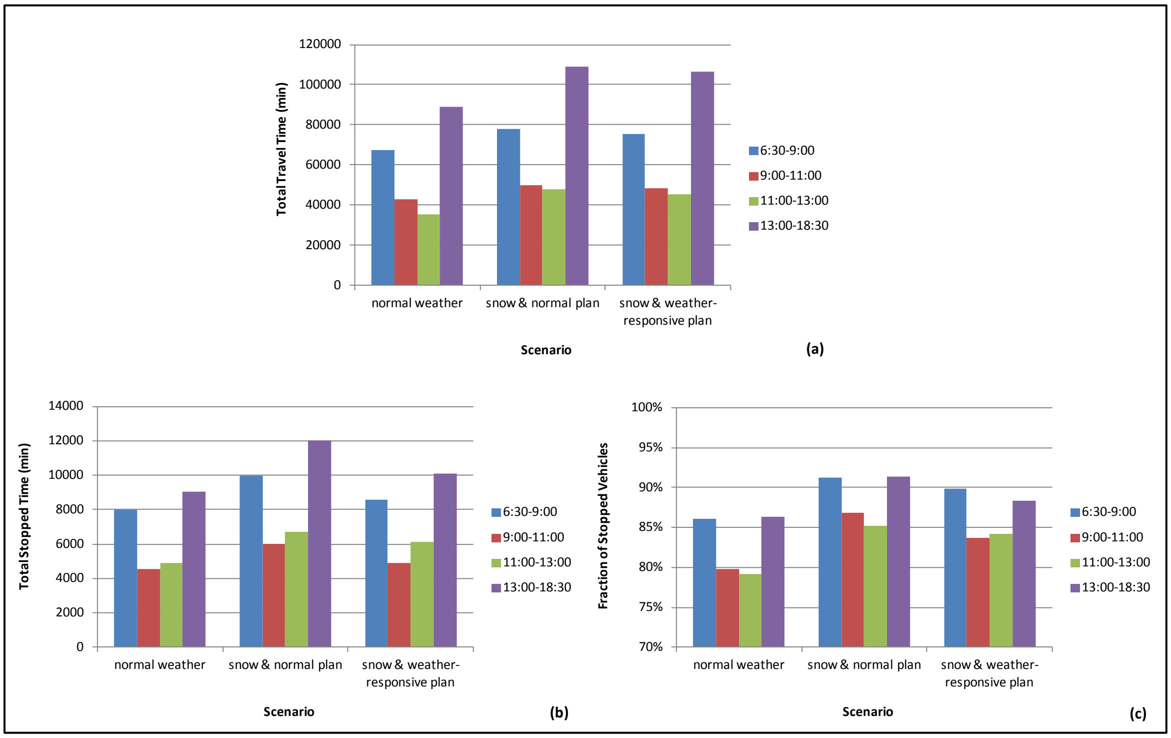



**Figure 4-10. Aggregated (a,b) Total Travel Time (c,d) Total Stopped Time (e,f) Total Fraction of Stopped Vehicles for All Impacted Vehicles on the Entire Corridor.**

**Table 4-14. 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% |

Source: Northwestern University

## Corridor Level Analysis

The corridor level performance measures are calculated based on simulated vehicle trajectories that traversed the corridor. Similar to the other results presented so far, a directional analysis is performed for normal weather, snow with normal plan, and snow with weather-responsive signal plan scenarios. Also for this analysis, the evaluation was divided into two time periods: 7 a.m. to 10 a.m., and 11 a.m. to 2 p.m. The first time period represents the peak hours, while the second represents off-peak. The analysis focuses on two primarily performance measures:

- Average travel time of through vehicles on Riverdale Rd.
- Average stopped time

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.

### *Average Travel Time*

For this analysis, average travel time is the travel time of those vehicles that entered Riverdale Road on the mainline at the first intersection and traveled to the last intersection on the mainline. It is a reflection of the smoothness of the overall traffic state along the study corridor. Figure 4-12 and Figure 4-12 show the simulated average travel time along Riverdale corridor, on eastbound and westbound respectively. The results under three different scenarios are presented.

Figure 4-11 and Figure 4-12 show that drivers on Riverdale Rd can expect a five to twenty percent increase in travel time in both directions under snow conditions, regardless of the type timing plans used during the event. The figures also show that UDOT's weather-responsive signal plans help reduce travel time during certain periods (e.g., from 11:00 to 11:30 a.m.) on the eastbound direction of Riverdale corridor; while the weather responsive plan did not perform as well as normal signal plans in the westbound direction towards the end of the a.m. peak.

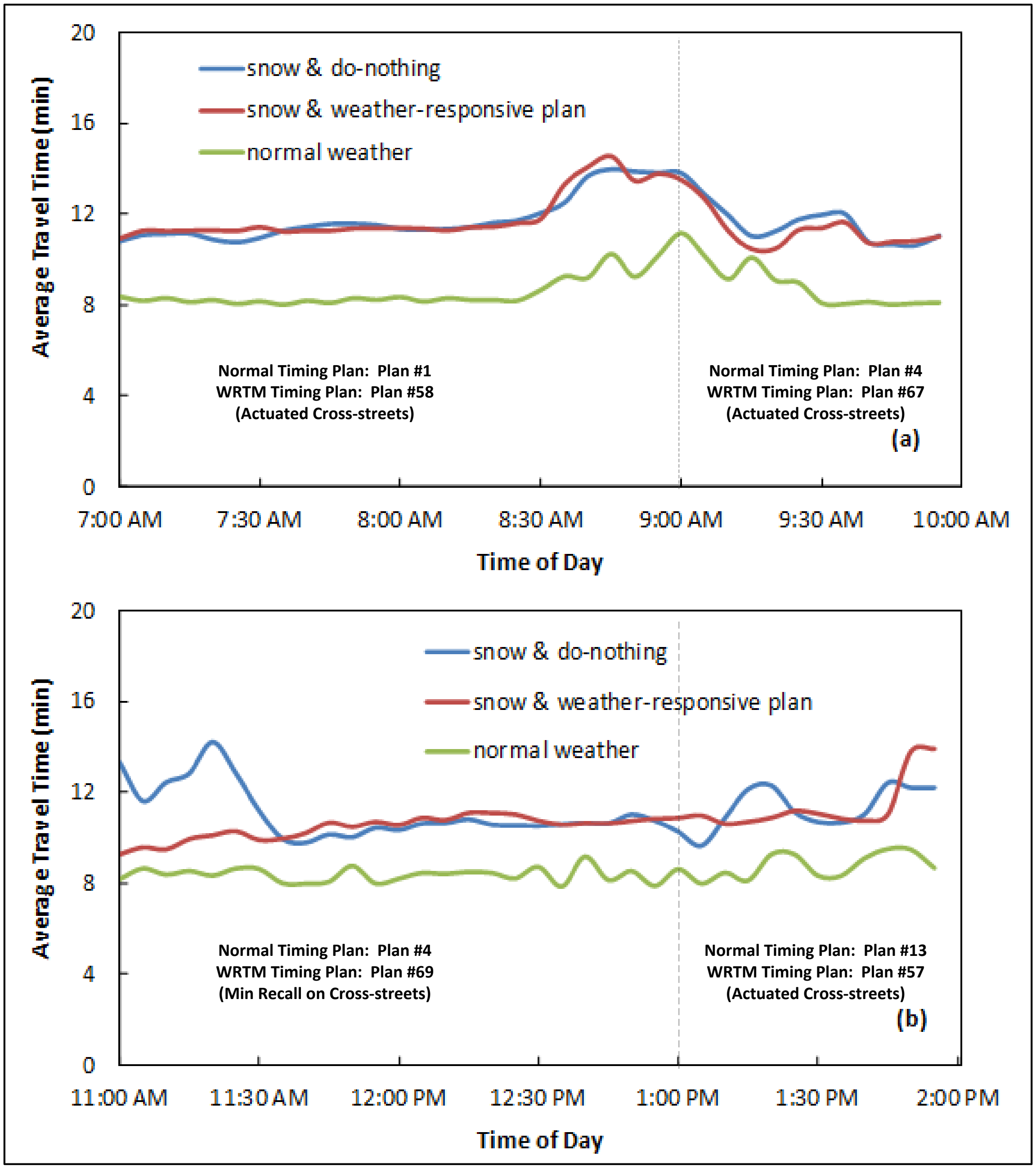





**Figure 4-11. Simulated Average Travel Time Along Riverdale Road Eastbound: (a) Peak; (b) Off-peak.**

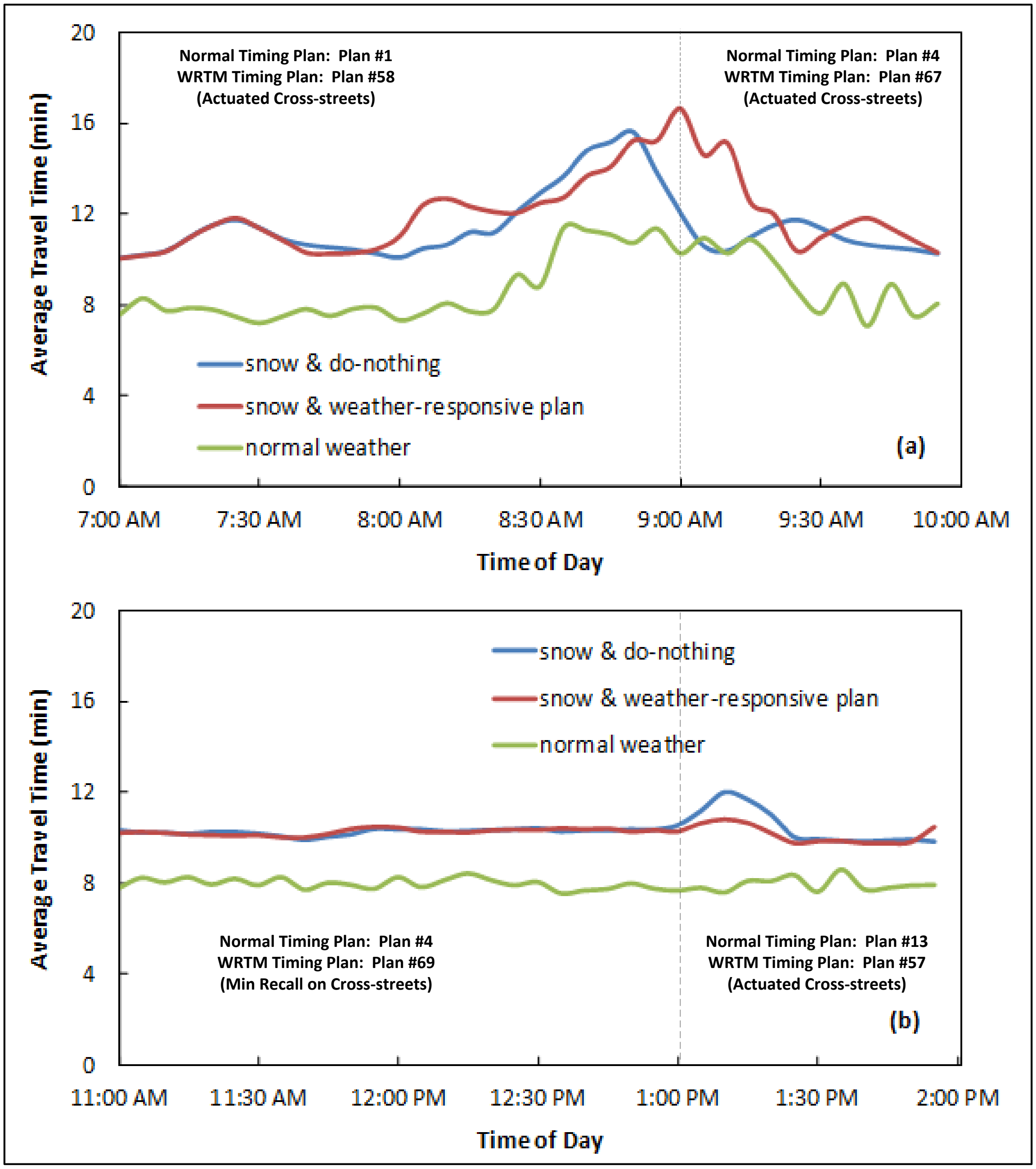





**Figure 4-12. Simulated Average Travel Time Along Riverdale Road Westbound: (a) Peak; (b) Off-peak.**

### *Average Stopped Time*

Average stopped time is an estimate of how long through vehicles stopped at intersections as they traveling along the studied corridor. In this study, stopped time was calculated by summing the time that vehicles were stopped at each individual intersection on the main-street approaches along the entire corridor. The results show that in most of cases, the snow event has a negative impact on traffic progression, which increases average total stopped time and reduces the fraction of non-stopped vehicles.

The aggregate level analyses are performed not only for the entire corridor, but also for two selected sub-corridors, as illustrated in Figure 4-13. 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).

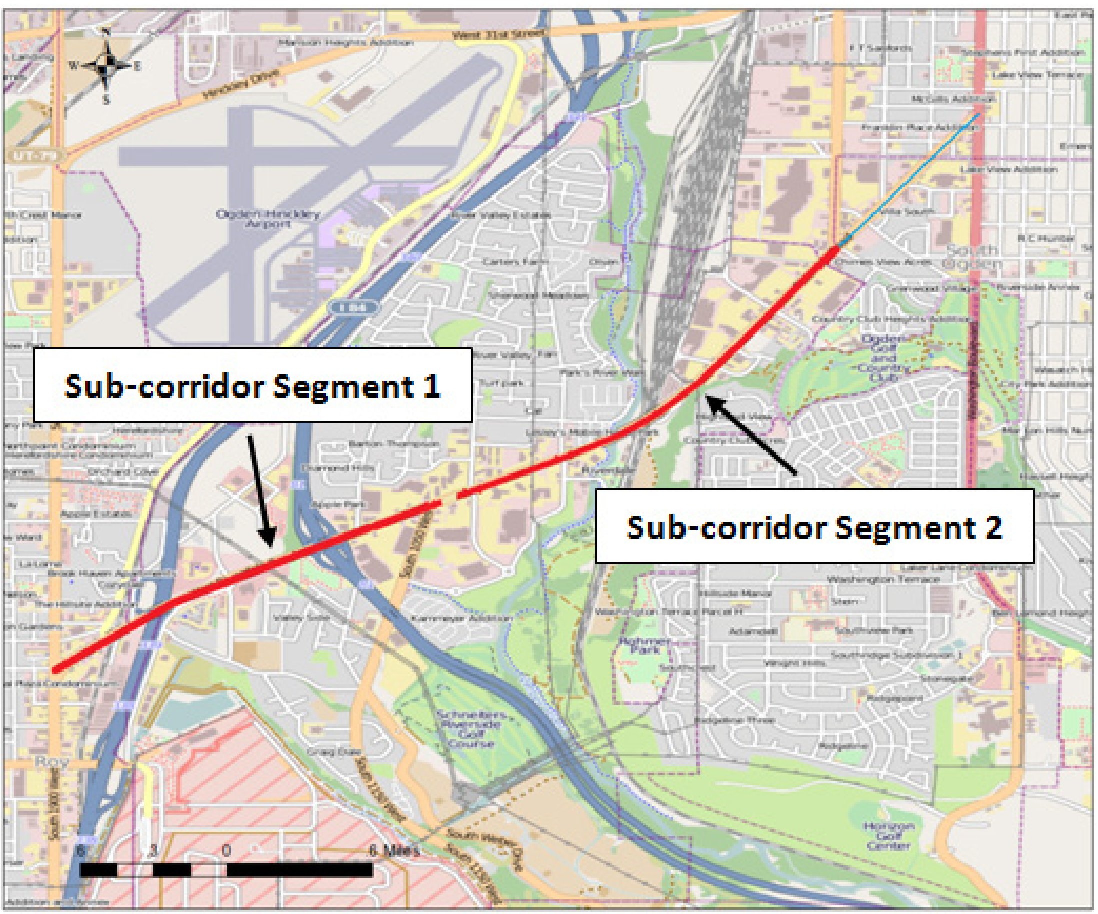





**Figure 4-13. Selected Sub-Corridor Segments.**

Figure 4-14 shows a comparison of the modeled average stopped time for vehicles traveling on two segments under different weather and traffic signal timing strategies. The figure shows that average stopped time for traffic traveling on Segment #1 is estimated to increase by approximately 4 seconds in the eastbound and by approximately 12 seconds in the westbound direction during snow events if no change in the traffic signal timing was implemented. Figure 4-14 also shows that by implementing weather responsive timing plans, UDOT is able to reduce travel time in this segment by approximately 4 seconds, an 8 percent reduction, during inclement weather events. Similarly on Segment #2, the model shows that average stopped time for traffic traveling in this segment increased by approximately 8 seconds and 22 seconds due to snow conditions in the corridor. When the weather responsive timing plans were deployed in the corridor, estimated average stopped time in the segment reduce by approximately 4 seconds in the eastbound direction and by 11 seconds in the westbound section.

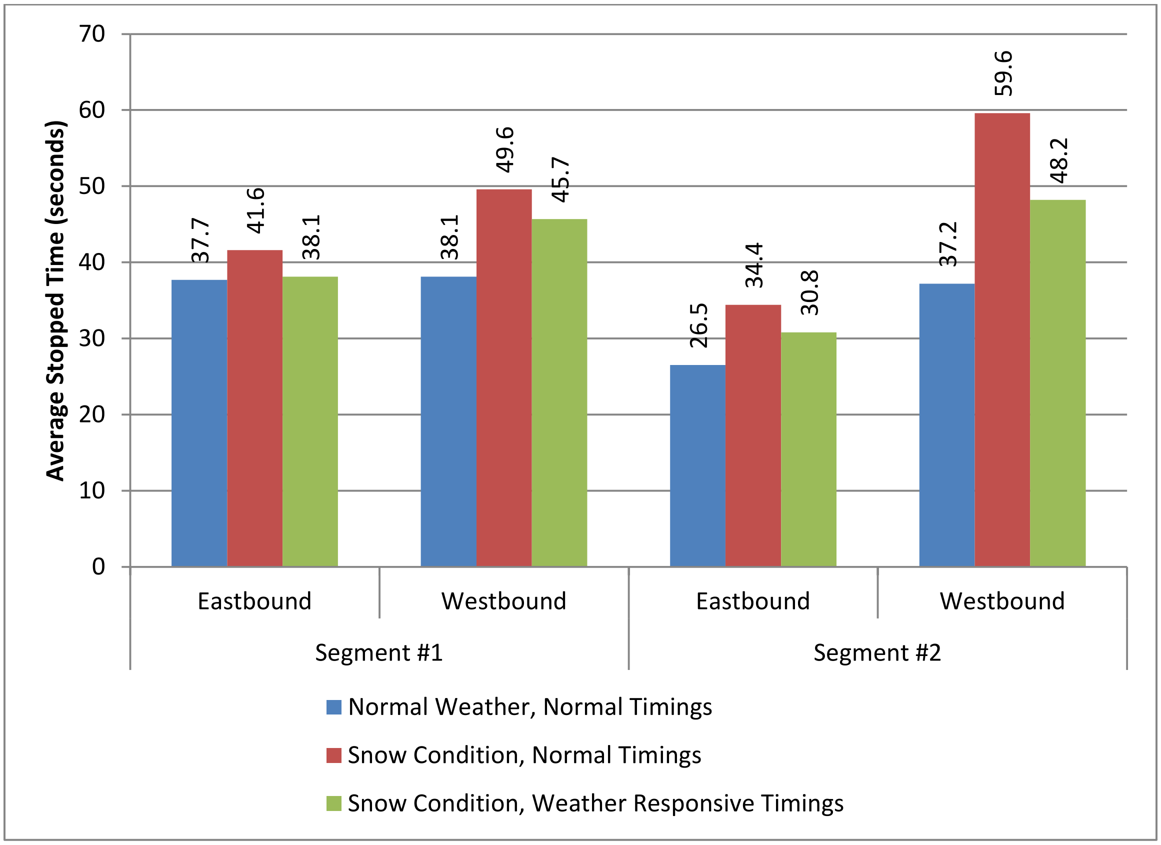



**Figure 4-14. Comparison of Average Stopped Time of Main-line Traffic on Riverdale Rd With and Without WRTM Traffic Signal Timings.**

## Intersection Level Analysis

Figure 4-15 provides a comparison of the modeled average stopped time for both directions of travel on Riverdale Road at each intersection during the a.m. period. The figure shows that except at a few intersections, implementing the weather responsive traffic signal timing plans was able to reduce average stopped time on both main-street approaches during the snow event. Deploying the weather responsive timing plans during the snow event (as opposed to keeping the normal time-of-day timing plans active) resulted in a reduction in average stopped time on the eastbound approach of Riverdale Road at seven of the eleven intersections where the snow plans were deployed. Likewise, deploying the weather responsive timing plans during the snow event resulted in a reduction in average stopped time on seven of the eleven westbound approaches on Riverdale Rd (although not necessarily the same intersections). During the a.m. peak, the reductions in average stopped times were more substantial for the westbound approaches of Riverdale Rd, compared to the eastbound direction.

Figure 4-16 provides a similar comparison of average stopped time for each direction of travel on Riverdale Road during the off-peak period. The figure shows a similar impact associated with deploying the weather responsive timing plans during snow conditions during this period as in the a.m. peak periods. Average stopped time declined at six of the eleven intersections for the eastbound direction of travel on Riverdale Rd and seven of the eleven intersections in the westbound direction. The most significant changes occurred on the westbound approaches of 1500 West, I-84, and 1050 West where the weather plans out-performed the normal, time of day plans greatly during the snow conditions.

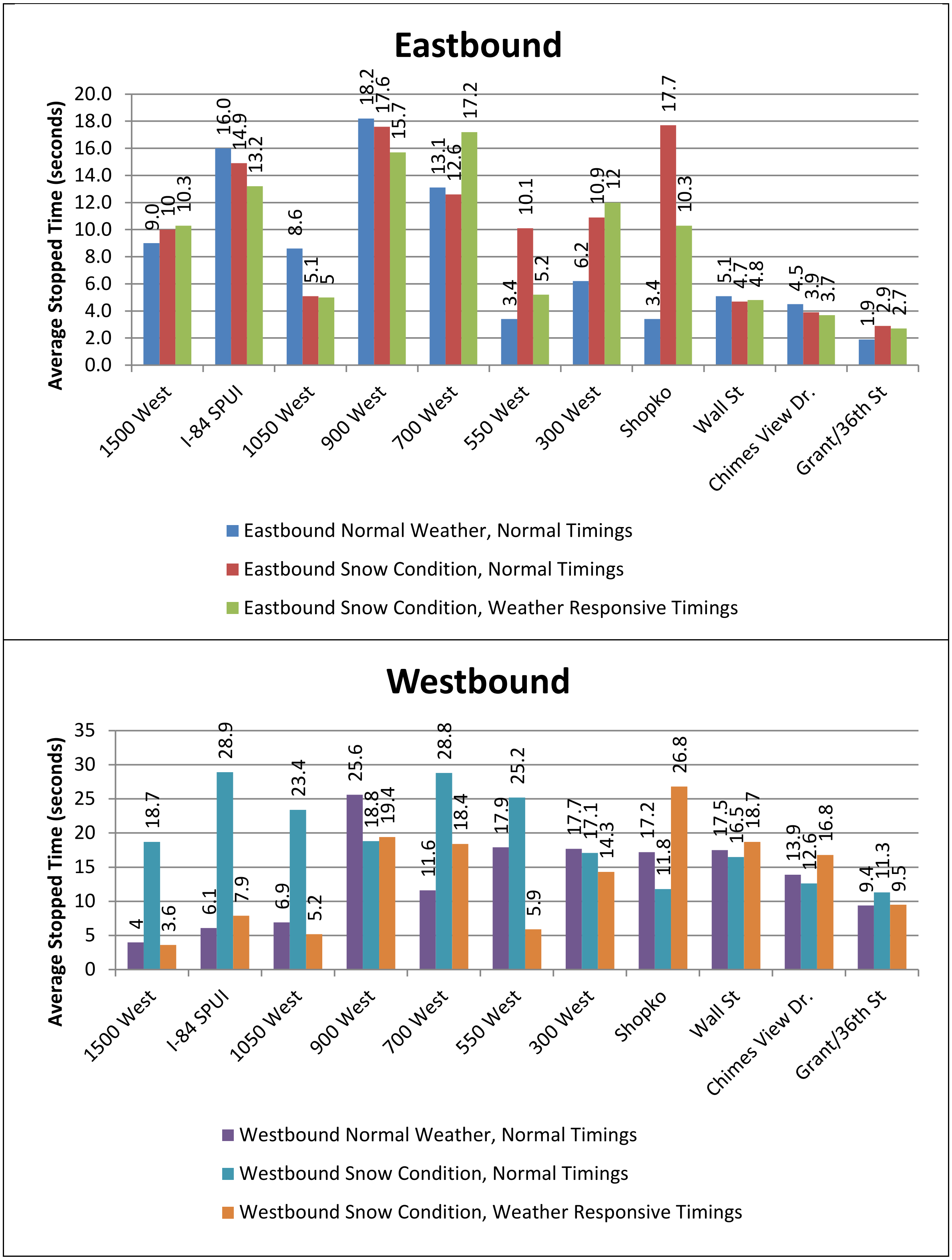



**Figure 4-15. Average Stopped Time per Intersection – Peak Period.**

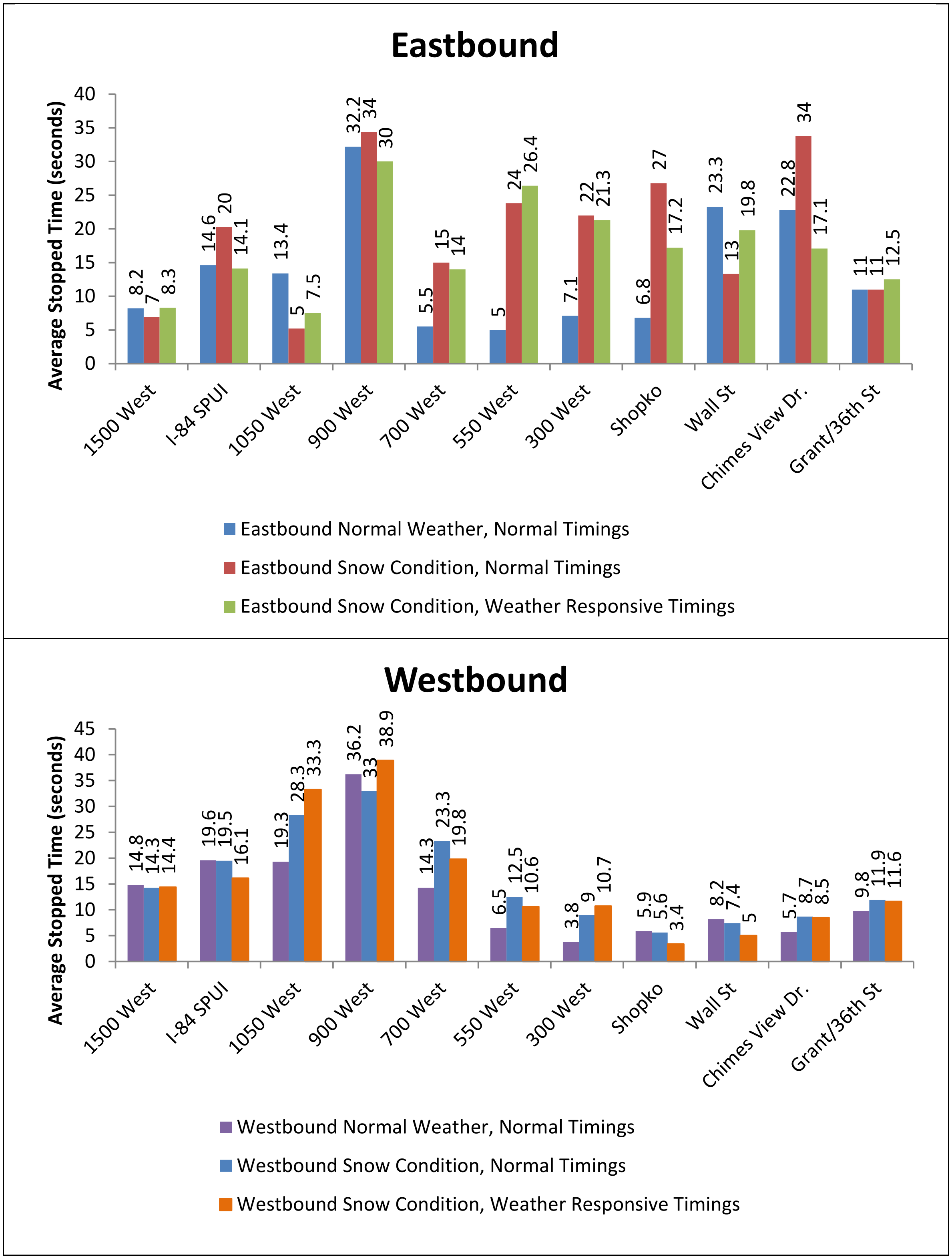



**Figure 4-16. Average Stopped Time per Intersection – Off-Peak Period.**

## 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 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 percent of travel times / free flow travel time)

All these metrics are popular for travel time reliability evaluation; however, they emphasize on 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 4-15 and Table 4-16 summarize the performance measures of travel time reliability for the two selected corridor segments described previously in both directions respectively. Figure 4-17 provides visual comparison of travel time reliability performance for the three simulation scenarios for both segments. East and West directions for the segments are noted as 1E, 1W, 2E, 2W in the figure.

**Table 4-15. Travel Time Reliability Measures for Eastbound Corridor Segments.**

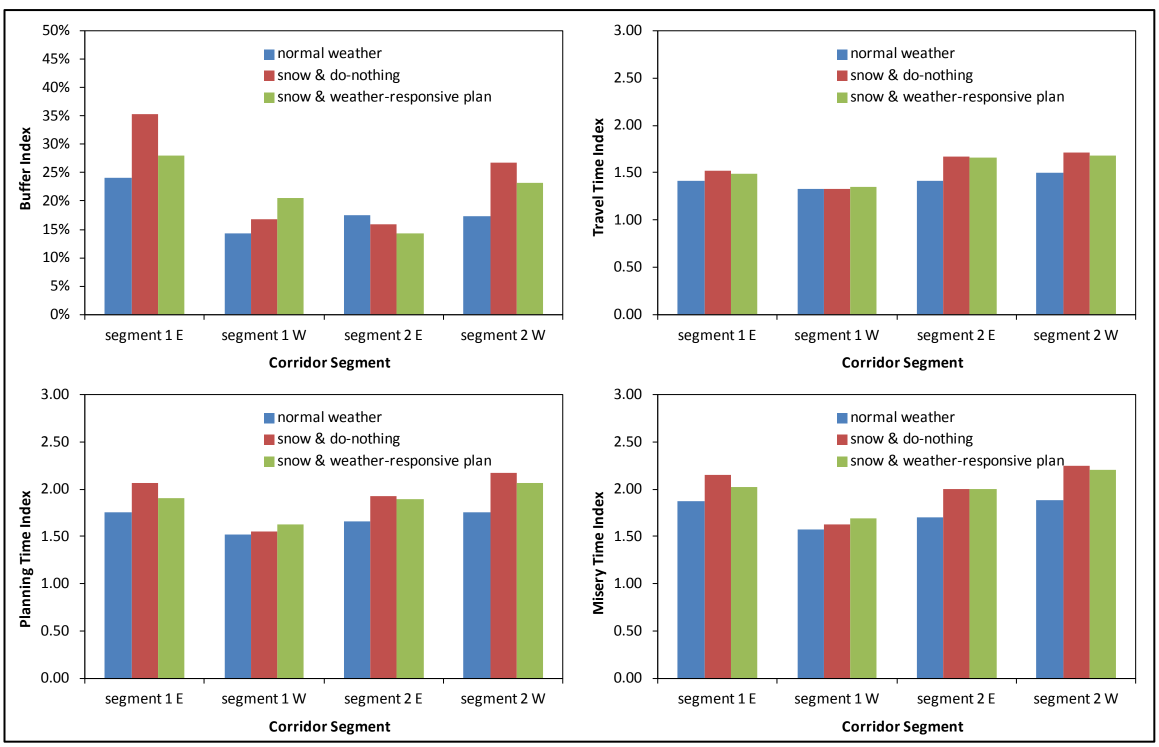
| | | Eastbound | | | |
|---|---|---|---|---|---|
| **Scenario** | **Corridor Segment** | **Buffer Index** | **Travel Time Index** | **Planning Time Index** | **Misery Index** |
| Normal Weather, Normal Timings | segment 1 | 24% | 1.42 | 1.76 | 1.87 |
| | segment 2 | 17% | 1.41 | 1.66 | 1.70 |
| Snow Condition, Normal Timings | segment 1 | 35% | 1.52 | 2.06 | 2.15 |
| | segment 2 | 16% | 1.67 | 1.93 | 2.00 |
| Snow Condition, Weather Responsive Timings | segment 1 | 28% | 1.49 | 1.91 | 2.02 |
| | segment 2 | 14% | 1.66 | 1.90 | 2.00 |

Source: Northwestern University

**Table 4-16. Travel Time Reliability Measures for Westbound Corridor Segments.**

| Scenario | Corridor Segment | Westbound Buffer Index | Travel Time Index | Planning Time Index | Misery Index |
|---|---|---|---|---|---|
| Normal Weather, Normal Timings | Segment 1 | 14% | 1.33 | 1.52 | 1.58 |
| | Segment 2 | 17% | 1.50 | 1.76 | 1.88 |
| Snow Condition, Normal Timings | Segment 1 | 17% | 1.33 | 1.55 | 1.63 |
| | Segment 2 | 27% | 1.71 | 2.17 | 2.25 |
| Snow Condition, Weather Responsive Timings | Segment 1 | 21% | 1.35 | 1.63 | 1.69 |
| | Segment 2 | 23% | 1.68 | 2.07 | 2.20 |

Source: Northwestern University




Northwestern University

**Figure 4-17. Travel Time Reliability Performance Comparison.**

The reliability measures under three different scenarios provide fairly consistent results across the metrics. As the buffer index indicates, the travel time on 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 help reduce travel time unreliability for segments 1E, 2E, and 2W; however, they perform worse than normal signal plans for corridor segment 1W.

# Overall Assessment

The evaluation was structured to answer the following evaluation questions:

- How did the weather-responsive traffic signal system in the Riverdale corridor improve UDOT's ability to respond to different inclement weather conditions?
- By using the system, was UDOT able to maintain a high quality of progression on Riverdale Road during inclement weather?
- Was UDOT able to maintain throughput and reduce delays on the corridor during different types of weather conditions?
- Was UDOT able to maintain equitable service to the cross-streets during different weather conditions on the corridor?

Operator assessments, field measures, and modeling were all used to examine the effects of deploying weather responsive traffic signal timing impacts in the corridor.

All the analyses showed that UDOT was able to better manage traffic signal operations in the Riverdale Road corridor as a result of deploying special weather responsive traffic signal timings during inclement weather. Weather responsive timing planes were deployed a total of 13 times during different weather events during the winter months of 2013. One of these events was one of the worst winter storms experienced in the Salt Lake City/Ogden area in the past decade. In over half of these events, including this major storm, operators assessment indicated either an average or above average improvement in performance in traffic operations as a results of deploying the weather responsive timing plans. In the majority of those cases where the timing plans were not judged to be effective, the weather conditions were judged not to have a significant impact on travel speeds in the corridor.

UDOT' s high resolution performance monitoring system in the corridor showed that UDOT was able to maintain at least the same (or higher) level of arrival on green and platoon ratios with weather responsive timing planes during implement weather conditions as normal, time-of-day operations in the corridor. Crucially, TrEPs modeling showed that total travel times and corridor-level travel times were less when the weather responsive timing plans were deployed in the corridor when inclement weather existed compared to normal time-of-day timing plans under the same weather and traffic conditions. The ability to compare against a "do-nothing approach" was vital in establishing the efficacy of these plans.

TrEPS modeling showed that the weather responsive signal timing plans reduced total stop time by 11 percent compared to using normal, timing-of-day timing plans during inclement weather. At the intersection level, deploying the weather responsive timing plans during inclement was able to reduce average stopped time at the majority of the intersections in the corridor, compared to using normal time-of-day timing plans. During the a.m. peak, deploying the weather responsive timing plans during the snow event (as opposed to keeping the normal time-of-day timing plans active) resulted in a reduction in average stopped time on the eastbound approach of Riverdale Road at seven of the eleven intersections where the snow plans were deployed. Likewise, deploying the weather responsive timing plans during the snow event resulted in a reduction in average stopped time on seven of the eleven westbound approaches on Riverdale Rd (although not necessarily the same intersections). The reductions in average stopped times were more substantial for the westbound approaches of Riverdale Rd, compared to the eastbound direction. In the off-peak, average stopped time declined at six of the eleven intersections for the eastbound direction of travel on Riverdale Rd and seven of the eleven intersections in the westbound direction. The most significant changes occurred on the westbound approaches of 1500 West, I-84, and 1050 West where the weather plans out-performed the normal, time of day plans greatly during the snow conditions.

# Chapter 5 Summary of Findings and Lessons Learned

The following section highlights some of the conclusions and lesson learned through this deployment of weather responsive traffic signal timing on the Riverdale corridor.

## Summary of Findings

UDOT's implementation of Wx-SIG concepts has resulted in a truly weather-responsive approach to traffic signal management. Starting with the role of the meteorologist, UDOT monitored Riverdale Corridor conditions to identify the best time to implement weather-based signal plans. Using forecast information, UDOT engineers were able to time the deployment of weather-related plans better for a majority of the weather events encountered in 2013.

By using the signal performance management system, UDOT was able to actively adjust signal timing plans during weather events to match observed conditions (primarily link speeds). Using the PCDs as the performance indicator, UDOT signal engineers were able to maintain comparable levels of progression to non-weather conditions as measured by the Arrivals on Green and the Platoon Ratios across the corridor.

As the following section will illustrate, the past winter was a learning experience for UDOT as they figured out the right operating approach to maintain a true weather responsive traffic control system in a corridor. The implementation allowed UDOT to understand the level of effort required to monitor the corridor during weather events, the nature and the frequency of adjustments to signal plans, and the required performance measurement tools to manage the system. UDOT is committed to continue these operations on the Riverdale Corridor as well as expanding the use of weather-responsive signal management to other appropriate corridors.

## Lesson Learned

The following summarizes some of the lesson learned from this deployment of weather responsive traffic signal timing strategies. The lessons learned that are specific to the Riverdale Road corridor are provided separately from those related to the deployment of overall concept of weather responsive traffic signal operations.

### Lessons Learned Specific to Riverdale Corridor

The following are some of the lessons learned during the deployment of the advanced weather responsive signal timing plans on the Riverdale corridor.

- Implement and/or modify coordination offsets during a storm should be carefully considered and not be hastily implemented. Speed changes can vary significantly from weather event to weather event, depending upon a number of factors, including the intensity of the storm, the duration of the storm, and the level of maintenance (in this case, plowing operations) performed on the roadway.

- Knowing when to deactivate a timing plan requires knowledge about actual conditions in the field. The lack of current precipitation does not automatically imply that a weather plan should be deactivated. Similarly, the occurrence of precipitation doesn’t mean a weather plan should be implemented. Agencies should use field data to correlate speed changes with different types of storm intensity events when developing special weather responsive timing plans. Simply put, weather responsive timing plans need to be developed and implemented based on measuring conditions in the field.
- Forecasters can do a pretty good job of accurately predicting when a weather event will begin to impact traffic operations. Forecasters have a more difficult time predicting whether a weather event will stop impacting operations for a number of reasons. Storm intensities have a tendency to ebb and flow throughout the duration of the event, and the effect of a snow event on traffic operations is highly dependent upon the time at which the event occurs, the degree to which maintenance operations can keep pace with the storm, traffic volume levels, and pavement temperatures.
- In developing weather responsive timing plans, the number of timing plans must be kept to a manageable size. Weather responsive timing plans need to be robust so as to provide adequate service over a wide range of potential snow conditions.
- The goal of a weather responsive timing plan, especially during the period when snow begins to accumulate on the pavement, should be to minimize stops. Avoid timing plans that utilize maximum recalls for minor and cross-street phases. Utilizing maximum recalls on the cross-street and minor movement phases could require the main-street to stop more frequently and increase delays to the main-street.
- The need to use recalls in timing plans is dependent upon the detector technology. UDOT experienced considerable issues associated with their video detection system during weather events that impacted visibility (i.e., heavy snowfall, blowing snow, etc.). This frequently required them to use phase recalls to ensure that the signals service minor and cross-street phases. A detector technology that is more robust during weather events can reduce the need to rely upon recalls ensuring service to the cross-street phases.
- In turning the WRTM plans on and off, the speed performance metrics were evaluated looking for a drop in speeds of roughly 5-10 mph, or a return to normal on the speeds. However, the latency of the data is 15-20 minutes. While the information was near enough to real-time to be of value, the timing of the plan deployment can be improved if the latency of the data were improved. By actively linking the intersection data to the signal performance system, UDOT now plans to receive the latest packet of data from the intersection each time the “Create Metrics” button is pushed, instead of relying on data uploaded to the server on a 15-minute schedule. This would speed up the latency to near-real time data of only 10 seconds old.

## Lessons Learned on Weather Responsive Traffic Signal Timing

- Weather events are somewhat random and no two weather events are exactly the same. The effects of a storm on traffic operations are highly dependent upon the storm intensity, the duration of the storm, the accuracy of the weather forecasts and the effectiveness and aggressiveness of the treatment strategies, etc. Therefore, it may be difficult to get an adequate sample size of weather events during just one season. It is highly recommended that the evaluation of any weather responsive traffic management strategy, particularly weather responsive traffic signal timing plans, extend across multiple seasons to ensure adequate sampling across a wide range of conditions.

- It is difficult to plan and execute an evaluation study that utilizes field measured data to assess the effectiveness of deploying a weather responsive traffic management strategy. Often, only a few days advance notice exists of an impending weather event. This makes it difficult to mobilize data collection personnel in time to be in position to collect data when the impact occurs. Furthermore, it is generally impractical and unsafe to require manual data collection during some weather condition, which requires agencies to have automated system in place to collect performance data. While automated system for collecting performance data are subject to failure and power losses during inclement weather, they provided a significant upgrade and enabled true weather responsive signal timing in Utah.
- The traditional before and after comparisons used to assess traffic signal performance (such as reductions in travel times, delays, etc.) may not be appropriate for assessing weather responsive signal timing strategies. During inclement weather events, one would expect traffic operations to be worse than during non-inclement weather conditions. Furthermore, no two weather events are exactly the same or have the same effect on traffic operations. This makes it is difficult to isolate the effects of the weather event from the effects of the weather responsive strategy. A modeling approach, which takes into account the worsening of conditions under a do-nothing scenario, is essential to document benefits.
- In this deployment, only two weather responsive signal timing strategies were deployed: changing coordination timing to account for slow travel speeds, and changing the way detectors operate during inclement weather conditions. However, a number of other weather responsive signal timing strategies exist that could potentially affect safety and operations. These strategies include changes to vehicle clearance intervals based on reduced pavement friction, using dynamic red clearance intervals, etc. As UDOT becomes more comfortable with the active management of traffic signals during weather, some of the other strategies should be considered for implementation as well.
- Because weather conditions and their impacts can vary within a region, it is difficult for operators to continuously monitor and fine-tune traffic signal setting manually if weather responsive timing were implemented on a regional basis (as opposed to an individual corridor like Riverdale Road). In order to be deployed at a regional level, operators are going to rely on an on-line decision support system that can take real-time information about roadway and weather conditions and assist them with making recommendations to operators on when and where to implement traffic signal timing strategies. The decision support system would need to include the setting of implementation thresholds and the unique expert rules necessary for the particular location.

# Recommendations for Next Steps

Based on the outcomes of this project, UDOT expects to continue utilizing the system to fine-tune their signal operations on the Riverdale Road corridor and expand its use to other corridor. UDOT expects to completely overhaul their current time-of-day signal timing plans along Riverdale Road in summer/early fall of 2014 utilizing the technologies deployed in the corridor. Updates to the weather responsive timing planes are also likely to be developed to correspond to the updated time-of-day plans. UDOT is also planning on expanding its use of weather responsive timing plans to other corridors where sufficient technology exists to allow them to produce PCDs. Other potential corridors include Foothill Boulevard, Bangerter Highway, and other major corridors in the Wasatch Front Range area.

Specific recommendations associated with deploying weather responsive timing plans in the corridor include the following:

- Conduct an analysis of the potential impacts of weather conditions on traffic operations and signal performance in these corridors to determine the extent to which different weather conditions change traffic patterns and corridor speeds.
- Develop a library of alternate traffic signal timing plan strategies to address the specific conditions and impacts in the corridors.
- Identify clear and ambiguous weather and traffic performance thresholds for determining when to implement the identified weather responsive plan.
- Deploy weather monitoring and video surveillance stations in these corridors to detect when and where weather events
- Implement the online decision support system portion of TrEPS to allow operators to compare the effects of deploying different timing plans and select the optimum timing plan to deploy based on current and forecasted traffic and weather conditions.

# Appendix A.

# Wx-SIG Strategy Concept of Operations

# Introduction

The purpose of this document is to discuss the concepts of operations for the Utah weather responsive signal control project on Riverdale road from 1500 West in Roy to 36th Street in Riverdale. The project includes 11 intersections along the northeast-southwest corridor, is a 6-lane road with 30,000 AADT and signal spacing ranging from 700 feet to over 3,000 feet. The goal of the project is to improve traffic signal operations and safety during adverse weather conditions along the corridor by developing standard operating procedures and decision support aids to assist Traffic Management Division (TMD) operators in determining when and where different weather responsive traffic signal timing plans should be implemented under different operating conditions. Tools will be developed in helping to monitor the effectiveness of the optimized signal timing parameters, including adverse weather signal timing plans. Some of these tools will include evaluating Purdue Coordination Diagrams (PCD's), percent of vehicles arriving on green and red, approach volumes and speed data for each intersection.

To better analyze and forecast the weather, a road weather information system (RWIS) station will be permanently deployed at one location along the corridor so the severity of the storms can be better forecasted, assessed and used to make better decisions regarding the action to take with signal operations.

This document is organized into several areas so to better understand why this project is needed, how this project can better improve signal timing operations and what will be done to ensure success of this project.

# Referenced Documents

- Utah Department of Transportation TOC Guideline and Procedure Update titled, "Adverse Weather Timing Plans – Region 2): Effective date: February 2008".
- Report # UT-01.03 "R&D Network Shadow Advanced Traffic Operations Center to Model Signal Timing for Severe Weather conditions". Submitted by: University of Utah. Principle Investigator: Peter T. Martin, Ph.D. Research Associates: Joseph Perrin, Ph.D., P.E.; PTOE & Blake Hansen. Research Assistant: Isaac Quintana. July 2000.

# Current System

UDOT has in-house meteorologists' whose main functions and responsibilities are to forecast specific road weather to UDOT. The UDOT Weather Operations / RWIS program is unique among state departments of transportation (DOT) nationally, as it assists the DOT operations, maintenance, and construction functions by providing detailed, often customized, area-specific weather forecasts (http://udottraffic.utah.gov/forecastview/Default.aspx). UDOT owns 75 RWIS stations (7 more are planned for installation). Staff meteorologists are stationed in the Traffic Operations Center (TOC), providing easily accessible weather information and quality control of weather forecasts. UDOT Weather Operations / RWIS program consists of one full-time UDOT employee who is a meteorologist who oversees the program and 8 contracted employees who work for Northwest Weathernet. The contracted employees reside at the UDOT TOC and are physically present 24/7 365 days a year (except for a gap between 3 AM and 6 AM, where they do phone support if needed). If a storm is coming in, they will change the staffing to cover the hole in coverage from 3 AM to 6 AM. The UDOT Weather Operations meteorologists provide weather briefings in advance of the storms (usually about 48 hours out and the briefings increase when the storm gets closer). During these briefings, the traffic signal operations staff is informed of the time and locations when various inclement weather signal timing plans may be needed.

A signal timing console is staffed in the Control Room of the UDOT TOC Monday thru Friday from 6:30 AM to 7:00 PM by a signal timing engineer / technician. The main functions of the signal timing console is to make real-time adjustments to signal timing due to atypical situations, such as crashes, construction, special events and adverse weather using the Siemens i2 central management system (this system is scheduled to be replaced next year with a new system). The operator at this desk will run the “adverse-weather” signal timing plans as needed, as determined from the meteorologists’ weather briefings and as determined using the CCTV cameras (we have over 700 CCTV’s statewide). In one case, the UDOT shed supervisor may call in and request to run the “inclement weather-plans” along Bangerter Hwy as they run special phase sequences (i.e. lead/lead) to assist the snowplow operations in plowing. In absence of the signal timing desk, the TOC operators (who are present 24/7) have the ability to run the inclement weather plans as requested. Normally, however if the storm is coming in after hours when the signal timing desk is vacant, we will set up the scheduler in the Siemens i2 system to run the desired inclement weather plans. UDOT follows guideline and procedures in implementing the adverse weather timing plans as outlined in the referenced document “Adverse Weather Plans (Region 2)”. In this document, it specifies:

- Special plans may be implemented if requested by a shed supervisor for that area and to remain active until snowplowing operations are complete.
- Special plans may be implemented if requested by TOC meteorologists’.
- Special plans are to be implemented by a predefined schedule (as referenced in the document).

The document also specifies when not to run the special plans and is based off of previous research titled, “R&D Network Shadow Advanced Traffic Operations Center to Model Signal Timing for Severe Weather conditions” submitted by University of Utah July 2000:

- There is not a significant reduction in travel speed due to weather (30 percent reduction).
- Signals are not normally coordinated during this time-of-day.
- Delay-causing weather conditions will not last at least 20 minutes.

The adverse weather special timing plans have been created after new time-of-day (TOD) signal timing plans along the corridor were developed and fine-tuned. The special plans take the existing fine-tuned TOD plans and in a Synchro model the speeds are reduced 30 percent. Two plans are usually produced: 1) A “light” inclement weather plan with no-recalls and an optimized offset (based off of the 30 percent speed reduction). 2) A “heavy” inclement weather plan with 30 percent speed reductions and max recalls on all phases. Sometimes these plans are produced to favor certain directions along the corridor.

# Justification for Changes

Over 10 years, UDOT has been running special signal timing plans for adverse weather based off of the research conducted by the University of Utah in 2000. However, we have learned some important and valuable lessons as we have run previous inclement weather plans in the past. In addition, we have had no way to verify the effectiveness of the previous inclement weather plans in the past. While the previous research seems sound, it was a limited study conducted at just two intersections and during 7 storms.

UDOT uses four different types of vehicle detection (inductive loops, video, magnetometers and radar). Experience has shown that video detection in some areas stops working when inclement weather builds up on the lenses. Sometimes the video goes into safe mode and other times it doesn't work at all. To manage the problem, many signals are operated as pre-timed by using max recalls in the special signal timing plans.

It is UDOT's policy since 2008 to install radar for dilemma zone protection at all intersections where the speed is 40 mph and higher. The Wavetronix Advance Smartsensor ® provides dilemma zone protection for each vehicle that is based on the estimated arrival of the vehicle at the intersection. The radar is capable of doing this as it knows the distance back the vehicle is and the speed of each vehicle. As technology develops, it is now possible to leverage this technology to figure out the speeds approaching each intersection during the green phase, as radar is not affected by adverse weather. UDOT already has over 500 sites already deployed of this radar, so the knowledge gained on this project can be deployed to the other sites.

UDOT has also been working diligently on automatic performance measures for traffic signals and has partnered with Dr. Darcy Bullock of Purdue University and James Sturdevant of Indiana DOT. UDOT joined a pooled fund study titled, "Traffic Signal Systems Operations and Management" with the FHWA (Richard Denney as the FHWA technical liaison). Ten other agencies are involved in this pooled fund study (City of Chicago, CA, GA, KS, MN, MS, NH, TX, UT, WisDOT). As part of this study UDOT has started the process in collecting automatic performance measures (http://udottraffic.utah.gov/signalperformancemetrics/). We currently are showing the Purdue Coordination Diagrams (PCD's) and approach volumes at some locations. These PCD's will help us assess the effectiveness of the inclement weather plans during inclement weather and will allow us to go through an iterative process in fine-tuning the coordination offsets.

# Concept for the Proposed System

During inclement weather, UDOT's service goals for its traffic signal system are as follows:

> To the extent practical without compromising safety, UDOT will strive to maintain a similar level of traffic moving performance through the operations of their traffic signal system during mildly inclement weather conditions as provided during normal, non-inclement weather events.

To the extent possible and practical, UDOT will rely upon its standard detection systems to determine when demand is present for traffic signal phases at intersections; however, when, in the judgment of the TMC operators, weather conditions affect the ability of the detection systems to adequately detect traffic demands, TMC operators will take action to ensure that all demand at intersection is serviced safely and efficiently. To assist in obtaining these service goals, UDOT will be developing standard operating procedures and decision support aids to assist Traffic Management Division (TMD) operators in the Traffic Management Center (TMC) in determining when and where different weather responsive traffic signal timing plans should be implemented under different operating conditions. Operators and meteorologists in the TMC will monitor travel conditions in corridor using information provided by a Road Weather Information Station (RWIS) deployed in the corridor. The RWIS stations will provide TMC personnel with information about weather and travel conditions such as road and air temperature, road surface condition, precipitation accumulation and visibility. Operators in the TMC will also monitor the effects of the deteriorating weather conditions on traffic operations using information provided by a series of radar-based traffic detectors as well as video surveillance. The radar-system will be used to determine when travel speeds in the corridor have dropped to below the progression design speed of the traffic signal timing plans in the corridor. UDOT's video surveillance system will be used to determine when precipitation type and accumulations affect travel speeds and the performance of the traffic signal detection system to accurately detect traffic demands for cross-street and turning movements in the corridor. Once alerted about potential deteriorating travel conditions, operators can determine which of several different traffic special timing plans to implement in the corridor to use during the weather event in the corridor. These special timing plans have been developed to account for slower mainline travel speeds in the corridor common with travel in weather events in the corridor. The timing plans have been designed to provide mainline travelers with similar level of performance (in terms of progression) as exists during non-inclement weather conditions while at the same time providing guaranteed service to cross-street demands.

# Components of the Proposed System

The proposed uses a combination of existing and new components that are integrated together to allow UDOT to better manage their traffic signals in the Riverdale Road corridor during weather events. A logical architecture of the proposed system is shown in Figure A-1. The role and purpose of each of the system components are described below.

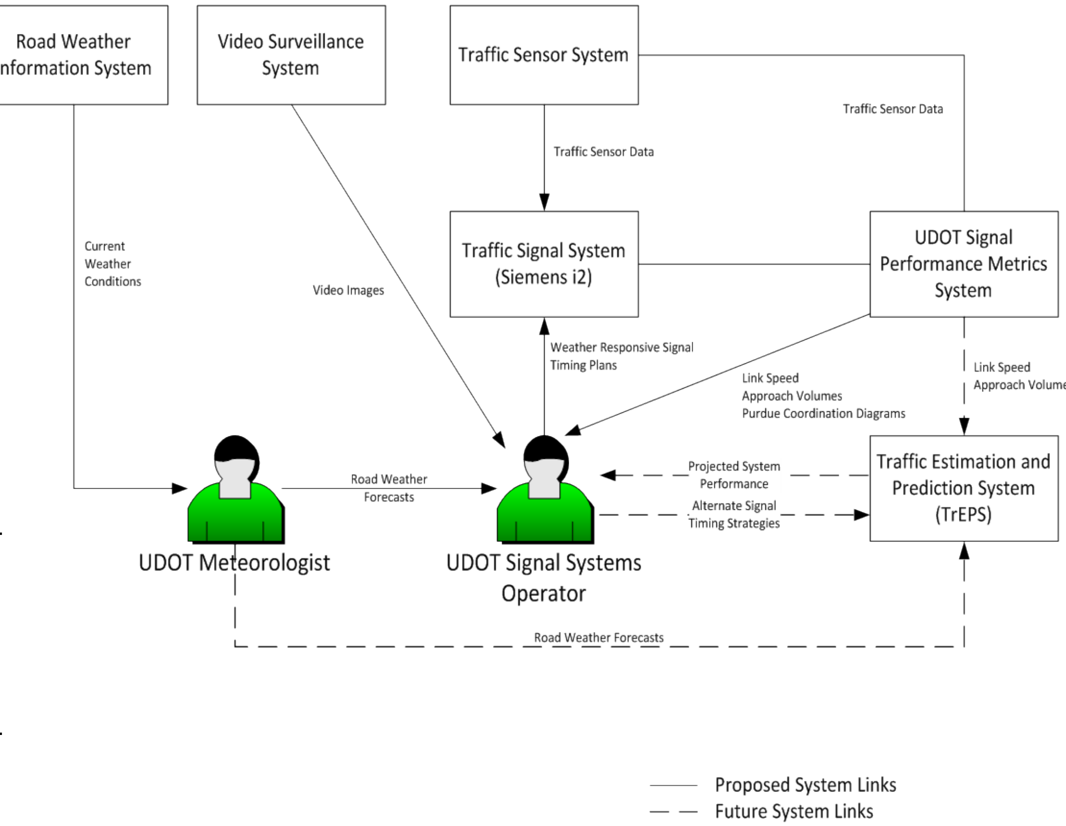



**Figure A-1. Proposed Architecture of UDOT Wx-SIG System Deployment.**

## Road Weather Information System

In order to effectively manage traffic signal operations during adverse weather, it is important to have reliable data on actual conditions while signal coordination plans are running. The point at which an operator would activate special inclement weather responsive traffic signal timing plans depends a lot on weather conditions. UDOT currently has an extensive network or Road Weather Information System (RWIS) station located throughout the state; however, one is not located in the Riverdale Road corridor. UDOT plans to procure, install and integrate a RWIS station directly in the corridor. This station will provide UDOT Meteorologists with information on road temperature, road surface, and depth of precipitation, the type of accumulation on the road, air speed, and air temperature.

## UDOT Meteorologist

UDOT Meteorologist staff play a critical role in UDOT Weather Responsive Traffic Signal System deployment. Using information from the RWIS stations and other systems, UDOT Meteorologists are responsible for providing UDOT Signal Systems Operators with forecasts of weather conditions and road weather impacts for the corridor. These forecasts include not only estimates of the type, severity, and duration of the weather event, but also the degree to which the weather is expected to impact travel speeds and visibility in the corridor. UDOT Signal System Operators then use this information to determine when specific traffic signal timing plans will be deployed in the corridor.

## Traffic Signal System

UDOT will create special traffic signal timing plans that will be implemented during significant weather events. The timing plans will be patterned after new time-of-day (TOD) signal timing plans were developed and fine-tuned for the corridor. UDOT developed two weather responsive timing plans produced for each of the A.M., Off-Peak, and P.M. base timing plan: 1) A "light" snow plan with optimized offset (based off of the 30 percent speed reduction) and normal detector operations, and 2) A "heavy" snow plan with 30 percent speed reductions and recalls on all phases to ensure that all phases are serviced when either a) weather impacts to the vehicle detectors may cause problems or b) the striping is not clearly visible. Below is a summary of each signal timing strategy:

<u>Light Adverse Weather Signal Timing Plan</u>

- Will not use any recalls (except the arterial phases which are normally on a min recall).
- Same cycle length & splits currently in use by the normal TOD plan.
- Initial offsets (from fine-tuned normal TOD plans) are designed for a 30 percent reduction in free-flow speed.

<u>Heavy Adverse Weather Signal Timing Plan</u>

- All non-arterial phases are placed on recall to ensure service to the cross-streets.
- Same cycle length & splits currently in use by the normal TOD plan.
- Initial offsets (from fine-tuned normal TOD plans) are designed for a 30 percent reduction in free-flow speed.

These weather responsive timing plans will be deployed in UDOT Traffic Signal Management System as special timing plans, and downloaded to each of the 11 signalized intersections in the deployment corridor.

## UDOT Traffic Signal Systems Operator

UDOT Traffic Signal Systems Operators will be responsible for actually deploying/implementing weather responsive traffic signal timing plans. UDOT's Meteorology Desk will provide the UDOT Traffic Signal System desk with estimates on the type, arrival time, duration, and severity of weather events. The Traffic Signal System Operators will schedule the start and end time of the appropriate weather responsive timing plans. Weather responsive timing plans will be set to activate when the following conditions exist:

- The weather event is predicted to create a significant reduction in travel speed in the corridor (i.e., 30 percent reduction in free-flow speed – about 10 mph)
- The traffic signal would normally operate in a coordinated mode during the time of day the weather is expected to impact operations.
- The effects of the weather event are forecasted to last at least 20 minutes

After the weather responsive timing plans have been activated in the corridor, UDOT's Traffic Signal Systems Operators will monitor travel conditions in the corridor using UDOT's Video Surveillance system. The weather responsive timing plans should be disabled when they are no longer needed and/or effective. Weather responsive timing plans may be discontinues when any of the following is true for the corridor:

- Travel speed return to their “normal” level (timing plans are generally designed for a 30 percent reduction in free-flow speed – about 10 mph)
- Signals are not normally coordinated during this time of day (i.e., it is late at night.

After each weather event, the Traffic Signal Systems Operator will review the information produced by UDOT’s Signal Performance Metrics System to identify changes in signal timing strategies might be needed to improve operations in the corridor.

Guideline and procedures will be developed to help TMC operators in determining when the different timing plans can be implemented. These standard operating procedures will be used for operating in the TMC so to implement and adjust special adverse weather signal timing plans. The RWIS data will also be evaluated in helping to identify trends when inclement weather plans should be implemented.

## UDOT Signal Performance Metrics System

Using information from both the RWIS and UDOT’ Signal Performance Metrics System, UDOT Traffic Signal Systems Operators will develop and fine-tune special adverse weather signal coordination plans along the corridor. To accomplish this, UDOT Signal System Operators will utilize the following three automated performance monitoring tools specifically deployed in the corridor:

- Purdue Coordination diagrams
- Approach Volume Profiles
- Link Speed Profiles

## Traffic Sensor System

Part of the project will be to install the radar Wavetronix Advance Smartsensors® along the arterial at locations where the smart sensors are currently not installed. The project will see the following benefits with this radar technology:

Data from these sensors are expected to be used to collect PCD’s and capture approach volumes and speeds, some intersections are in need of detection upgrades from video detection to radar detection.

### *Traffic Estimation and Prediction System (TrEPS) /Decision Support System*

It is anticipated that FHWA, under a different contract, will support the integration of the Traffic Estimation and Prediction System (TrEPS) into the proposed system design. TrEPS is a support system that can assist UDOT Traffic Signal Systems Operators with decisions regarding when and what traffic management strategies to deploy in a corridor during inclement weather events. TrEPS is designed to forecast future traffic conditions utilizing existing traffic and weather conditions. Using TrEPS, UDOT Traffic Signal Systems Operators can assess the impacts different traffic signal and traffic management strategies before they are deployed in the field. This can help UDOT determine 1) the degree to which weather conditions will impact operations, and 2) the appropriate time and strategy for deploying various traffic signal timing strategies based on anticipated travel conditions in the corridor.

The potential also exists to use TrEPS to quantify the amount of improvements that using weather responsive timing plans had on operations in the corridor. The TrEPS model could compare the performance of the corridor both with and without the weather responsive timing plans under the same operating conditions. This offers a potentially valuable comparison in evaluating the effectiveness of deploying weather responsive timing plans in the corridor during inclement weather conditions.

# Operational Scenarios

UDOT plans on using the tools deployed along Riverdale Road to run special signal timing plans for various adverse weather conditions. Prior to the event, UDOT will closely monitor the 6 existing CCTV cameras, RWIS data and automatic performance measures to make decisions when traffic conditions warrant a change in signal timing plans. During the event, UDOT will monitor the impacts and when approach speeds and conditions return to normal, the special plans will be turned off. After the event, UDOT will evaluate the progression quality using automatic performance measures to fine-tune the special plans for the next inclement weather-event. We plan on this procedure being an iterative process.

<u>PRE-EVENT</u>

Prior to the event, UDOT will do the following:

- Develop signal timing plans for various inclement weather events. The quantity of plans developed is yet undetermined and will be a factor of the various characteristics and different attributes of the storms.
- Develop guidelines and procedures explaining the purposes of the inclement weather plans, operational guidelines, plan descriptions and follow-thru.
    - PURPOSE – The purpose will explain the reasons why the plans were created and help give some clarification to others of the purpose of the plans.
    - Operational Guideline – Will explain when, where and by whom the plans can be implemented. Will also explain procedures or criteria on when to determine running the plans and which plan to run.
    - Plan Descriptions – will list the library of available plans to run for the groups of signals and brief description of each plan
- Evaluate staffing needs of anticipated storm.
- Collaborate with the UDOT meteorologists by using the website at http://udottraffic.utah.gov/forecastview/Default.aspx and also by attending formal weather briefings prevent and personal visitations as needed.
    - Set up guidelines & procedures for the meteorologists to inform the operators when they recommend deactivating plans

EVENT

During the event, UDOT will do the following:

- Using the approach speed metric which is very near real-time; CCTV camera images and considering the time-of-day of the weather event, run the appropriate inclement weather plan.
- Selecting the appropriate plan may also factor in with the need of running recalls at the video detection locations or locations where the striping (lane markings) are not clearly visible.
- Documentation of the times the inclement weather plans were in operation.
- Observations will be made and notes kept of areas viewed with the CCTV cameras where problems or delay exists.

POST-EVENT

After the event, UDOT will do the following:

- Evaluate the MOE's (PCD's, approach volumes, approach speeds, split monitoring) to evaluate any changes needed with the inclement weather timing plans.
- Evaluate RWIS data with meteorologists in evaluating the weather data from the RWIS.
- Prepare a brief report for each major weather event
- Fine-tune the inclement weather signal timing events for the next event.

# Summary of Impacts

UDOT does not anticipate an increase of work-load at the TOC for implementation of the special inclement weather plans, as we are already staffed to proactively respond to these situations during business hours from 7:00 AM to 7:00 PM weekdays when the signal timing desk is staffed. Depending on the severity of the forecast of the storm, UDOT will determine on a case-by-case basis if extra staffing should be available during the times the signal timing desk is not staffed, or if implementing the actions based off of forecasts may be the best approach. Additional work will be needed evaluating the effectiveness of the plans during each storm. UDOT will do this assessment internally during the duration of the project.

# Analysis of Proposed System

Optimizing mobility and improving safety are two strategic goals of UDOT. National research studies have shown that retiming signals yields a very high benefit to cost ratio (average 40:1). By proactively adjusting traffic signal timing to changes in traffic flow during inclement weather, travel delay will be reduced and in turn it will result in less air pollution from idling vehicles. In addition, better synchronization of the traffic lights for the changes in travel speeds will result in less vehicles stopping and in turn will be safer. We also anticipate that over time there will be less rear-end collisions.

Once the proposed system is deployed, UDOT plans to conduct an evaluation to assess the degree to which the system impacted the way UDOT manages traffic signal operations in the corridor. The evaluation will be structured to explore the following questions:

- How did UDOT use the system to develop and improve the traffic signal timing responses to different inclement weather conditions in the Riverdale Corridor?
- By using the system, was UDOT able to maintain a high quality of progression on Riverdale Road during inclement weather?
- Was UDOT able to maximize performance of the signal system during different types of weather conditions in the corridor?
- Was UDOT able to maintain equitable service to the cross-street approaches during inclement weather events?

Internally to UDOT, this project will help us make better decisions and develop better coordination plans for inclement weather. UDOT has over 500 sites of the Advance radar smart sensors installed already, so this project will be a catalyst in helping us better our operations statewide. UDOT will use various performance measures (including the PCD's, approach volumes and speeds), RWIS data and CCTV cameras, in determining other locations for adverse weather signal timing plans.

# Notes

List of Acronyms

- TOC – Traffic Operations Center
- TMC – Traffic Management Center
- PCD – Purdue Coordination Diagrams
- UDOT – Utah Department of Transportation

# Appendix B.

# Wx-SIG Strategy Evaluation Plan

# Introduction

The purpose of this document is to present a plan for evaluating the use of weather responsive signal timing plans by UDOT during winter weather conditions on Riverdale Road. The goal of implementing weather responsive traffic signal timing in this corridor is to improve safety and optimize mobility by proactively managing signal operations during adverse weather conditions. This document outlines the evaluation questions, and details the methodologies by which each question will be evaluated, including the data to be used. Project evaluation will begin January 1st, 2013 and will end in April, 2013.

## Project Description

Inclement weather can have a significant impact on traffic signal operations in Utah. Drivers are more cautious during heavy rain, fog and snow. Inclement weather causes vehicles to travel and accelerate more slowly, thus causing normal signal coordination plans to be less than ideal because of the reduction in speeds and headways.

In the past, UDOT would schedule special "snow plans" to run on selected corridors. These snow plans are scheduled to run by time-of-day and scheduled from UDOT's Siemens i2 traffic management system, as determined by UDOT's traffic engineers and UDOT's in-house meteorologists. The development of the plans followed guidelines from previous research titled, "R&D Network Shadow Advanced Traffic Operations Center to Model Signal Timing for Severe Weather conditions", submitted by the University of Utah, July 2000, where in summary it suggests developing plans that have the following changes:

- Decrease the measured or calculated "dry" saturation flows by 20 percent.
- Decrease the average "dry" speeds by 30 percent.
- Increase start-up lost time by 23 percent from 2.0 to 2.5 seconds.
- Activate inclement weather signal timing plans based on engineering judgment that takes into account storm severity, storm duration, area of influence, and traffic flows.

UDOT created these special snow plans after new time-of-day (TOD) signal timing plans were developed and fine-tuned. The special plans take the existing fine-tuned TOD plans, and in a Synchro model the speeds are reduced 30 percent. UDOT developed two weather responsive timing plans produced for each of the A.M., Off-Peak, and P.M. base timing plan: 1) A "light" snow plan with optimized offset (based off of the 30 percent speed reduction) and normal detector operations, and 2) A "heavy" snow plan with 30 percent speed reductions and recalls on all phases to ensure that all phases are serviced when either a) weather impacts to the vehicle detectors may cause problems or b) the striping is not clearly visible. Below is a summary of each signal timing strategy:

*Light Adverse Weather Signal Timing Plan*

a. Will not use any recalls (except the arterial phases which are normally on a min recall).
b. Same cycle length & splits currently in use by the normal TOD plan.
c. Initial offsets (from fine-tuned normal TOD plans) are designed for a 30 percent reduction in free-flow speed.

*Heavy Adverse Weather Signal Timing Plan*

a. All non-arterial phases are placed on recall to ensure service to the cross-streets.
b. Same cycle length & splits currently in use by the normal TOD plan.
c. Initial offsets (from fine-tuned normal TOD plans) are designed for a 30 percent reduction in free-flow speed.

Over the years, UDOT has not had the systems or technologies to verify the effectiveness of the previous snow plans.

## Project Deployment

See ConOps

# Evaluation Approach

The purpose of the evaluation is to assess the effectiveness of the system to allow UDOT to better manage traffic signal operations in the corridor during weather events. By collecting data on how UDOT operators used the system during multiple weather events, UDOT plans to demonstrate how the system can be used to proactively manage traffic signal operations during inclement weather conditions, with the goal of achieving the best level of performance during inclement weather conditions as conditions permit. The evaluation is structured to answer the following evaluation questions:

- How did the weather-responsive traffic signal system in the Riverdale corridor improve UDOT's ability respond to different inclement weather conditions?
- By using the system, was UDOT able to maintain a high quality of progression on Riverdale Road during inclement weather?
- Was UDOT able to maintain throughput and reduce delays on the corridor during different types of weather conditions?
- Was UDOT able to maintain equitable service to the cross-streets during different weather conditions in the corridor?

Table B-1 identifies the operational objectives and evaluation questions that will be examined during the project evaluation. Table B-1 also identifies the measures of effectiveness (MOEs), analysis methods, and data that will be used to perform the evaluation. Note that equitable service to the cross-streets is included as an objective but will not be evaluated as part of this plan because traffic and performance data on the cross-streets are not available.

## Descriptive Information

At the conclusion of the evaluation period, UDOT will generate standard distributive statistics that will be used to quantify how often weather responsive signal timing plans were deployed in the corridor and under what circumstances the timing plans were deployed and/or changed. Throughout the duration of the evaluation period, UDOT will keep a log of events related to the use of the system during events. This log will include information about the event (e.g., type of event, magnitude of the event, impact of the event on operations, duration of the event, etc.) and the traffic management decisions made during the event (i.e., the different timing strategies deployed during the event, the duration the strategies were in effect, etc.). The data that will be used to generate the statistics includes the following:

- The predicted and actual start and duration times of the weather event.
- The type of events (snowfall, rain, ice, fog, wind, etc.).
- The predicted and actual severity of the event and impacts on the road weather conditions.
- The planned and actual weather responsive traffic signal timing plans implemented

**Table B-1. Evaluation Approach.**

| Operational Objective | Evaluation Question | Measures of Effectiveness (MOE) | Evaluation Method | Data Source |
|---|---|---|---|---|
| 5. Improve UDOT's ability to manage traffic signal operations during inclement weather | 5.1. How did the weather-responsive traffic signal system in the Riverdale corridor improve UDOT's ability to respond to different inclement weather conditions? | Are the timing plans sensible and workable from the operator's perspective? | Operator Assessments/ Interview | UDOT Signal Desk Operator |
| | | Are the timing plans responsive to various weather events observed in the corridor? | Operator Assessments/ Interview | UDOT Signal Desk Operator |
| | | Did the implementation of the system reduce agency resource requirements? (e.g. staff hours to view cameras or check field conditions) | Operator Assessments/ Interview | UDOT Signal Desk Operator |
| | | Rating of operations during weather event | Operator Assessments | UDOT Signal Desk Operator |
| 6. Maintain Quality of Progression | 2.1 By using the system, was UDOT able to maintain a high quality of progression on Riverdale Road during inclement weather? | Percentage of Vehicles Arriving on Green (AoG) | Calculate AoG for each intersection and compare with threshold | Purdue Coordination Diagram |
| | | Platoon Ratio | Calculate Platoon ratio for each intersection and compare with HCM thresholds | Purdue Coordination Diagram |
| | | Average Link speed during inclement weather / Standard Deviation of Link Speed | Compare link speed averages and standard deviations with and without weather events. | Wavetronic sensors |
| 7. Maintain Throughput and Reduce Delay | 3.1 Was UDOT able to maximize performance of the signal system during different types of weather conditions in the corridor? | System Delay | Compare System delay with and without WRTM Timing plans | TrEPS Model |
| | | System Throughput | Compare system throughput with and without WRTM timing plans | TrEPS Model |

| Operational Objective | Evaluation Question | Measures of Effectiveness (MOE) | Evaluation Method | Data Source |
|---|---|---|---|---|
| 8. Maintain Equitable Service | 4.1 Was UDOT able to maintain equitable service to the cross-streets during different weather conditions in the corridor? | Not Evaluated in this Deployment (See Note below) | Not Evaluated in this Deployment | Not Evaluated in this Deployment |

Source: Battelle/TTI

Note: As part of this deployment the cycle length, splits and timing parameters (i.e. min green, passage, yellow, red, max green) were left the same for both normal and weather conditions. UDOT believes that equitable service is being maintained as a result of these constraints.

These data will be used to produce the following descriptive statistics related to deployment and performance of the system:

- Number of inclement weather events
- Number of WRTM signal timing plans implemented
- Average duration of weather events
- Average duration WRTM timing plan in effect
- Number of times the traffic signal timing plans were modified throughout the duration of the event

In addition to this information, UDOT signal system operators will provide a short descriptive narrative after each storm event that describes the event, event timing, and UDOT responses during different phases of the event. This will be integrated into the event analysis and evaluation report.

## Operational Objective #1: Improve Management of Traffic Signal Operations

One reason for evaluating this deployment is to assess the degree to which the system can assist UDOT in making better, more informed decisions about how to manage and operate their traffic signal systems during weather events. The system provides feedback to TMC and traffic signal system operators that lets them identify, through post-event evaluation and in real-time, improvements to deployed traffic management strategies. UDOT plans to use information obtained from the system to continuously improve and fine-tune their traffic signal timing responses to different weather events.

***Evaluation Approach***

UDOT's approach for evaluating the benefits of the system on improving their ability to better manage traffic signal operations is largely subjective At the conclusion of the winter season, UDOT Signal System operators will be interviewed to obtain their opinions as to the extent to which the deployed system allowed UDOT to better operate the traffic signals in the corridor. The intent of this survey is to document 1) how UDOT utilized the system in making/modifying signal timing plan changes in the corridor throughout the course of the evaluation period, and 2) the opinions of system operators as to the general effectiveness of the weather responsive traffic signal timing plans to improve operations in the corridor.

Operator logs will also be used to examine how UDOT used the systems deployed as part of this project to better manage the traffic signal systems. The operator logs will be examined to determine what type of changes UDOT made to the traffic signal timing plans and why these changes were made. UDOT signal system operators will be asked to describe the processes and reasoning associated with making these changes and to describe how their weather responsive operating goals and objectives changed as a result of having the deployed technologies in the corridor.

After each event, UDOT traffic signal system operators will be asked to subjectively rate the effectiveness of the performance of the weather responsive timing plans for each event using the following form:

**Table B-2. Subjective Evaluation of Weather Signal Timing Response.**

| Event Date and Time: | Event Type: | Evaluator: |
|---|---|---|
| | | |

| Factor to Consider in Rating Weather Plan Effectiveness | Yes | No |
|---|---|---|
| Was the start time of the signal timing response appropriate? | ☐ | ☐ |
| Was the end time of the signal timing response appropriate? | ☐ | ☐ |
| Did a significant speed reduction (7-10 mph) occur in the corridor as a result of the weather? | ☐ | ☐ |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | ☐ | ☐ |
| Were the deployed timing plans sensible and workable for the event? | ☐ | ☐ |
| Were the deployed timing plans responsive to various weather events observed in the corridor? | ☐ | ☐ |
| Did the implementation of the system reduce agency resource requirements? (e.g. staff hours to view cameras or check field conditions) | ☐ | ☐ |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | ☐ | ☐ |
| How would you rate the overall operation of the weather responsive signal timing plan(s) for this event?<br>☐ No Improvement ☐ Little Improvement ☐ Average Improvement ☐ Above average improvement ☐ Major Improvement | | |
| Please Provide Detailed Comments on the Responses Above: | | |

Source: Utah Department of Transportation

UDOT signal system operators will use a variety of inputs in making their score assessments. These include using the CCTV cameras deployed along the corridor, the Purdue Coordination Diagrams (PCDs) and the speed profiles after the event, comments from field personnel, and their expert knowledge of signal operations. The subjective evaluation will also assist UDOT in making decisions on how to improve the operations along the corridor.

## Operational Objective #2: Maintain Quality of Progression

The primary objective in deploying the Wx-SIG system in the Riverdale corridor is to assist UDOT in making traffic signal timing decisions that result in the best possible level of traffic signal operation during inclement weather events. Inclement weather conditions are expected to reduce travel speeds and change travel demands to the point where UDOT will need to deploy special traffic signal timing strategies in order to maintain a progression in the corridor. UDOT's performance objective for their deployed weather responsive traffic signal timing plans is to maintain the same level of progression and signal efficiency during inclement weather conditions as they do using traditional time-of-day timing plans during normal (non-inclement) weather conditions.

***Evaluation Approach***

In this evaluation, quality of progression measures of weather responsive traffic signal timing plans will be compared to quality of progression measures of normal time-of-day control non-inclement weather conditions. UDOT plans to use two measures of effectiveness to assess the quality of progression*:* Percent Arrival on Green (AoG) and Platoon Ratio ($R_P$).

Percent arrival on green is the proportion of vehicles traveling on the main street, or on coordinated approaches, arriving when the traffic signal indication is green, with the percentage showing the percent of vehicles arriving during the green phase. A high AoG value (i.e., greater than 0.5) is an indication of good progression, while a low AoG value indicates poor signal progression (i.e., the majority of the main street traffic is arriving when the traffic signal is displaying a red indication).

The 2000 *Highway Capacity Manual (HCM)* suggests Platoon Ratio ($R_P$) as a measure to assess the quality of progression. It is the ratio of percentage of vehicle arriving on green to the green split allocated to that phase. The *HCM* uses the following table to rate the quality of progression using computed $R_P$ values:

| Range of Platoon Ratio ($R_P$) | Progression Quality |
|---|---|
| ≤ 0.50 | Very Poor |
| > 0.50 – 0.85 | Unfavorable |
| > 0.85 – 1.15 | Random Arrivals |
| > 1.15 – 1.50 | Favorable |
| > 1.50 – 2.00 | Highly Favorable |
| > 2.00 | Exceptional |

The goal of UDOT's Wx-SIG system deployment is to maintain a "favorable" or higher rating during significant weather events.

As part of the deployment, UDOT is implementing technology that automatically generates these two performance measures via Purdue Coordination Diagrams (PCD). The PCD automatically generates AoG and $R_P$ values for each active timing plan. A PCD will be produced for each of the 11 intersections located in the deployment corridor

After each event, a PCD will be generated for each intersection for the duration of the event. The AoG and $R_P$ associated with each weather responsive timing plan deployed during the event will be extracted from the diagrams for the duration of the event. These values will be compared to AoG and $R_P$ values produced by timing plans deployed during typical, non-inclement weather timing plan for a similar duration.

In addition, UDOT will compute an aggregate, corridor-wide AoG and $R_P$ for the duration of the event by combining individual AoG and $R_P$ values from each intersection. Similar corridor-wide values will be produced for non-inclement weather conditions.

## Operational Objective #3: Maintain Throughput and Reduce Delay

Throughput is defined as the number of vehicles served in a corridor under a given set of conditions. One of the purposes of UDOT's Weather Responsive Traffic Signal Deployment is to ensure that the traffic signal timing plans deployed in the corridor maintain a high quality of service to the main-street, regardless of the severity of the weather event.

### *Evaluation Approach*

The Traffic Estimation and Prediction System (TrEPS) will be used to compare the effectiveness of the WRTM traffic signal timing plans during weather events. Following each weather event, traffic volume and speed data collected by the systems will be used to compare the throughput and delays in the Riverdale corridor with and without the weather responsive traffic signal timing plans in place. In this analysis, corridor throughput and delays with the weather responsive timing plans in place will be compared to the corridor throughput that results when the normal, time-of-day traffic signal timing plan is used in place of the weather responsive one. Because only the traffic signal timing will be different between the two cases, the difference in the corridor throughput and delays would be directly attributable to the use of the different timing plans. UDOT expects the corridor throughput to be at least the same (if not higher) using the weather responsive timing plans compared to corridor throughput/delays achieved under the deteriorated weather conditions using normal traffic signal timing plans designed assuming ideal weather conditions.

## Data Sources

In addition to manual logs, UDOT has recently implemented several systems to automatically collect performance measures for traffic signals and has partnered with Dr. Darcy Bullock of Purdue University and James Sturdevant of Indiana DOT. UDOT joined a pooled fund study titled, "Traffic Signal Systems Operations and Management" with the FHWA (Richard Denney as the FHWA technical liaison). Ten other agencies are involved in this pooled fund study (City of Chicago, CA, GA, KS, MN, MS, NH, TX, UT, WisDOT). These systems automatically collect data and generate the following performance measures that can be used to assess the effectiveness of the weather responsive traffic signal timing plans during inclement weather and will allow UDOT to go through an iterative process to fine-tune the coordination offsets in an attempt to optimize mainstream throughput. The system will allow UDOT to generate the traffic signal performance metrics at each intersection:

- A volume report showing the total approach volume measured on the main street at each intersection for each hour of the day,
- A speed profile showing the average, 85th percentile, and standard deviation of the speed of traffic on the main street approaches for each hour in the day.
- The Purdue Coordination Diagram showing the percentage of main street traffic arriving during the green indication, the percentage to green split time allocated to the main street through traffic, and the platoon ratio associated with each timing plan deployed throughout the day.

Examples of the UDOT Signal Performance Metrics can be found at the following website http://udottraffic.utah.gov/signalperformancemetrics/.

# Challenges and Constraints

UDOT has identified the several challenges and constraints associated with evaluating the effectiveness of the system. These challenges and constraints are shown in Table B-3.

**Table B-3. Challenges and Constraints Associated with Evaluating UDOT Initial Deployment of Weather Responsive Traffic Signal Timing Strategies.**

| Challenge / Constraint | Mitigation Strategy |
|---|---|
| Too few storms or too mild of winter to yield adequate data for the evaluation | The analysis can possibly be carried over into winter of 2013/2014. |
| Variability in storminess from month to month or season to season may make it difficult in establishing a bench mark and comparisons of storms. | The severity index and operator assessment of performance will help identify variability of storms. Also, the overall goal is to match normal conditions as much as possible with % of vehicle arriving on green. |
| Automatic Performance Metrics may not work, stop recording data or data coming back may be delayed for weeks. | By January 15th, 2013, UDOT software engineers will finish taking measures in stabilizing the data which will improve the data reliability. Steps will include installing a new and faster server, re-writing the translator system and prioritizing the intersections bringing back data. In addition, the day before large storms are forecasted, checks can be made to ensure that the automatic performance measures are working properly. |
| Split monitor in Siemens i2 system may not work as designed or may not record data. | Data is not as critical for analysis, due to split percentages being held constant. A check will be made the day before to make sure split monitor is turned on. |
| Adverse weather signal timing plans may not get implemented for the storm. | A reminder will be set the day before the anticipated event to schedule adverse weather signal timing plans. |
| Equipment (RWIS & radar) may not get implemented until too late in the season. | UDOT is moving as quick as possible through the procurement process to get the equipment installed. Backup plan is to use the existing locations at 1050 W, 700 W & 550 W for data collection. MesoWest locations for RWIS will be sought in the area if RWIS not installed. |

Source: Utah Department of Transportation

# Appendix C.

# Summary of Weather Events

| Event Date and Time: | Event Type: | Evaluator: |
|---|---|---|
| January 10, 2013 | Road Snow, Low Visibility, Bridge Ice | Mark Taylor, UDOT |

| Factor to Consider in Rating Weather Plan Effectiveness | Yes | No |
|---|---|---|
| Was the start time of the signal timing response appropriate? | X | □ |
| Was the end time of the signal timing response appropriate? | X | □ |
| Did a significant speed reduction (7-10 mph) occur in the corridor as a result of the weather? | X | □ |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | X | □ |
| Were the deployed timing plans sensible and workable for the event? | X | □ |
| Were the deployed timing plans responsive to various weather events observed in the corridor? | X | □ |
| Did the implementation of the system reduce agency resource requirements? (e.g. staff hours to view cameras or check field conditions) | X | □ |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | X | □ |

How would you rate the overall operation of the weather responsive signal timing plan(s) for this event?

□ No Improvement
□ Little Improvement
X Average Improvement
□ Above average improvement
□ Major Improvement

Comments:

This was a significant snow storm that dropped 20+ inches of snow over a 40 hour continuous period. The main benefits of the plans were the recalls implemented.

Forecast: 01-10-13 10:32 AM:

Heavy snow, road and low visibility from 15-2200 THU, then improving conditions

| **Event Date and Time:** | **Event Type:** | **Evaluator:** |
|---|---|---|
| January 11, 2013 | Road Snow, Low Visibility, Bridge Ice | Mark Taylor, UDOT |

| **Factor to Consider in Rating Weather Plan Effectiveness** | **Yes** | **No** |
|---|---|---|
| Was the start time of the signal timing response appropriate? | X | □ |
| Was the end time of the signal timing response appropriate? | X | □ |
| Did a significant speed reduction (7-10 mph) occur in the corridor as a result of the weather? | X | □ |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | X | □ |
| Were the deployed timing plans sensible and workable for the event? | X | □ |
| Were the deployed timing plans responsive to various weather events observed in the corridor? | X | □ |
| Did the implementation of the system reduce agency resource requirements? (e.g. staff hours to view cameras or check field conditions) | X | □ |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | X | □ |

How would you rate the overall operation of the weather responsive signal timing plan(s) for this event?

□ No Improvement　□ Little Improvement　X Average Improvement
□ Above average improvement　□ Major Improvement

Comments:

This was a significant snow storm that dropped 20+ inches of snow over a 40 hour continuous period. The main benefits of the plans were the recalls implemented.

| **Event Date and Time:** January 12, 2013 | **Event Type:** Road Snow | **Evaluator:** Mark Taylor, UDOT |
|---|---|---|

| **Factor to Consider in Rating Weather Plan Effectiveness** | **Yes** | **No** |
|---|---|---|
| Was the start time of the signal timing response appropriate? | □ | X |
| Was the end time of the signal timing response appropriate? | X | □ |
| Did a significant speed reduction (7-10 mph) occur in the corridor as a result of the weather? | X | □ |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | X | □ |
| Were the deployed timing plans sensible and workable for the event? | X | □ |
| Were the deployed timing plans responsive to various weather events observed in the corridor? | X | □ |
| Did the implementation of the system reduce agency resource requirements? (e.g. staff hours to view cameras or check field conditions) | X | □ |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | X | □ |

How would you rate the overall operation of the weather responsive signal timing plan(s) for this event?

□ No Improvement　□ Little Improvement　□ Average Improvement
X Above average improvement　□ Major Improvement

Comments:

This was a significant snow storm that dropped 20+ inches of snow over a 40 hour continuous period. The main benefits of the plans were the recalls implemented.

The plans did not start on-time (were not turned on until 11:00). They should have been started earlier.

| **Event Date and Time:** January 24, 2013 | **Event Type:** Freezing Rain | **Evaluator:** Mark Taylor, UDOT |
|---|---|---|

| **Factor to Consider in Rating Weather Plan Effectiveness** | **Yes** | **No** |
|---|---|---|
| Was the start time of the signal timing response appropriate? | X | □ |
| Was the end time of the signal timing response appropriate? | X | □ |
| Did a significant speed reduction (7-10 mph) occur in the corridor as a result of the weather? | X | □ |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | X | □ |
| Were the deployed timing plans sensible and workable for the event? | X | □ |
| Were the deployed timing plans responsive to various weather events observed in the corridor? | X | □ |
| Did the implementation of the system reduce agency resource requirements? (e.g. staff hours to view cameras or check field conditions) | X | □ |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | X | □ |

How would you rate the overall operation of the weather responsive signal timing plan(s) for this event?

□ No Improvement □ Little Improvement □ Average Improvement
X Above average improvement □ Major Improvement

Comments:

Forecast: 01-23-13 1:21 PM:

Snow with road snow may change over to rain with ice concerns through 1000, wet roads after.

This was a significant freezing rain storm (largest received in Utah in a decade).

| **Event Date and Time:** January 26, 2013 | **Event Type:** Fog | **Evaluator:** Mark Taylor, UDOT |
|---|---|---|

| **Factor to Consider in Rating Weather Plan Effectiveness** | **Yes** | **No** |
|---|---|---|
| Was the start time of the signal timing response appropriate? | □ | X |
| Was the end time of the signal timing response appropriate? | X | □ |
| Did a significant speed reduction (7-10 mph) occur in the corridor as a result of the weather? | □ | X |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | □ | X |
| Were the deployed timing plans sensible and workable for the event? | X | □ |
| Were the deployed timing plans responsive to various weather events observed in the corridor? | □ | X |
| Did the implementation of the system reduce agency resource requirements? (e.g. staff hours to view cameras or check field conditions) | X | □ |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | □ | X |

How would you rate the overall operation of the weather responsive signal timing plan(s) for this event?

X No Improvement □ Little Improvement □ Average Improvement
□ Above average improvement □ Major Improvement

Comments:

This was a fog event and weather plans were not scheduled to run. The evening of Saturday, January 26th, the traffic signal maintenance supervisor called me on my cell phone stating that two intersections that use video detection are not cycling and vehicles are stuck. So, I immediately contacted the TOC operators and had them run the minimum recall weather plans for the corridor for just the benefit of the recalls only. The downside is that the plans we ran have offset adjustments for speed reductions that did not occur with this event.

Forecast: 01-25-13 10:51 AM: Areas of fog re-develop after 7-8pm, and could become dense once again. Fog lifts by 9-10am SAT.

Forecast: 01-26-13 10:58 AM: Fog is dense through 12-1pm. Some improvement in visibility after 1pm, then dense fog again after 7-8pm. Few rain showers 6-11pm SAT, and after 11am SUN

| **Event Date and Time:** January 28, 2013 | **Event Type:** Moderate to Heavy Snow | **Evaluator:** Mark Taylor, UDOT |
|---|---|---|

| **Factor to Consider in Rating Weather Plan Effectiveness** | **Yes** | **No** |
|---|---|---|
| Was the start time of the signal timing response appropriate? | X | □ |
| Was the end time of the signal timing response appropriate? | X | □ |
| Did a significant speed reduction (7-10 mph) occur in the corridor as a result of the weather? | X | □ |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | X | □ |
| Were the deployed timing plans sensible and workable for the event? | X | □ |
| Were the deployed timing plans responsive to various weather events observed in the corridor? | X | □ |
| Did the implementation of the system reduce agency resource requirements? (e.g. staff hours to view cameras or check field conditions) | X | □ |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | X | □ |

How would you rate the overall operation of the weather responsive signal timing plan(s) for this event?

□ No Improvement □ Little Improvement □ Average Improvement
X Above average improvement □ Major Improvement

Comments:

Storm started Sun January 27th at noon and ended Monday January 28th at 11:00 AM.

Forecast: 01-27-13 10:48 AM -

Snow develops around 12pm, possibly mixed with rain to start. Road snow by 1-2pm. 4-5" Road Snow expected through 6pm, then snow showers through 12am.

Forecast: 01-28-13 10:22 AM –

Another round of snow moves in just before the morning commute and continues moderate to occasionally heavy through the morning. Light snow continues through the afternoon into the evening before slowly diminishing.

| Event Date and Time: January 29, 2012 | Event Type: Light to Moderate Snow | Evaluator: Mark Taylor, UDOT |
|---|---|---|

| Factor to Consider in Rating Weather Plan Effectiveness | Yes | No |
|---|---|---|
| Was the start time of the signal timing response appropriate? | X | □ |
| Was the end time of the signal timing response appropriate? | X | □ |
| Did a significant speed reduction (7-10 mph) occur in the corridor as a result of the weather? | X | □ |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | X | □ |
| Were the deployed timing plans sensible and workable for the event? | X | □ |
| Were the deployed timing plans responsive to various weather events observed in the corridor? | X | □ |
| Did the implementation of the system reduce agency resource requirements? (e.g. staff hours to view cameras or check field conditions) | X | □ |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | X | □ |

How would you rate the overall operation of the weather responsive signal timing plan(s) for this event?

□ No Improvement □ Little Improvement □ Average Improvement
X Above average improvement □ Major Improvement

Comments:

Forecast: 1-29-13 8:49 AM -

Snow showers continue today, heaviest before 1500. Light snow will continue all night and through the day on Wednesday as well. Steady light accumulations continue through the period after 1500.

| **Event Date and Time:** | **Event Type:** | **Evaluator:** |
|---|---|---|
| February 4, 2013 | Low Visibility - Fog | Mark Taylor, UDOT |

| **Factor to Consider in Rating Weather Plan Effectiveness** | **Yes** | **No** |
|---|---|---|
| Was the start time of the signal timing response appropriate? | □ | X |
| Was the end time of the signal timing response appropriate? | □ | X |
| Did a significant speed reduction (7-10 mph) occur in the corridor as a result of the weather? | □ | X |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | □ | X |
| Were the deployed timing plans sensible and workable for the event? | □ | X |
| Were the deployed timing plans responsive to various weather events observed in the corridor? | □ | X |
| Did the implementation of the system reduce agency resource requirements? (e.g. staff hours to view cameras or check field conditions) | □ | X |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | □ | X |

How would you rate the overall operation of the weather responsive signal timing plan(s) for this event?

X No Improvement □ Little Improvement □ Average Improvement
□ Above average improvement □ Major Improvement

Comments:

Fog. The visibility on the morning of February 4th seemed to be good enough as to not affect speeds along the corridor. I checked the CCTV's this morning at 7:00 AM and also checked the speed performance measures. I decided to leave the AM plans in for comparison under dry conditions with the weather plans running for comparison before/after.

Forecast: 02-03-13 10:51 AM:

Dry conditions continue. Fog is expected to develop again after 2000 SUN, becoming dense at times 2200 SUN through 1000 MON.

Forecast: 02-04-13 11:19 AM:

Dry conditions continue. Fog re-develops again after 1900 MON, becoming very dense at times 2000 MON through 0900 TUE

| **Event Date and Time:** February 7, 2013 | **Event Type:** Light Snow | **Evaluator:** Mark Taylor, UDOT |
|---|---|---|

| **Factor to Consider in Rating Weather Plan Effectiveness** | **Yes** | **No** |
|---|---|---|
| Was the start time of the signal timing response appropriate? | X | □ |
| Was the end time of the signal timing response appropriate? | X | □ |
| Did a significant speed reduction (7-10 mph) occur in the corridor as a result of the weather? | □ | X |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | □ | X |
| Were the deployed timing plans sensible and workable for the event? | X | □ |
| Were the deployed timing plans responsive to various weather events observed in the corridor? | X | □ |
| Did the implementation of the system reduce agency resource requirements? (e.g. staff hours to view cameras or check field conditions) | □ | X |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | □ | X |

How would you rate the overall operation of the weather responsive signal timing plan(s) for this event?

X No Improvement □ Little Improvement □ Average Improvement
□ Above average improvement □ Major Improvement

Comments:

Forecast 02-06-13 2:28 PM:

Dry overnight with light snow showers developing after 1000 then continue through the day. No major impacts before 1200.

| **Event Date and Time:** February 8, 2013 | **Event Type:** Light to Moderate Snow | **Evaluator:** Mark Taylor, UDOT |
|---|---|---|

| **Factor to Consider in Rating Weather Plan Effectiveness** | **Yes** | **No** |
|---|---|---|
| Was the start time of the signal timing response appropriate? | X | □ |
| Was the end time of the signal timing response appropriate? | X | □ |
| Did a significant speed reduction (7-10 mph) occur in the corridor as a result of the weather? | X | □ |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | X | □ |
| Were the deployed timing plans sensible and workable for the event? | X | □ |
| Were the deployed timing plans responsive to various weather events observed in the corridor? | X | □ |
| Did the implementation of the system reduce agency resource requirements? (e.g. staff hours to view cameras or check field conditions) | X | □ |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | X | □ |

How would you rate the overall operation of the weather responsive signal timing plan(s) for this event?

□ No Improvement □ Little Improvement □ Average Improvement
X Above average improvement □ Major Improvement

Comments:

Forecast: 02—8-13 11:08 AM -

Snow showers develop after 1300/1400 FRI, with heaviest snow expected from 1600/1700 FRI through 2100/2200 FRI, then decreasing to much lighter snow showers.

| Event Date and Time: | Event Type: | Evaluator: |
|---|---|---|
| February 21, 2013 | Light Snow | Mark Taylor, UDOT |

| Factor to Consider in Rating Weather Plan Effectiveness | Yes | No |
|---|---|---|
| Was the start time of the signal timing response appropriate? | X | □ |
| Was the end time of the signal timing response appropriate? | X | □ |
| Did a significant speed reduction (7-10 mph) occur in the corridor as a result of the weather? | □ | X |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | □ | X |
| Were the deployed timing plans sensible and workable for the event? | X | □ |
| Were the deployed timing plans responsive to various weather events observed in the corridor? | X | □ |
| Did the implementation of the system reduce agency resource requirements? (e.g. staff hours to view cameras or check field conditions) | □ | X |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | □ | X |

How would you rate the overall operation of the weather responsive signal timing plan(s) for this event?

X No Improvement
□ Little Improvement
□ Average Improvement
□ Above average improvement
□ Major Improvement

Comments:

| **Event Date and Time:** February 22, 2013 | **Event Type:** Light Snow | **Evaluator:** Mark Taylor, UDOT |
|---|---|---|

| **Factor to Consider in Rating Weather Plan Effectiveness** | **Yes** | **No** |
|---|---|---|
| Was the start time of the signal timing response appropriate? | X | ☐ |
| Was the end time of the signal timing response appropriate? | X | ☐ |
| Did a significant speed reduction (7-10 mph) occur in the corridor as a result of the weather? | ☐ | X |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | ☐ | X |
| Were the deployed timing plans sensible and workable for the event? | X | ☐ |
| Were the deployed timing plans responsive to various weather events observed in the corridor? | X | ☐ |
| Did the implementation of the system reduce agency resource requirements? (e.g. staff hours to view cameras or check field conditions) | ☐ | X |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | ☐ | X |

How would you rate the overall operation of the weather responsive signal timing plan(s) for this event?

X No Improvement ☐ Little Improvement ☐ Average Improvement
☐ Above average improvement ☐ Major Improvement

Comments:

Forecast 02-21-13 2:16 PM: Flurry threat 0400-1000 with trace road snow.

Forecast 022213 10:53 AM: Snow showers develop after 0200-0300 SAT with light road snow…band of moderate to heavy snow 0700-0900/1000 SAT with snow sticking to signal heads

| **Event Date and Time:** | **Event Type:** | **Evaluator:** |
|---|---|---|
| February 23, 2013 | Moderate to Briefly Heavy Snow | Mark Taylor, UDOT |

| **Factor to Consider in Rating Weather Plan Effectiveness** | **Yes** | **No** |
|---|---|---|
| Was the start time of the signal timing response appropriate? | X | □ |
| Was the end time of the signal timing response appropriate? | X | □ |
| Did a significant speed reduction (7-10 mph) occur in the corridor as a result of the weather? | X | □ |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | X | □ |
| Were the deployed timing plans sensible and workable for the event? | X | □ |
| Were the deployed timing plans responsive to various weather events observed in the corridor? | X | □ |
| Did the implementation of the system reduce agency resource requirements? (e.g. staff hours to view cameras or check field conditions) | X | □ |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | X | □ |

How would you rate the overall operation of the weather responsive signal timing plan(s) for this event?

□ No Improvement □ Little Improvement □ Average Improvement
X Above average improvement □ Major Improvement

Comments:

Forecast 02-23-13 10:07 AM: Heaviest snow will be ending around 11:30am with roads trending slushy this afternoon. Some very light road snow possible this evening, but minimal impacts

| **Event Date and Time:** March 21, 2013 | **Event Type:** Before / After Comparison | **Evaluator:** Mark Taylor, UDOT |
|---|---|---|

| **Factor to Consider in Rating Weather Plan Effectiveness** | **Yes** | **No** |
|---|---|---|
| Was the start time of the signal timing response appropriate? | □ | X |
| Was the end time of the signal timing response appropriate? | □ | X |
| Did a significant speed reduction (7-10 mph) occur in the corridor as a result of the weather? | □ | X |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | □ | X |
| Were the deployed timing plans sensible and workable for the event? | □ | X |
| Were the deployed timing plans responsive to various weather events observed in the corridor? | □ | X |
| Did the implementation of the system reduce agency resource requirements? (e.g. staff hours to view cameras or check field conditions) | □ | X |
| Do you think the intensity of the storm warranted the used of weather responsive signal timing plans? | □ | X |

How would you rate the overall operation of the weather responsive signal timing plan(s) for this event?

X No Improvement □ Little Improvement □ Average Improvement
□ Above average improvement □ Major Improvement

Comments:

Forecast: 03-21-13 3:49 PM: Scattered snow showers moderate at times through the day with plenty of dry time in between. Roads are mainly wet with any shower.

Pavement was dry for the most part. Ran plans for a before /after comparison.

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