DEPLOYING WEATHER RESPONSIVE TRAFFIC SIGNAL OPERATIONS IN UTAH.

Kevin Balke (Principal and Corresponding Author)  
Research Engineer  
Texas A&M Transportation Institute  
The Texas A&M University System  
MS 3115  
College Station, TX  77843-3135  
k-balke@tamu.edu  
Phone: (979)845-9899  
Fax: (979)845-9873

Mark Taylor  
Traffic Signal Operations Engineer  
Utah Department of Transportation  
marktaylor@utah.gov  
Phone: (801)887-3714

Deepak Gopalakrishna  
Program Manager  
Battelle gopalakrishnad@battelle.org  
Phone: (202) 479-9645

Roemer Alfelor  
Program Manager, Weather Responsive Traffic Management  
Federal Highway Administration  
US Department of Transportation  
Roemer.Alfelor@dot.gov  
Phone: (202) 366-9242

Submitted for Considerations for Presentation and Publication at the  
93rd Annual Meeting of the  
Transportation Research Board  
Washington, D.C.  
January 12-16, 2014

Submitted: July 31, 2013

Word Count: 5724 + 750 (3X250) Figures + 1000 (4X250) Tables = 7469
ABSTRACT

Proactive management of traffic signal operations during weather events remains a priority with the Utah Department of Transportation (UDOT). With the assistance of the Federal Highway Administration’s (FHWA) Road Weather Management Program (RWMP), UDOT recently deployed an advanced concept of traffic signal operations during weather events (WX-SIG). The concept relies upon systems, tools, and technologies to measure and forecast roadway weather conditions and traffic signal performance during inclement weather to fine-tune traffic signal timing responses throughout the duration of the event. UDOT meteorologists and traffic signal operators use these systems to assess current traffic conditions and determine when and how to deploy special weather responsive traffic signal timing plans. UDOT traffic signal operators use system performance monitoring tools, such as Purdue Coordination Diagrams and real-time corridor speed measures, to assess the effectiveness of special weather responsive signal timing plans and to make fine-tuning adjustments in signal timing strategies. This paper provides a description of the tools and technologies developed and deployed by UDOT to assist in developing proactive traffic signal timing responses to weather events, the standard operating procedures used by UDOT operators to decide when, where, why, and how to implement weather traffic signal timing responses. This paper also provides some results of an assessment of the effectiveness of these initial responses during the winter of 2013. The paper also contains lessons learned from this initial deployment related to the deployment corridor itself as well as weather responsive traffic signal operations in general.
INTRODUCTION
The Utah Department of Transportation (UDOT) has implemented special traffic signal timing plans on several arterials to minimize stops and delays during severe winter weather events for years; however, UDOT has had no mechanism in monitoring or fine-tuning the effectiveness of the special timing plans. With assistance from Purdue University and Indiana Department of Transportation, UDOT recently installed a new traffic signal performance monitoring system that collects cycle-by-cycle statistics at many intersections in Utah, including the Riverdale Road corridor in Ogden. As of August 1, 2013, UDOT and its city partners have installed the automatic performance measures at 755 of the 1860 intersections in Utah (with more being added each month). Through this project, UDOT is examining how the using this system, coupled with new technologies that were deployed as part of this project, can be used for better monitoring and operating of traffic signals during significant weather events in the corridor.

UDOT’s goal is to allow traffic signal operators to anticipate when weather conditions have deteriorated to the point of impacting travel speeds in the corridor and allowing the operators to deploy traffic signal timing plans that best match the prevailing travel conditions in the corridor. By having traffic signal timing plans that better match the prevailing travel conditions in the corridor, UDOT can achieve the following operational objectives:

- 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.

BACKGROUND
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 and potentially control strategies based on forecasts of weather conditions, and not just the results of those conditions.

In 2011, the RWMP initiated a project to collate 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 deployment is based on FHWA’s Weather Responsive Signal Management (WX-SIG) concept of operation (1). In the WX-SIG ConOps, information about roadway surface and weather conditions is used in real-time to determine when, why, and how to change traffic signal timing and intersection detector settings to improve traffic flow and safety during inclement weather conditions. These new settings would be sensitive to the changes in vehicle operating characteristics caused by adverse weather. The vision is to use these strategies to better match signal timing plans and parameters to the prevailing travel conditions to promote more efficient traffic operations and reduce the potential of some weather-related vehicle crashes.
PROJECT IMPLEMENTATION

UDOT’s initial deployment of WX-SIG Concept was in the Riverdale Road corridor in Ogden, Utah. UDOT selected the Riverdale Rd corridor for this initial deployment because of the high degree of instrumentation that already exists in the 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 1 shows the traffic signals that are included as part of this initial deployment.

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

Figure 1  Site Map of Riverdale Road Wx-SIG Deployment

SYSTEM COMPONENTS

The system uses information about travel speed in the corridor coupled with road condition information from roadway weather information system (RWIS) stations and signal performance data from UDOT’s traffic signal monitoring system to make decisions as to when different weather-responsive traffic signal timing plans should be implemented in the corridor by operators in the TMC. The following provides a brief description of some of the major system components.
Weather Monitoring Station
UDOT procured, installed and integrated a RWIS station directly in the corridor. This station provided UDOT Meteorologist and TMC operators with information on road temperature, road surface, precipitation detection and accumulation, soil temperature up to 18 inches from the surface, visibility sensor, incoming solar radiation, 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. Secondly, 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 so as to provide greater detection capabilities over the previously deployed video detection systems. Because the sensors monitor individual vehicles as they approach the intersection, the SmartSensor Advance were selected to provide increased dilemma zone protection, approach speeds, approach volume counts as well as increased intersection efficiency. Data from these sensors were used to assist in generating the Purdue Coordination Diagrams (PCD) and in capturing approach volumes and speeds throughout the corridor.

UDOT's Signal Performance Metrics System
In conjunction with this deployment, UDOT is developing and deploying their Signal Performance Metrics System (2). 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 different traffic signal timing plans and to identify necessary changes in traffic signal timing plans for future events. Through a web interface (http://udottraffic.utah.gov/signalperformancemetrics/), operators are able to access the following tools and data to assist them in making their evaluations:
- Purdue Coordination Diagrams.
- Approach Volumes Profiles
- Corridor Travel Speeds.

Purdue Coordination Diagrams
The Purdue Coordination Diagram (PCD) is a tool for visualizing and quantitatively evaluating signal performance and identifying opportunities for improvements (3). Developed by 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 of) 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. UDOT Signal Engineers can predict the impact of offset adjustments from manipulation of PCDs for an arterial corridor.
Periodically throughout the course of the winter, UDOT Signal Engineers 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 is changing plans have on the operations?
- Early return to green on main line – what effect does this have the reduced speeds?
- Impact of queuing – the shock wave associated with queues over the advanced detector

Approach Volumes Profiles

Traffic Signal Engineers also used approach volumes to determine not only when to activate and deactivate the inclement weather traffic signal timing plans but also in fine-tuning the traffic signal timing parameters as part of a post-event evaluation. UDOT’s Signal Performance Metrics System provided the approach volume profiles. These profiles reflect how traffic demands changes in the corridor during weather events. 

The approach volumes are already being displayed on the secondary Y axis of the PCD’s. As part of this deployment UDOT modified the system 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 20 minutes. UDOT used the he 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

Links speeds were also used by the Traffic Signal System Operators to determine when to activate and deactivate the inclement weather traffic signal timing plans. UDOT’s Signal Performance Metrics System provides these link speeds. The link speeds were gathered by graphing the approach speed at UDOT’s website. The UDOT’s Signal Performance Metrics System produces this graph by pulling the raw radar speeds from the radar sensors by using a listener service. The listener service time-stamps the speeds. 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. The approach speed (both the average speed and 85%-tile speed) were added to the automatic performance measure website as part of this project.

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.

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 be used with 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% speed reduction in the posted speed limit 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% posted speed limit 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 became 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 phases (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
  service 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 deployment corridor. TABLE 1 provides a summary of the timing plans used
in this deployment.

**TABLE 1 UDOT’s Weather Responsive Timing Plans for Riverdale, Road**

<table>
<thead>
<tr>
<th>Action Sets &amp; Plans</th>
<th>Recommended Time-of-Day Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sunday</td>
</tr>
<tr>
<td></td>
<td>To</td>
</tr>
<tr>
<td>154 Riverdale AM Snow No RCL 58</td>
<td>-</td>
</tr>
<tr>
<td>155 Riverdale OffP Snow No RCL 67</td>
<td>1000</td>
</tr>
<tr>
<td>195 Riverdale PM Snow No RCL 55</td>
<td>-</td>
</tr>
<tr>
<td>196 Riverdale AM Snow Max RCL 59</td>
<td>Only run with permission from UDOT Signal System Engineer</td>
</tr>
<tr>
<td>197 Riverdale OffP Snow Max RCL 68</td>
<td></td>
</tr>
<tr>
<td>198 Riverdale PM Snow Max RCL 56</td>
<td></td>
</tr>
<tr>
<td>199 Riverdale AM Snow Min RCL 60</td>
<td>Only run on request of Region 1 traffic –</td>
</tr>
<tr>
<td>200 Riverdale OffP Snow Min RCL 69</td>
<td>300 W &amp; 900 W on Max RCL</td>
</tr>
<tr>
<td>201 Riverdale PM Snow Min RCL 57</td>
<td></td>
</tr>
</tbody>
</table>
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 weather responsive timing plans were as follows:

- During the weather months, UDOT Meteorologists continuously monitors 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 Maintenance and Operations 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 the UDOT Meteorologists, the UDOT Signal Engineer 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 Signal Engineer would schedule the “Light” snow plan to be activated initially.

- As the weather event unfolded, the UDOT Signal Engineer would monitor weather and operating conditions as well as reports from Traffic Signal Maintenance personnel to determine if and which one of the two a “Heavy” snow plan was needed based on conditions in the field. The operator would also use the surveillance camera deployed in 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 UDOT Signal Engineer. The UDOT Signal Engineer 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 Signal Engineer assessed the effectiveness of the timing plan to determine if modification were needed.

EVALUATION

FHWA/UDOT conducted an evaluation of the deployed advanced weather responsive traffic signal system. The purpose of the evaluation was 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 demonstrated how the system could 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 was 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 2 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 3 shows the number of times and average duration over which each weather responsive timing strategy was deployed during the evaluation period.

Operator Assessments
Of the thirteen events where weather responsive signal timing plans were implemented, the UDOT Signal Engineer 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 Signal Engineer 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. In the five events where the Signal Engineer rated the timing plans as not having an impact of operations, the severity of the events was judged by the Signal Engineer to be relatively minor compared to their forecasted conditions.

TABLE 4 provides an overview of the operator assessments associated with each event. UDOT operators were also asked to provide their general opinions as to the overall effectiveness of the weather responsive signal timing plans to improve operations in the corridor. UDOT operators commented that the 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 2  Type and Duration of Weather Events Occurring during the Evaluation Period

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

## TABLE 3  Number of Times and Average Duration that Each Traffic Signal Timing Plan was Deployed

<table>
<thead>
<tr>
<th>Weather Responsive Timing Plan Number</th>
<th>Number of Event where Plan was Deployed</th>
<th>Average Durations of Deployment (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>55</td>
<td>4</td>
<td>225</td>
</tr>
<tr>
<td>56</td>
<td>2</td>
<td>195</td>
</tr>
<tr>
<td>57</td>
<td>4</td>
<td>288.75</td>
</tr>
<tr>
<td>58</td>
<td>5</td>
<td>156</td>
</tr>
<tr>
<td>59</td>
<td>1</td>
<td>120</td>
</tr>
<tr>
<td>60</td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td>67</td>
<td>3</td>
<td>180</td>
</tr>
<tr>
<td>68</td>
<td>3</td>
<td>158.33</td>
</tr>
<tr>
<td>69</td>
<td>4</td>
<td>138.75</td>
</tr>
</tbody>
</table>
### TABLE 4 Operator Assessments for Each Weather Event included in the Evaluation Period

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

**Arrivals on Green**

FIGURE 2 shows 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 intersection, 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 that tuning of offsets at these intersections is needed.

- 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 recalls are 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.
FIGURE 2 Average Percent Arrival on Green for Corridor.

**Platoon Ratio**

Platoon Ratio (RP) as a measure of the quality of progression provided by the coordinated phases on the main-street. It is the ratio of percentage of vehicle arriving on green to the green split.
allocated to that phase. The 2010 *Highway Capacity Manual* (5) rate the quality of progression using computed $R_p$ values.

The overall average platoon ratio associated with each timing plan is shown in FIGURE 3 for the northbound/westbound and southbound/eastbound direction 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.

**LESSON LEARNED**

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

**Riverdale Corridor**

The following represents several of the lessons learned during the deployment of the advanced weather responsive signal timing plans in the Riverdale Road corridor.

- Operators should not be too quick to implement and/or modify coordination offsets during a storm. 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. Just because it has stopped snowing does not automatically imply that a weather plan should be deactivated. Similarly, just because snow is falling doesn’t mean a snow 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. 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.
FIGURE 3 Overall Quality of Progression Achieved by the Different Weather Responsive Timing Plans in the Riverdale Road Corridor.
In developing weather responsive timing plans, keep the number of timing plans down 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, is 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 can require the main-street to stop more frequently and increase delays to the main-street.

The need to use recalls in timing plans is very 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.), which 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 off and on the WRTM plans, 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. The latency of the data is 15-20 minutes old, however, were near enough to real-time to be of value. Operations can be improved if the refresh rate was more real-time. A recommendation would be to ftp the intersection and receive the latest packet of data each time the “Create Metrics” button is pushed, instead of the server sending out ftp’s on a 15 minute schedule. This would speed up the latency to near-real time data of only 10 seconds old.

Weather Responsive Traffic Signal Operations

The following represents several of the lessons learned during the deployment related weather responsive traffic signal timing operations in general:

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; therefore, it is highly recommended that the evaluation of any weather responsive traffic management strategy, particular weather responsive traffic signal timing plans, extend across multiple seasons to as to ensure a 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 effect occurs. Furthermore, it is generally impractical and unsafe to require manual data collection during some weather condition. Automated system seem to be a viable approach to collect performance data during inclement weather events. The traditional metrics 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. Good before and after
data are needed to isolate the effects of the weather event from the effects of the
weather responsive strategy.

- In this deployment, only three weather responsive signal timing strategies were
deployed: changing coordination offsets to account for slow travel speeds, changing
the way detectors operate during inclement weather conditions and the use of
alternate sequencing with the phasing. However, a number of other weather
responsive signal timing strategies exist that could potentially affect safety and
operations, but were not included as part of deployment. These strategies include
changes to vehicle clearance intervals based on reduced pavement friction, using
dynamic red clearance intervals, actuated/coordinated operation, etc. Additional
deployments are needed to examine how the other strategies can be used to help
improve traffic performance and safety during weather events.

- Agencies need better guidance on how to deploy weather responsive traffic signal
timing strategies. A guidebook is needed that can be used to help agencies determine
the appropriate timing strategy (or strategies). Implementation thresholds, etc. for
their situation.

- Because weather conditions and their impacts can vary within a region, it would be
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 need decision support systems that can take
real-time information about roadway and weather conditions and assist them with
making recommendation to operator as to when and where to implement traffic signal
timing strategies. UDOT is currently working to integrate the Traffic Estimation and
Prediction System (TrEPS) (6) in both an on-line and off-line mode to assist with this
decision making process.

ACKNOWLEDGEMENTS
The authors would like to thank the Utah Department of Transportation for their assistance and
cooperation in conducting this study. This deployment was sponsored by the Road Weather
Management Program of the Federal Highway Administration.

REFERENCES
30, 2013.
High-Resolution Event Data and Measuring Travel Time. In Transportation Research
Record: Journal of the Transportation Research Board, No. 2192. Transportation Research
