Evaluation of a Traffic and Weather Responsive Variable Advisory Speed System in Portland, Oregon

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ABSTRACT

The first variable advisory speed (VAS) system in Portland, Oregon was recently installed as part of a comprehensive active traffic management (ATM) project on OR-217. This system, designed to be both congestion-responsive and weather-responsive, was installed to address a series of noted issues along the corridor, including unreliable travel times, high crash rates and a tendency to experience significant declines in performance during adverse weather. To assess the merits and effectiveness of VAS, a “before and after” analysis of corridor performance in terms of capacity, reliability and safety is being conducted. This paper summarizes the findings of the “before” analysis along with some preliminary results from the “after” analysis. Though the system was only activated on July 22, 2014, limiting the present ability of the researchers to identify and study its effects, some evidence of travel time reliability improvements have already been noticed.
INTRODUCTION

Active traffic management (ATM) has become an increasingly common tool in recent years for dealing with the challenges posed by congestion and adverse weather to freeways. Widely-used ATM strategies include ramp metering, variable speed limits, and queue warning systems. Variable speed limit (VSL) or variable advisory speed (VAS) systems are unique in that they can be both weather-responsive and congestion-responsive, and have produced promising results in both types of applications (1). Systems can differ in how they operate and what their intended purpose is, but in general they collect data regarding performance measures such as FLOW and speed and use it to compute and recommend a set of adjusted speed limits to enhance performance and/or safety. Weather-responsive systems are also outfitted with the means for monitoring roadway weather conditions.

A comprehensive ATM project, composed of a VAS system, real-time travel time postings, and a queue warning system, was recently constructed along Highway 217 outside of Portland, Oregon. In addition, ramp-metering has been in place along the corridor for several years (2), making OR-217 one of the most ATM-rich highways in the state. As shown in Figure 1, there are seven VAS signs each on the northbound and southbound directions. The Oregon Department of Transportation (ODOT) selected this freeway as a test corridor for urban ATM in the state due to its proclivity for severe congestion and high crash rates. The VAS system in particular is subject to an ongoing evaluation to determine its effectiveness at improving performance during both congestion and adverse weather and to help inform future decisions on VAS/VSL deployment statewide.

The intended purpose of this paper is to provide an initial glimpse into what impact the VAS system is having or may have on the performance of OR-217. As of August 1, 2014, the system has been active for ten days, so drawing any significant conclusions at this point is not possible, though some impacts are already noticeable. Thus, the majority of the paper focuses on the “before” analysis to highlight the major issues with OR-217 and why it stands to potentially benefit from a VAS system.

BACKGROUND

ODOT recently constructed an ATM system on OR-217, a 7.5-mile freeway located southwest of Portland, Oregon. Figure 1 shows schematic drawings detailing the northbound and southbound lanes. The corridor runs north-south between US-26 and Interstate 5 and is a common route for commuters traveling between western and southern suburbs and downtown Portland. The corridor is generally two lanes in each direction but has added and dropped lanes associated with entrance ramps in each direction. OR-217 has been well-outfitted with loop and radar traffic detectors, as detailed in Figure 1.

The commuter-heavy nature of OR-217 means it is prone to severe congestion on a regular basis during both morning and evening hours on typical weekdays. It also has a crash rate greater than the regional average for urban freeways, with rear-end crashes being particularly frequent. As part of the 2010 OR-217 Interchange Management Study (3), ODOT identified a VAS system as one of the most promising cost-effective solutions for dealing with the corridor’s problems, claiming it could lead to savings of about $6.6 million based on estimated reductions in crashes and vehicular delay.

ODOT’s decision to outfit OR-217 with the state’s first VAS/VSL system was informed largely by studying the evaluation results of other VAS/VSL applications throughout the world. Most evaluation studies tend to focus on the safety benefits of VSL/VAS, and have often discovered significant reductions in crash rates of between 10 and 40% after system activation (4, 5, 6, 7). These findings have come from VAS/VSL systems in a variety of applications; urban and rural, weather-responsive and congestion-responsive, and around construction zones, seeming to indicate that the safety benefits of VAS/VSL are not restricted to one setting.

Other studies have focused more on the performance and capacity benefits of VAS/VSL, but the results of these studies are much more varied and it is still difficult to claim with any certainty whether or not the systems do improve operations. In a review of ATM applications throughout Europe, Mirshahi et al. (8) reported that a system in the Netherlands led to increases in throughput of between 3 and 5 percent.
Weikl et al. (9) studied the effects of a VSL system in Germany on a number of traffic flow characteristics and found that while flows were more evenly distributed between lanes with VSL in place, total capacity was slightly diminished. Kianfar et al. (10) studied changes in flow following VSL implementation at 8 locations near St. Louis and did not find any consistent increase in flow. Hourdos et al. (11) found that implementation of a VSL system on I-35 in Minnesota reduced total congestion, defined as speeds below 45 miles per hour (mph), by 7% for one bottleneck, but did not provide any indication of the effects on corridor capacity. Such inconsistency regarding the impacts of VSL/VAS on capacity is a clear indication that more evaluation results are needed to better understand this relationship, and the study of OR-217 will add to this growing body of research.

**METHOD**

Data for this evaluation has been obtained primarily from Portal (www.portal.its.pdx.edu), a database that collects and stores of data relating to the performance of Portland’s transportation networks. Portland-area freeways are equipped with double loop detectors that continuously record speed, volume, and occupancy in 20-second increments and all of this data has been stored in Portal since 2004. As detailed in Figure 2, OR-217 has 9 loop detector stations in the northbound direction and 12 stations in the southbound direction, all located just downstream of entrance ramps. ODOT has also installed several WAVETRONIX radar detectors along OR-217, also shown in Figure 1, that collect identical data to the loop detectors, for a total of 14 and 17 sensor stations in the northbound and southbound directions respectively.

Portal also stores hourly weather data such as precipitation and temperature from National Oceanic and Atmospheric Administration (NOAA) sensors located at regional airports. The hourly nature of the weather data limited the researchers’ ability to identify any definite affects that adverse weather has on freeway performance.

To analyze the effects of the VAS system on crash rates along OR-217, crash data was obtained from ODOT’s statewide crash report database for 2011-2013. This database provides several different relevant pieces of information related to each reported crash, including type, location, and severity. In addition, data from all incidents, including crashes, along OR-217 requiring a response from ODOT was available from the ODOT dispatch system’s incident logs.

As mentioned earlier, this evaluation was structured in the form of a “before” and “after” study to establish some preliminary insight into the effects of the VAS system. Given the small pool of “after” data currently available, most of the work to date has focused on the “before” period. Numerous performance measures of interest have been computed, analyzed, and visualized using different techniques, including oblique plots, statistical tests, and contour plots. The intent of these “before” plots is to demonstrate some of the primary problems with OR-217. Now that the system has been activated, these same techniques can start be applied to the “after” data and any changes in performance measures can be identified by comparison.
FIGURE 1 OR-217 detection and VAS system layout.

STUDY PARAMETERS

The year from June 1, 2012 to July 1, 2013 was selected as the “before” period for this evaluation. One year’s worth of data was deemed an appropriate sample for establishing an adequate picture of OR-217’s pre-VAS performance in all types of weather. The specific period mentioned was chosen because major construction along OR-217 beginning in July 2013 limited the availability of loop detector data in the latter half of 2013. Aside from analysis of the crash and incident data, Mondays and Fridays were excluded from the evaluation due to inconsistent travel patterns along OR-217 during those days. Given the heavy usage of OR-217 by commuters, weekends and mid-week days were split and analyzed separately, and morning and afternoon peak periods were defined as 7-9 AM and 4-7 PM, respectively. For analysis of the crash trends, data from the three latest years for which it was available (2011-2013) was analyzed to compensate for annual fluctuations.

For analysis of OR-217’s performance in adverse weather prior to activation of the VAS system, hours were split into categories depending on the weather observed during them. Precipitation was the only phenomenon found to have a significant impact on performance. An hour was defined as wet if
precipitation was recorded at Hillsboro Airport during that hour, and any loop detector readings during that hour were assumed to have occurred in wet conditions. Since the weather data obtained from NOAA is hourly, aggregation of the loop detector data was necessary to make it compatible, limiting the capability to directly link adverse weather with short duration changes in performance. In order to obtain a robust sample size of “wet” hours, the three wettest months in Portland during the “before” period (October, November, and December 2012) were analyzed. Of the 435,334 5-minute aggregate loop detector readings from midweek and weekend days obtained, approximately 15% came during “wet” hours. Since the weather-responsive component of the VAS is not yet active, only “before” weather data is currently available, but the upcoming fall and winter will allow for a more robust “after” evaluation of the system’s effectiveness during adverse weather.

RESULTS

The results of this evaluation are divided into two primary sections. The first summarizes the findings from the “before” analysis. The intent of this section is to highlight the major performance issues OR-217 was having prior to VAS implementation and demonstrate why the corridor stands to potentially benefit from a well-designed system. The second section introduces some preliminary findings from comparing the “before” and “after” periods. Since the system has only been active for ten days as of August 1, not enough “after” data is available yet to make any claims regarding its effectiveness, but some changes in performance are already noticeable.

Pre-VAS Performance Issues

This section presents results from analysis of OR-217’s performance prior to VAS implementation. Corridor issues with the most potential to be mitigated by a VAS system are highlighted. This analysis was comprehensive and wide-ranging, encompassing everything from bottleneck patterns to the impacts of adverse weather. The first sub-section focuses on speed, flow, and travel time trends along OR-217, the second provides a more in-depth summary of the corridor’s recurrent bottlenecks, the third shows the effects of adverse weather, and the final sub-section describes crash trends along the freeway.

Speeds, Flows, and Travel Times

Both directions of OR-217 follow the bimodal speed and flow distributions typical of commuter-heavy freeways, with distinguishable peaks for volumes and valleys for speeds in the morning and evening of weekdays. Figures 2A and B present the typical distributions of speed and flow over the course of a weekday in the northbound and southbound directions, respectively. These plots were created using one month of loop detector data for midweek days (Tuesday through Thursday) aggregated into 5-minute averages. To generate corridor-wide volumes and speeds, 5-minute flows from each individual detector were summed and 5-minute average speeds from each individual detector were averaged.

Free flow speeds along OR-217 generally hover between 55 and 60 miles per hour (mph), and can drop by up to 30 mph during peak demand hours. Peaks flows during both the morning and evening approach nearly 3,500 vehicles per hour (vph) across all lanes in both directions. The speed and flow trends for the northbound and southbound directions are similar, but morning peak congestion tends to be slightly worse in the southbound direction because of commuters heading for I-5, while the reverse is true in the evening as commuters return home. Between the morning and evening peaks, flows subside and speeds recover, but typically not all the way to free-flow levels.
A common goal for congestion-responsive VSL/VAS systems is to aim to equalize speeds and flows across the lanes of a freeway during peak demand times. In congested conditions, significant differences in terms of speeds between adjacent lanes encourage drivers to try to take advantage of faster lanes by making unnecessary lane changes. This can have negative effects on freeway throughput and safety by leading to more conflicts and stop-and-go traffic. By maintaining a more uniform speed across lanes, a VAS system should help to minimize the incentive for excessive lane changing and stabilize traffic. OR-217 is susceptible to lane speed differentials during weekdays, which is one reason why the freeway has the potential to benefit from the VAS system.
Figure 3A and 3B highlight the discrepancies that often exist between lanes during peak hours along OR-217. These plots were created using one month of midweek 20-second loop detector readings from one southbound station. The speed data in 4a was aggregated into 1-minute averages, and the volume data in 3b was aggregated into 5-minute averages. As shown, during the evening peak, speeds in the left lane are consistently between 2 and 6 mph greater than in the right lane, while volumes in the right lane are consistently about 100 vph greater. As evening peak demand approaches its maximum around 5:00 PM, the speed and flow differentials between lanes noticeably decrease, suggesting a lot of unnecessary and performance-inhibiting lane changing. A VAS system would ideally do away with the speed differentials shown in 3A, negating any incentive to change lanes except when needed.

Travel times along OR-217 follow a similar bimodal distribution to speeds and flow during the course of a typical weekday, but can be highly variable and unreliable. Figure 4 demonstrates this by showing the gaps between 95th, 50th, and 5th percentile travel times typical during the morning and evening peaks. These plots were created using one month (October 2012) of midweek 5-minute aggregated loop detector readings for the leftmost lanes of OR-217 NB and OR-217 SB. Large discrepancies between the three values in each case are clearly noticeable, with 95th percentile travel times at times exceeding average travel times by double digits. For Figure 4A, the average range between the 95th and 5th percentile travel times is 6.26 minutes, while for Figure 4B, the average range is 5.24 minutes. The ranges of experienced travel times are equally wide for OR-217 SB, at 8.43 minutes for 4C and 4.51 minutes for 4D. These are substantial differences for a freeway with a free-flow travel time of...
approximately 7 minutes. Such discrepancies between the three plotted values indicate that travel time reliability along the corridor is poor, making it difficult for drivers to accurately predict how long the route will take them on any given weekday. Additional evidence of OR-217’s unreliable travel times can be obtained from calculation of the travel time buffer index, a value representing how much extra time drivers must allow for trips in order to reach their destinations on time as a percentage of the average travel time. For the months’ worth of data shown, the buffer index exceeds 50% during the most congested times in each case.

**FIGURE 4A** AM peak travel time reliability, OR-217 NB left lane.

**FIGURE 4B** PM peak travel time reliability, OR-217 NB left lane.

**FIGURE 4C** AM peak travel time reliability, OR-217 SB left lane.

**FIGURE 4D** PM peak travel time reliability, OR-217 SB left lane.
**Bottleneck Pattern**

Bottleneck formation is a recurrent problem along both directions of OR-217 during the morning and evening peaks on typical weekdays. Figure 5 demonstrates typical weekday congestion patterns for the northbound direction, along with the effects the noticeable bottlenecks have on flow. In Figure 5A, the $x$-axis represents time, the $y$-axis represents location, and the colors represent measured speeds in mph. This plot was created using aggregated 5-minute average speed measurements for the day indicated. Figure 5B is an oblique flow plot developed by following a well-established procedure for bottleneck diagnosis (12). It was each created using 20-second loop detector counts from one detector station located within the evening bottleneck shown in 5a.

![Figure 5A OR-217 NB congestion pattern and 5B oblique flow plot, February 13, 2013.](image)

As shown in Figure 5A, a bottleneck typically develops on OR-217 NB near the interchange with Denney Road (milepost 3.12) around 7:00 AM and propagates upstream to the corridor’s southern end, lasting for several hours. In the evening, a similar bottleneck generally forms around 4:00 PM. As indicated by the orange and red colors of the congestion plot upstream of these bottlenecks, average

**FIGURE 5A OR-217 NB congestion pattern and 5B oblique flow plot, February 13, 2013.**

Total No. of Detector Readings = 53,105
Mean Speed = 54.78 mph

Total No. of Detector Readings = 900
Mean Flow = 3566 vph
speeds drop well below free-flow speed for a total of more than 4 hours along more than half of the corridor, resulting in over 50 hours of cumulative vehicular delay during just the peak hours of this particular day.

The recurrent bottlenecks along OR-217 can significantly reduce the capacity of the corridor for extended periods of time, as demonstrated in Figure 5B. The y-axis represents cumulative vehicle counts through the 99W WB detector station (milepost 5.85) minus a rescaling factor to clearly show when major changes in flow occur. Following the trend in average flow for this station during the evening peak reveals the effects that the second bottleneck in 5A had on the capacity of OR-217 NB. Increased demand from evening commuters began to hit this segment of the corridor around 3:30 PM, when average flow peaked at 4,105 vph. At approximately 4:30 PM, congestion caused by the downstream bottleneck backed up to this station, causing average flow to drop by 22.5% to 3,178 vph. This restricted throughput persisted for about half an hour, until average flow rebounded to 3,787 vph around 5:00 PM. Such reductions in flow severely inhibit the performance of OR-217 during the peak period.

Effects of Adverse Weather on Corridor Performance

Adverse weather, particularly precipitation, can have a significant impact on the performance of OR-217. Figure 6 demonstrates this by showing average travel times along OR-217 NB recorded during each hour of the day during the 3-month period under “wet” and “dry” conditions, split between midweek days and weekend days. Significant gaps between the “wet” and “dry” lines, particularly during peak hours on midweek days, are noticeable. For example, between 8:00 AM and 9:00 AM during the 3-month period, the average travel time was about 13 minutes in dry conditions, and nearly 17 minutes in wet conditions, a 31% difference. More detailed statistical analysis supports the differences shown. At a confidence level of 95%, t-tests revealed that travel times in wet conditions during the analysis period were an average of between 1.13 and 1.54 minutes greater on midweek days, and between 1.98 and 2.93 minutes greater during peak hours of midweek days. These numbers support the observation that the negative effects of precipitation on corridor performance are amplified during congested times.

The general unreliability of OR-217 travel times was discussed in a previous section, and the amount of variability in observed travel times was found to be even greater during adverse weather. During the 3-month period represented in Figure 6, the standard deviation of travel times during midweek peak hours was 4.57 minutes in dry conditions and 6.03 minutes in wet conditions, about 32% higher. This suggests that drivers on OR-217 vary significantly in how they adjust speeds in response to adverse weather, which may contribute to the corridor’s high crash rate. A major goal of the VAS system’s weather-responsive component is to proactively manage performance during adverse weather by bringing all drivers down to a speed deemed safe, thereby stabilizing flow and doing away with the current large variations in speeds. The speed harmonizing effects that VSL/VAS systems in other locations have been observed to have could thus be particularly beneficial to the safety and efficiency of OR-217.
FIGURE 6 Effect of precipitation on travel time, OR-217 NB.

Crash Trends

A primary motivation for installing a VAS system on OR-217 is to address its high crash rate. In 2012, the latest year for which statewide processed data is available, there were 314 crashes recorded by ODOT, equating to a crash rate of about 1.05 crashes per million vehicle miles traveled (13). This is higher than the statewide average of 0.88 for non-interstate urban freeways. OR-217, due to its severe congestion, is particularly prone to rear-end crashes, which tend to be highly correlated with stop-and-go traffic. Between 2010 and 2012, 944 total crashes were reported on OR-217. Of these, over two-thirds were rear-end collisions, translating to an average of more than 200 rear-end crashes annually, or more than one every other day. In comparison to other freeways in the Portland area, OR-217’s proportion of rear-end crashes is much higher than that of US-26 (51%) and OR-10 (42%).
The high incidence of rear-end crashes on OR-217 is of major concern for both safety and performance reasons. Depending on the severity, a rear-end crash can block an entire lane anywhere from a few minutes to several hours, further compounding congestion and possible contributing toward secondary crashes. Figure 7, by showing cumulative flow and averages speeds from one OR-217 NB detector station for the evening of January 10, 2012, demonstrates the impacts that one rear-end collision can have on the performance of OR-217. The data comes from 20-second loop detector readings. On this day, a rear-end collision was reported approximately 1 mile downstream of this station at 5:00 PM. About 10 minutes later, the congestion imposed by this crash propagated back to the station represented, at which time average speed plummeted to below 10 mph and the flow was reduced by more than 80%. This drop in throughput continued for more than 2 hours until about 7:20 PM, when speed and flow finally rebounded to normal levels.

Before and After Comparison

The congestion-responsive component of OR-217's VAS system was activated on July 22, 2014. Since it has only been operating for ten days as of August 1, not enough “after” data is available yet to make any substantial claims regarding the system’s effectiveness. However, through these first few weeks of operation, preliminary analysis has uncovered some evidence that the system is having an effect on corridor performance, particularly on travel time reliability.

The large ranges in observed travel times along OR-217 were detailed in a previous section, and one of the primary goals of the VAS system is to minimize these. Figure 8 presents some travel time reliability comparisons between the first week with the system activated and one month of “before” data and indicates that the system is already having an impact. The black shaded areas represent the range between 95th and 5th percentile travel times from mid-week days in June 2014, and the red areas represent the travel time ranges for the first three days with the system turned on (July 22-24, 2014). The data comes from 5-minute aggregated loop detector readings. In each of the four plots, the red shaded areas are generally thinner than the black shaded areas, indicating that the variation in observed travel times decreased after the VAS system was activated. Table 1 supports this observation by showing that the average buffer index and average difference between 5th and 95th percentile travel times decreased after VAS implementation in all four cases. For instance, the average afternoon peak buffer index for the left lane was 42.62% during June 2014 and declined more than 70% to 12.21% during the three days immediately following the system turn-on. While these observations are preliminary and based on a very small “after” data set, they are nonetheless encouraging and represent the types of results ODOT hopes to see from the VAS system.

Table 1 Travel Time Reliability Comparison

<table>
<thead>
<tr>
<th>Time Period</th>
<th>OR-217 NB Left Lane</th>
<th>OR-217 SB Left Lane</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Buffer Index</td>
<td>Envelope Range</td>
</tr>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>7:00 AM - 10:00 AM</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>31.18%</td>
<td>18.78%</td>
</tr>
<tr>
<td>3:00 PM - 7:00 PM</td>
<td>42.62%</td>
<td>12.21%</td>
</tr>
</tbody>
</table>
CONCLUSIONS

A thorough analysis of the current conditions on OR-217 shows that it has the potential to benefit significantly from the recent implementation of a congestion-responsive and weather-responsive VAS system. The corridor is prone to severe congestion and recurrent bottlenecks on a regular basis during weekdays, with average speed declines of 50% not uncommon during peak demand hours. Bottlenecks in both directions often create queues that are several miles long and last for several hours. In addition, the corridor’s performance varies greatly between different hours and days, making travel times unreliable and difficult for drivers to predict. During precipitation events, travel times are even higher and more unreliable. OR-217 is also particularly prone to rear-end crashes, with an average of more than one every other day, and these collisions can have major consequences in terms of both throughput and safety.

As of August 1, the VAS system has now been active for ten days. While too early to assess the system’s effectiveness, preliminary analysis suggests that the system may be helping to shrink the amount...
of variability in observed travel times. Based on a review of similar VAS/VSL applications, other major impacts it is hoped the system will have include a reduction in rear-end collision rates, a reduction in the duration of recurrent bottlenecks, and a reduction in speed variance between adjacent lanes. VAS activation data regarding the displayed speeds and their durations will also allow for analysis of compliance by comparing posted advisory speeds with actual speeds in each lane at 20-second intervals. Going forward, as “after” data is obtained, it will be subjected to the same in-depth analysis as the “before” data to determine whether the system is filling its intended purpose and making OR-217 a safer, more reliable freeway.

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