Transportation Research Procedia

Volume 15, 2016, Pages 640–651

ISEHP 2016. International Symposium on Enhancing Highway Performance

Evaluation of Driver Compliance to Displayed Variable Advisory Speed Limit Systems: Comparison between Germany and the U.S.

Gary Riggins[1], Robert L. Bertini[2], Williams Ackaah[3], Martin Margreiter[1]

[1]*Technische Universität München, Germany*

[2]*California Polytechnic State University, San Luis Obispo, California, USA*

[3]*University of the Federal Armed Forces, Munich, Germany*

gary.riggins@tum.de, rbertini@calpoly.edu, martin.margreiter@tum.de, williams.ackaah@unibw.de

Abstract

Variable Speed Limit (VSL) and Variable Advisory Speed (VAS) systems are applications of a growing field of active traffic management systems (ATM). This technology aims to improve safety while reducing congestion and emissions. VSL is common on German freeways, harmonizing traffic flow during congestion and weather events. Portland, Oregon installed a VAS system (advisory meaning it is not automatically enforced) on an eleven km (seven miles) segment of heavily congested urban freeway. The Portland region maintains archived, high-resolution data of both VAS sign messages and speed detection loop feedback, permitting reconstruction of traffic and sign data. This work analyses over 30 days of archived data from the Portland site in order to study driver compliance to the VAS signs. The focus is to suggest methods and parameters to score system performance. Such an analysis could benefit new rollouts of VAS corridors by providing system performance feedback and shed light on options for improving system performance.

Keywords: Variable Advisory Speed, Variable Speed Limits, Compliance, Traffic Management, Evaluation

1 Introduction

The state of Oregon has placed itself as an early adopter of intelligent transportation systems (ITS) and active traffic management (ATM) strategies for improving traffic safety and traffic flow in the U.S. Specifically on heavily used freeways surrounding Portland, the Oregon Department of Transportation (ODOT) has implemented, among other things, a centralized traffic management center, dynamic ramp metering, incident response, variable message signs with travel times and traveler information, as well as an online archived data service. Recently, ODOT has added a variable advisory speed (VAS) limit system on several freeways in the Portland area. The VAS system responds both to weather and traffic

Selection and peer-review under responsibility of the Scientific Programme Committee of ISEHP 2016
© The Authors. Published by Elsevier B.V.

doi:10.1016/j.trpro.2016.06.054

conditions (Downey, 2015) and displays advisory speeds (black on yellow signs) over each lane at specific gantry locations. While some variable speed limit (VSL) systems include regulatory speeds and automated enforcement, an advisory speed limit system was chosen after discussions with the Oregon State Police, who can use the basic speed rule for enforcement where a driver is not allowed to drive at a speed greater than is reasonable and prudent for conditions.

Oregon Route (OR) 217, an eleven km (seven mile) stretch of freeway experiences frequent rear-end collisions (approximately 200 per year) and heavy congestion during rush hours extending into the off-peak hours. ODOT chose this corridor due to the perennial rush-hour congestion and almost daily crashes. ODOT is currently evaluating this application of the VAS system in order to inform further installations of VAS signs. ODOT recorded 314 crashes in 2012, roughly a crash rate of about 1.05 crashes per million vehicle miles traveled (Yanfei, 2013). The state average is 0.88 on non-interstate urban freeways. Most of these are rear-end crashes which are linked with stop-and-go traffic. Recent work has documented the preliminary impacts of the VAS system on travel time reliability, safety, and other critical performance measures (Downey, 2015).

This paper explores the potential for developing a comprehensive scoring system for tracking the compliance of drivers to displayed VAS signs. Compliance is defined as the difference between the displayed speed and the actual measured speed of traffic. This will assist in gaining a full understanding of the success of the system, and includes a corridor-level perspective depicting when the signs are being used, and what the actual traffic conditions are during those times. It should be noted that we do not know if or when enforcement was performed by state police or other law enforcement during the study period. In order to compare the Portland advisory speed limit system with another VSL, a site in Munich, Germany is also analyzed. The Munich site uses regulatory speed limits and includes an automated enforcement system (though detailed knowledge of when it is activated is not available).

This study is made possible thanks to the availability of archived freeway sensor data, in order to reconstruct the “ground truth” of actual vehicular speeds, over space and time. In addition, the VAS/VSL system logs have been archived, which allows for the reconstructing the displayed messages. A standardized algorithm compares specific hours or entire days of information in order to detect driver compliance, variations in driver compliance and situations in which vehicular compliance is better/worse. This information can be helpful for enforcing speed limits at certain times of day, evaluating system effectiveness and providing useful information for deploying the system on other freeway corridors.

2 Background and Literature Review

OR 217, located southwest of Portland, Oregon, was converted in the past from a regional arterial to a limited access freeway corridor with frequent on/off ramps. As an alternative to considering a major widening project, ODOT recently constructed an ATM system on the eleven-km (7 mile) freeway to reduce crash frequency and decrease congestion. Figure 1 shows schematic drawings detailing the layout of the ATM system components in the northbound and southbound lanes, with the milepost (MP) reading for each detector and VAS gantry as indicated. As shown, there are 14 loop detector/radar sensor stations and seven VAS gantries northbound, and 17 loop detector/radar sensor stations and seven VAS gantries southbound. Each detector’s “influence area” is also shown, which is the distance measured along the freeway bounded by the midpoints between each detector pair. 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 auxiliary lanes near entrance ramps. OR 217 has been well outfitted with loop and radar traffic detectors, as detailed in Figure 1. Free flow speeds on OR 217 are between 89 and 97 km/h (55 and 60 mph). This can decrease by 48 km/h (30 mph) in rush hours. Rush hour peak flows reach 3,500 vehicles per hour (vph) in both directions (Downey & Bertini, 2015).

The OR 217 VAS system project was aimed at reducing crashes and congestion on the heavily traveled OR 217 (Downey, 2015). Previous work on driver compliance includes a study of driver behaviors linked to a weather-activated VSL system on rural roads in Wyoming (Yanfei, 2013) which found that VSL did reduce driver speed variation and that compliance grew worse with larger VSL speed reductions. The influence of a VAS or VSL system on traffic flow does not necessarily increase traffic flow but does contribute to fewer crashes by harmonizing traffic flow across lanes (Weikl, Bogenberger, & Bertini, 2013) and dampening speeds longitudinally. Importantly this research has reported that the system may not increase traffic flow, however, it does increase traffic safety and therefore may decrease congestion due to crashes.

The idea of evaluating the quality of traffic information by comparing actual traffic states regenerated with sensor data to navigation system congestion warnings exists already, and a quality index of system accuracy was proposed using a ratio of the reported coverage area versus actual area of traffic congestion and speed information (Ackaah, Huber, & Bogenberger, 2015). This method relies on the time-space area of the freeway affected, compared to the time-space area of the traffic signs and messages along the affected corridor. The analysis of VAS and VSL compliance discussed in this paper builds on the quality metrics developed by Ackaah, et al. (2015)

3 Data and Methodology

Data for this analysis has been obtained from Portal (www.portal.its.pdx.edu), which is the online multimodal transportation data archive for the Portland, Oregon, metropolitan region. As mentioned, freeway dual loop detector and radar detector data are available in each lane at 20-second intervals (count, occupancy and time mean speed). The VAS system was deployed on July 22, 2014. The analysis that is considered in this paper includes data from a period of time before the system was deployed (static speed limit), the initial week of system installation, and a week of data from each month since the VAS system was activated until March 2015.

The data for this study came from 13 speed detectors located along the eleven km (seven mile) route of Northbound OR 217. The VAS signs generally update themselves every two minutes and store a record in a database table with its location, lane, speed or warning message. In the early months of system installation, the VAS signs were mostly turned off with sporadic advisory speeds displayed for short durations.

To analyze the ground truth traffic situation compared with the displayed VAS speeds, the database of sensor data was compiled in one-minute segments, combining volume and speeds across lanes of northbound OR 217 per location and per time. Subtracting the detector (vehicular) speeds from the advisory sign speed yielded compliance graphs. These graphs show the differences in speeds between vehicles and the displayed VAS speeds. Figure 1 shows the arrangement of the VAS signs and the speed detectors (dual loop and radar).

The week of June 15-21, 2014 was used as a basis for driver compliance to previously posted static speed limits (a “before” scenario). The detected vehicle speed was compared to a posted 89 km/h (55 mph) base speed limit. After system initialization on July 22, 2014, the VAS sign data was compared to measured vehicle speeds in order to construct compliance speed tables. One week out of each month was analyzed for compliance in July, August, September of 2014 and January, February and March of 2015. The dynamically controlled ramp metering system was set using fixed-time rates and activation periods during October, November and December 2014, and therefore data from this period were not used for this study. Ramp metering was functioning normally during all other periods (before and after VAS deployment).

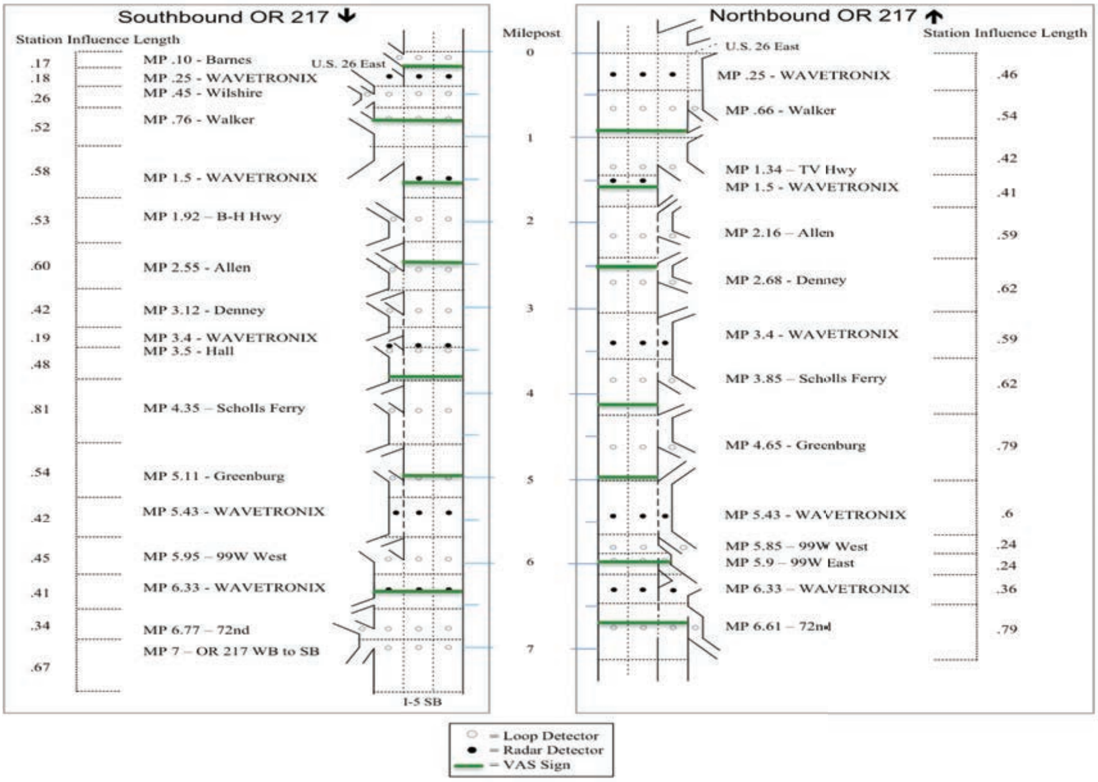

Figure 1: OR 217 detection and VAS system layout (Downey, 2015)

4 Results

4.1 VAS Performance of OR 217

The VAS signs are usually deployed at times of system congestion, but often the signs are also “on” during the whole day and on weekends. The details of the algorithm used to determine when to activate the VAS system and what speed to display are described elsewhere (Downey, 2015) (DKS Associates, 2013). The VAS signs are generally spaced every mile (1.61 km) with two or three speed detectors following before the next VAS sign. The VAS signs can display the advisory speeds “50”, “45”, “40”, "35", "30" in mph (80, 72, 64, 56, 48 km/h respectively), and "SLOW," in black text with a yellow background. The same speeds are always displayed for each lane at each gantry. The logs for all VAS messages for each northbound gantry are shown in Figure 2 for Wednesday March 18, 2015 (stair step function in blue). The speeds measured at the nearest detector station are also shown (time series in red). The sign off state is represented by "SO".

As shown in Figure 2, it appears that when speeds are high (e.g. for most of the day at MP 0.91), at most gantries the VAS is either off (SO) or displays 80 km/h (50 mph). At other times, at other locations, when speeds drop, it appears that the system also displays appropriate speeds (e.g. MP 4.13 during the morning and afternoon peak periods. It is also clear from Figure 2 that there are times and locations where the actual traffic speed is lower than the displayed VAS speed, and also times when the opposite is true. The compliance examination will continue to examine these issues in depth.

During substantial portions of the day, one or several of the VAS signs are either off in non-rush hour times or set to "SLOW" in heavy congestion. Figure 2 also shows the percent of time that the VAS system was active by hour of the day for March 18, 2015, at the bottom of the figure. In the months following the VAS system initialization, the signs were on less than 20% of the time. Also, measured

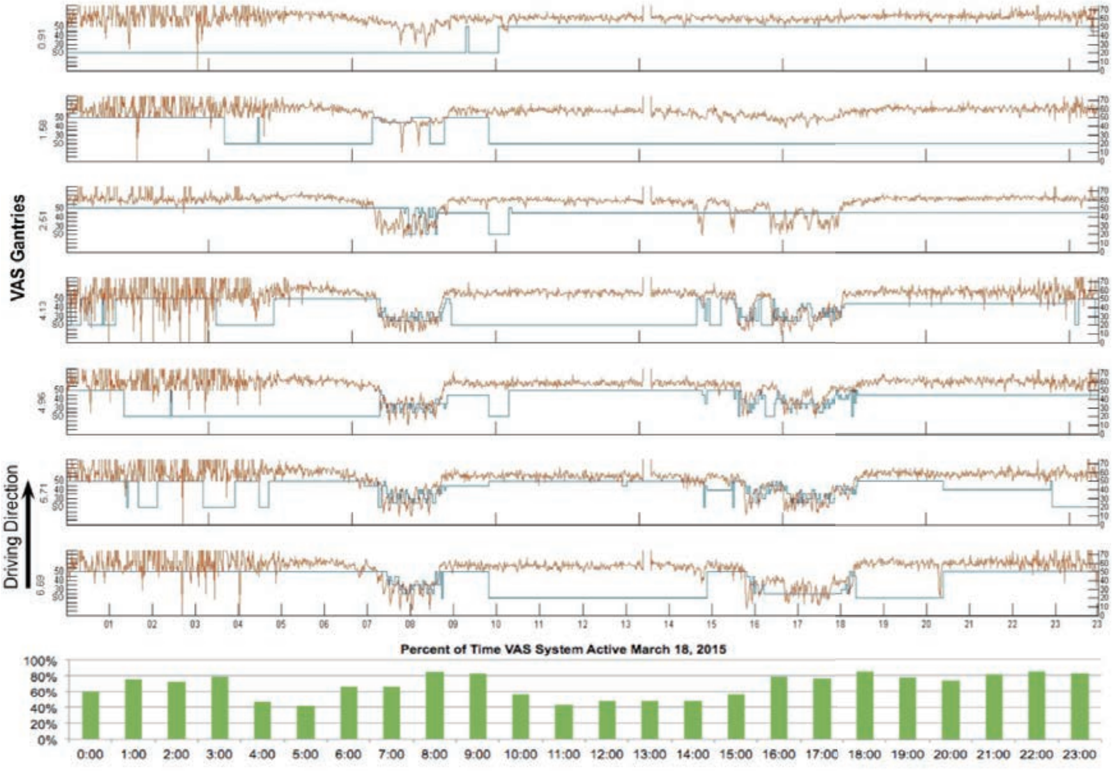

Figure 2: Northbound OR 217 VAS displayed speed and vehicle speeds and percent of time VAS system active, by hour of day, March 18, 2015

speed fluctuations during overnight/low flow periods seemed to trigger the system unnecessarily. Beginning in January 2015, after some system calibration, the VAS signs were usually on more than 60 % of the time. Traffic tended to move on average 16 km/h (10 mph) above the VAS speed limit, and 11 km/h (7 mph) faster than the displayed speed during the first few months following VAS installation. On average over the days tested, 88 % of drivers drive over the VAS limit. In order to systematically assess the VAS systems status, Figure 3 has been constructed displaying the details from the system for one sample day, March 18, 2015.

Building on the "slices" in Figure 2, Figure 3(a), (b), and (c) show the traffic speeds, displayed advisory speeds, and the difference between the two or the compliance of driver's to the posted speed. Figure 3(a), (b), and (c) are arranged in a bottom-to-top driving direction. Figure 3(a) is a time-space

Figure 3: OR 217 NB vehicle speed; (b) VAS displayed speed; and (c) Compliance, March 18, 2015

plot that builds on the data shown in Figure 2 for each station, and shows vehicular speeds measured at 20-second intervals at 13 detector locations along the 7-mile corridors. Vehicles are moving upward in the figure. To produce a "ground truth" plot, the speeds have been averaged into 1-minute segments throughout the day and interpolated longitudinally between detector locations. Speed is denoted by color, with high speeds shown in green and lower speeds in yellow→red. As indicated, during the morning and afternoon peak periods, congestion forms at a known bottleneck near the middle of the corridor.

Next, Figure 3(b) also builds on the data shown in Figure 2, but applies the VAS messages over space (along the next downstream segment until the next gantry) and time. The VAS plot in Figure 3(b) uses colors to illustrate the particular speed that is displayed at a particular gantry over time (green reflects the higher speeds, yellow and red move progressively slower). The speed messages may change as frequently as every two minutes. As shown, when the system is "off" (blank, SO in Figure 2), white space is shown in the figure. When the system reads "SLOW," a grey color is used on the figure. For much of the day, the green blocks indicate speeds displayed between 64-80 km/h (40-50 mph). During the peak periods, visually the zones with lower VAS speeds seem to match with the congestion mapped in Figure 3(a). Figure 3(b) indicates that somewhat surprisingly, the system was on between midnight and 06:00, and after 19:00, displaying 80 km/h (50 mph) speeds. During the middle of the day, the signs on several gantries in the middle of the corridor were off, while others displayed speeds in the 72-80 km/h (45-50 mph) range.

Now that we have constructed a time space plot for VAS displayed speed and actual/measured vehicular speeds, we would like to look at the compliance, which is the arithmetic difference between the two. So Figure 3(c) is the difference between the VAS sign readings and the measured speed detector readings. In this case, color is used to illustrate the arithmetic differences between measured vehicular speeds (from the nearest detector stations) and the displayed VAS speeds, applied downstream. Green represents times and locations where vehicles were traveling faster than the VAS displays. Visually from the figure it appears that during the off peak periods (overnight and mid-day), most of the traffic was traveling faster than the VAS displays. In the figure, the yellow-red colors reflect situations where vehicles were recorded traveling slower than the displayed speeds on the VAS signs. In most cases this

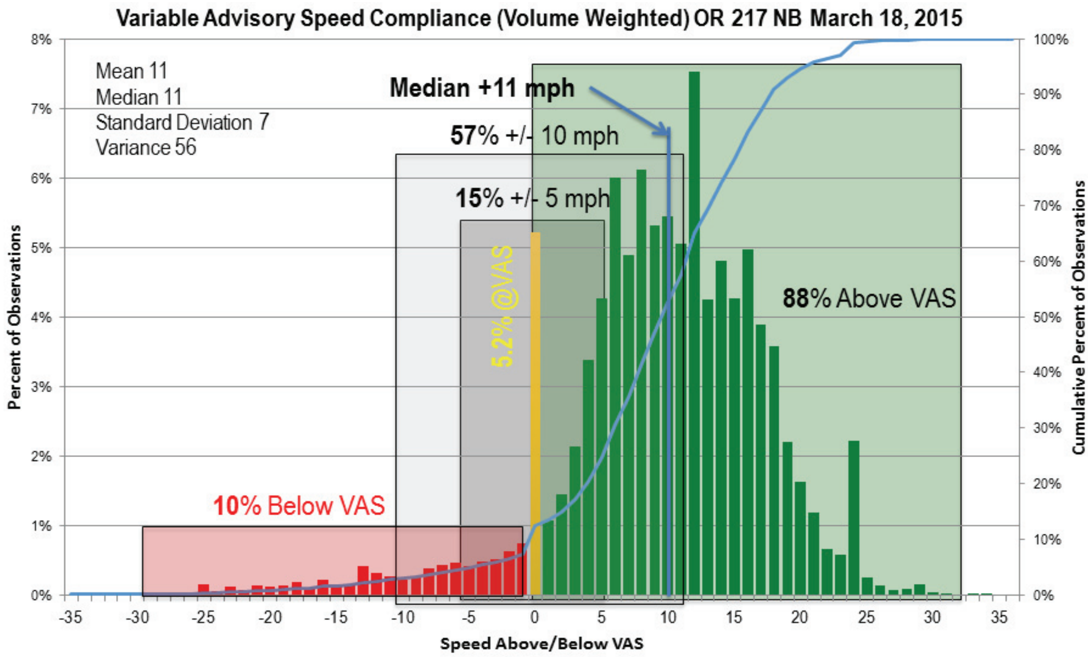

Figure 4: Volume weighted compliance histogram after VAS initialization, OR 217 NB, March 18, 2015

appears to have occurred during the peak periods, where traffic was likely moving more slowly than what the VAS displays indicated.

4.2 Compliance Scoring Parameters

To further assess the level of compliance with the VAS system, a set of analyses was prepared, with data from March 18, 2015 as an example. Using the matrix behind the creation of Figure 3(c), which contains one “compliance” value for each gantry every two minutes during the day (when the VAS system was on), a histogram was created, shown in Figure 4.

Figure 4 is constructed using a weighting system that proportionally weights each compliance observation based on observed vehicle counts in that time interval and at that location. Figure 4 shows that the mean (and median) compliance value was +18 km/h (11 mph) and the standard deviation was 11 km/h (7 mph). 88 % of the exposed vehicles were traveling above the VAS speed, while 10 % were below. A total of 57 % of drivers were within ±16 km/h (10 mph) of the display, while 15 % were within ±8 km/h (5 mph).

Going beyond the one day analyzed here, Table 1 shows a summary of the compliance statistics (similar to those shown on Figure 4, using volume weighted analysis, with percentages above or below the displayed VAS). The table includes the mean, median, standard deviation and variance of the compliance scores throughout each day and over the entire corridor. Further, the minimum maximum percent less than the posted speed and percent greater than the posted speed are tabulated. The percent of vehicles traveling at the VAS speed is shown, followed by groupings to indicate the percent of vehicles traveling ±5%, 10 %, 15 %, and 20 % below or above the posted speed. Finally the percent of vehicles traveling more than 20% above the posted speed is listed. A total of three days are included before the system was activated, with comparisons made against the posted regulatory speed limit of 89 km/h (55 mph). As shown 76 % of vehicles were traveling faster than the speed limit, while 22 % were traveling slower, likely due to congestion. A total of 90 % of vehicles were traveling up to 20 % below or above the speed limit, with only 5 % traveling more than 20 % faster.

In contrast to the “before” conditions, a total of 35 days are included in Table 1 after the system has been deployed, including 23 weekdays and 12 weekend days. As shown, on weekdays, 80 % of vehicles were traveling faster than the speed limit, while 15 % were traveling slower, likely due to congestion. A total of 58 % of vehicles were traveling up to 20 % below or above the variable speed limit, with 37 % traveling more than 20 % faster. On weekends, 87 % of vehicles were traveling faster than the speed limit, while 5 % were traveling slower, likely due to congestion (less congestion occurs on weekends). A total of 48 % of vehicles were traveling up to 20 % below or above the variable speed limit, with 51 % traveling more than 20 % faster.

4.3 Compliance per VAS Speed

Figure 5 shows a boxplot of the speed compliance at each of the displayed speeds for the volume-weighted observations on March 18, 2015. This reveals an interesting and generally increasing relation between the displayed speed and the compliance value. At times when the VAS displays “30” (48 km/h) and “35” (56 km/h), the median compliance is slightly less than zero, meaning that vehicles are traveling at speeds lower than those displayed. Also noticeable is that average compliance to higher advisory speeds, including “40”, “45”, and “50” (64, 72 and 80 km/h respectively), is on average approximately 16 km/h (10 mph) above. Also shown is the fact that when the VAS system was on, most of the time the sign was displaying “50” (80 km/h). The relationship between the sign display and the compliance level is a subject that should be analyzed further.

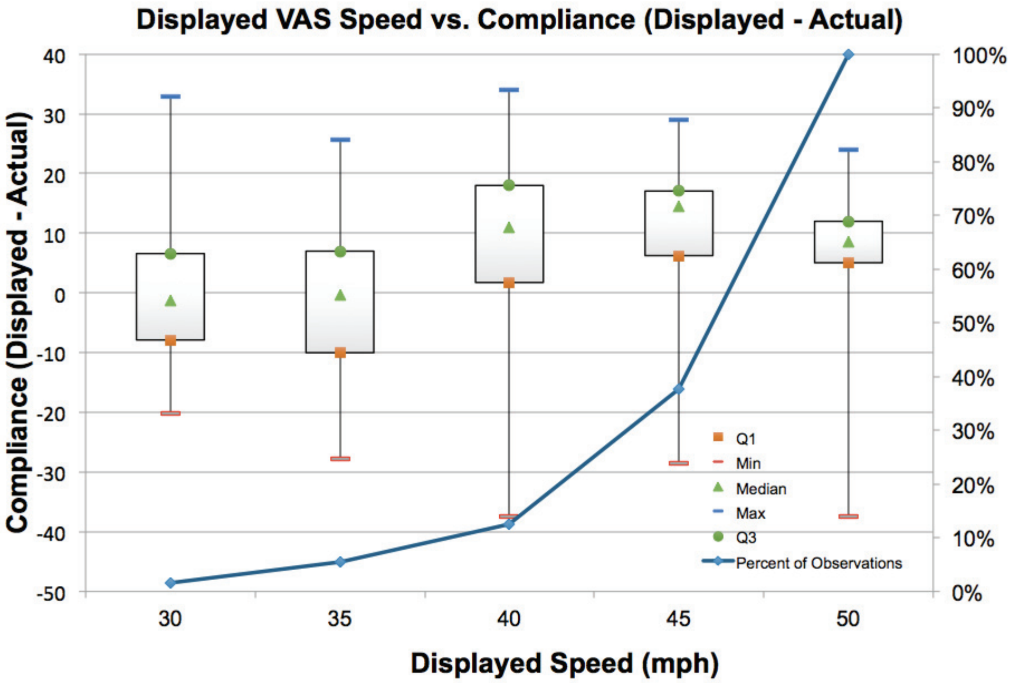

Figure 5: Volume weighted compliance histogram after VAS initialization, OR 217 NB, March 18, 2015

	Date	Day	Mean	Median	St. Dev.	Variance	Min	Max	%< 0	%> 0	%@VAS	%± 5%	%± 10%	%± 15%	%± 20%	%> 20%
Before	6/17/2014	Tue	2	5	17	284	-89	42	26%	71%	2%	28%	58%	78%	87%	5%
	6/18/2014	Wed	4	6	16	263	-91	80	22%	75%	3%	30%	60%	80%	89%	5%
	6/20/2014	Fri	3	5	14	209	-87	44	25%	72%	3%	33%	64%	82%	90%	5%
	6/21/2014	Sat	7	7	9	85	-70	55	13%	84%	3%	31%	63%	85%	94%	5%
	Mean		**4**	**6**	**14**	**210**	**-84**	**55**	**22%**	**76%**	**3%**	**31%**	**61%**	**81%**	**90%**	**5%**
After - Weekdays	7/23/2014	Wed	9	7	22	475	-72	77	28%	67%	6%	27%	44%	59%	69%	24%
	7/28/2014	Mon	11	12	31	969	-96	119	23%	70%	7%	19%	31%	45%	57%	35%
	8/13/2014	Wed	10	10	24	566	-63	85	28%	68%	4%	17%	33%	47%	61%	30%
	8/14/2014	Thu	10	10	20	396	-79	95	23%	66%	11%	25%	41%	56%	69%	26%
	8/15/2014	Fri	13	12	20	413	-67	104	18%	75%	7%	19%	35%	50%	65%	30%
	9/15/2014	Mon	14	16	22	469	-81	118	17%	77%	6%	12%	24%	38%	55%	38%
	9/16/2014	Tue	12	14	21	461	-78	95	20%	75%	5%	14%	26%	43%	60%	32%
	9/17/2014	Wed	12	14	24	589	-79	116	22%	72%	6%	16%	28%	42%	57%	34%
	9/18/2014	Thu	9	11	21	446	-80	110	26%	69%	6%	18%	32%	49%	67%	25%
	9/19/2014	Fri	10	14	25	632	-78	105	24%	71%	5%	13%	25%	39%	56%	32%
	1/26/2015	Mon	21	22	17	300	-88	108	6%	88%	6%	11%	17%	27%	43%	55%
	1/27/2015	Tue	14	15	17	288	-82	102	11%	85%	5%	13%	28%	46%	63%	33%
	1/28/2015	Wed	15	16	17	299	-87	95	10%	84%	6%	14%	26%	42%	61%	35%
	1/29/2015	Thu	16	17	18	334	-82	85	10%	84%	6%	13%	24%	40%	57%	39%
	2/10/2015	Tue	20	20	19	378	-73	101	8%	88%	4%	8%	17%	31%	49%	48%
	2/11/2015	Wed	20	20	19	378	-73	101	8%	88%	4%	8%	17%	31%	49%	48%
	2/12/2015	Thu	16	18	18	312	-83	103	10%	85%	5%	10%	20%	34%	54%	42%
	2/13/2015	Fri	20	18	23	535	-88	122	7%	89%	4%	11%	21%	36%	53%	44%
	3/16/2015	Mon	20	20	19	369	-81	122	6%	89%	5%	10%	18%	33%	49%	48%
	3/17/2015	Tue	19	18	19	344	-81	108	8%	88%	4%	10%	21%	36%	53%	44%
	3/18/2015	Wed	19	20	19	355	-83	109	8%	88%	5%	10%	19%	33%	47%	49%
	3/19/2015	Thu	17	18	17	277	-82	109	7%	90%	3%	8%	17%	35%	57%	40%
	3/20/2015	Fri	16	17	17	289	-82	95	8%	87%	5%	11%	22%	38%	56%	41%
	Mean		**15**	**15**	**20**	**428**	**-79**	**103**	**15%**	**80%**	**5%**	**14%**	**26%**	**41%**	**58%**	**37%**
After - Weekends	7/26/2014	Sat	17	17	20	416	-63	91	10%	81%	9%	16%	25%	36%	55%	41%
	7/27/2014	Sun	22	17	26	658	-56	120	7%	79%	14%	19%	27%	39%	54%	44%
	8/10/2014	Sun	15	16	17	298	-50	48	7%	75%	19%	22%	30%	45%	60%	37%
	8/16/2014	Sat	14	15	17	306	-70	87	9%	77%	15%	20%	32%	46%	61%	36%
	9/14/2014	Sun	23	25	15	238	-100	64	4%	89%	8%	9%	14%	21%	33%	66%
	9/20/2014	Sat	18	17	21	440	-66	115	9%	85%	6%	13%	24%	39%	57%	39%
	1/25/2015	Sun	23	22	16	268	-69	104	2%	92%	5%	7%	13%	24%	44%	55%
	1/31/2015	Sat	21	19	18	311	-81	111	2%	92%	5%	8%	16%	33%	53%	46%
	2/8/2015	Sun	30	26	21	440	-67	105	2%	93%	5%	7%	11%	19%	32%	67%
	2/14/2015	Sat	20	20	15	221	-72	99	4%	91%	5%	8%	16%	29%	47%	51%
	3/15/2015	Sun	26	25	14	195	-59	71	2%	97%	1%	2%	5%	20%	34%	66%
	3/21/2015	Sat	27	23	20	411	-86	111	3%	96%	2%	4%	10%	24%	40%	59%
	Mean		**21**	**20**	**18**	**350**	**-70**	**94**	**5%**	**87%**	**8%**	**11%**	**19%**	**31%**	**48%**	**51%**

Table 1: Summary of Results for VAS Compliance on OR 217

5 VAS Performance of the A99 in Munich, Germany

In order to compare the U.S. based VAS system with another deployment, the same compliance analysis procedure has been reproduced for 10 days of data from a 33 km (20 mile) section of the A99 freeway near Munich, Germany. The VSL displayed speed speeds can be either “60”, “80”, “100”, or “120” in km/h. Compliance statistics were computed for 10 days between April 1 and July 26, 2012.

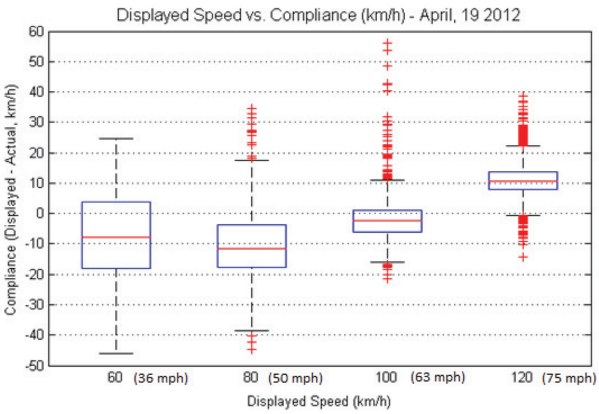

Figure 6: Volume weighted compliance histogram after VAS initialization, OR 217 NB, March 18, 2015

The German VSL system differs from the Oregon VAS system in that at some locations the German variable speed limits are enforced with gantry-mounted speed cameras while the Oregon system is advisory. Another distinguishing factor is that the German VSL system only turns on when activated by traffic congestion or weather. During other times, the system is off and drivers are allowed to travel as fast as they would like (no speed limit). The traffic control system displays no reading during free-flowing traffic. Twenty-five VSL signs regulate speeds on the 33 km section of freeway. Figure 6 illustrates the compliance statistics for April 19, 2012.

Figure 7 is a comparison of the Munich A99 data for all days studied with the OR 217 data. The difference between the German system and the Oregon system are seen very clearly. First, the lowest

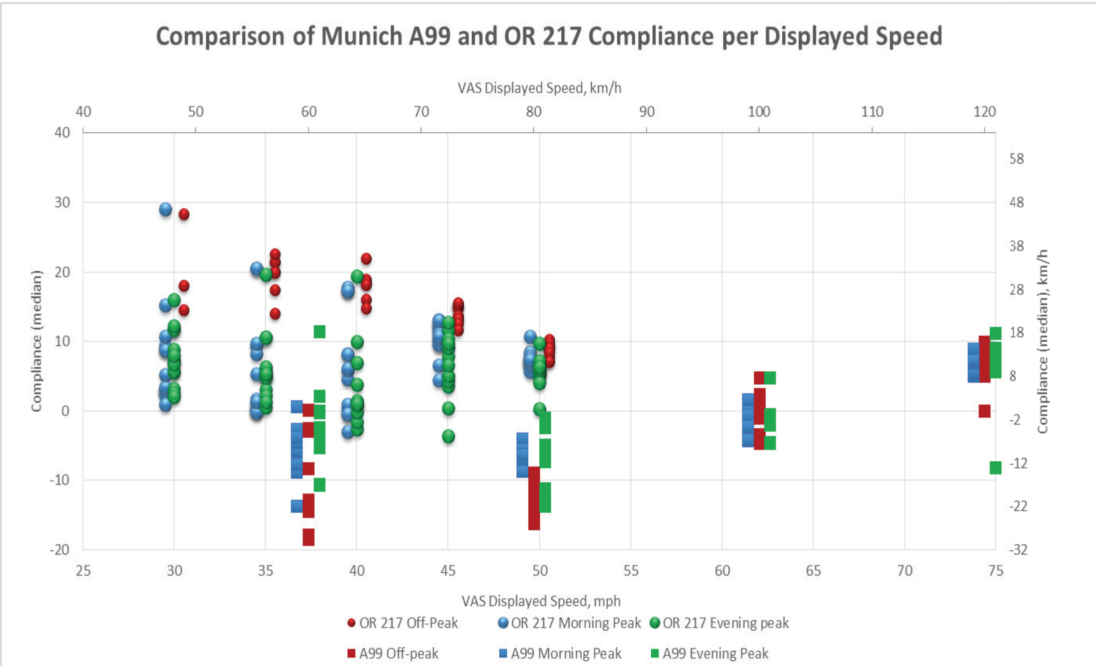

Figure 7: Median driver speed difference from VSL or VAS posted speed for days on Munich A99 SB and Portland’s OR 217 NB

speed of the German system starts mid-range in the Oregon system. The top speed for the OR 217 system is 50 mph or 80 km/h compared to 75 mph or 120 km/h for the A99 freeway in Munich. The compliance values and trends are also quite different between the two systems. In the Oregon system, as the displayed speed increases, driver compliance becomes better. On the A99, drivers tend to drive increasingly faster than the speed limit, as the speed limit becomes higher.

6 Conclusions

The implementation of a congestion-responsive VAS system has the potential to increase safety of heavily-used infrastructure. Harmonizing drivers' speeds prevents accidents and eases stop-and-go traffic. Considering the short time that the OR 217 system has been up-and-running, a year at the time of this paper, the algorithm has had time to be better tuned to be congestion-responsive. It remains important to evaluate the results of the VAS system influence on traffic in order to increase the effective potential of the system. Increasing effectiveness means making sure that the ground truth vehicle data is closely reflected within a tight time-space window on VAS sign displays in addition to investigating actual driver response to advisory speeds. The methods presented in this paper for evaluating system effectiveness may provide tools for refining system effectiveness. Further investigation into the detection-VAS response-driver compliance loop is needed to maximize full potential of the Variable Advisory Speed signs. As shown in the comparison with the A99 freeway in Munich, compliance rates are higher due to enforcement at each VSL gantry. Future research will also include steps to exclude congested intervals from the compliance analysis, and to separate periods when actual speeds are slower than the displayed speeds.

References

Ackaah, W., Huber, G., & Bogenberger, K. (2015). Quality Evaluation Method for Variable Speed Limit Systems. *94th Annual Transportation Research Board.* Washington, D.C.: Transportation Research Board.

DKS Associates. (2013). *Oregon Statewide Variable Speed System Concept of Operations.* Portland, Oregon: Oregon Department of Transportation.

Downey, M. (2015). *M.S. Thesis: Evaluating the Effects of a Congestion and Weather Responsive Advisory Variable Speed Limit System in Portland Oregon.* Portland, Oregon: Portland State University.

Downey, M., & Bertini, R. L. (2015). Evaluation of a Traffic and Weather Responsive Variable Advisory Speed System in Portland, Oregon. *94th Annual Transportation Research Board Meeting.* Washington, D.C.: Transportation Research Board.

Weikl, S., Bogenberger, K., & Bertini, R. L. (2013). Empirical Assessment of Traffic Management Effects of a Variable Speed Limit System on a German Autobahn: Before and After. *Presented at the 92nd Annual Transportation Research Board Meeting.* Washington, D.C.: Transportation Research Board.

Yanfei, S. (July 2013). Analysis of Speed Compliance in Rural Variable Speed Limit System. *ITE Western District Annual Meeting.* Phoenix.