Influence of Truck-Mounted Radar Speed Signs in Controlling Vehicle Speed for Mobile Maintenance Operations

Oregon Case Study

Ali Jafarnejad, John Gambatese, and Salvador Hernandez

Radar speed signs (RSSs) are a measure for reducing traffic flow speeds through work zones. The influence of truck-mounted RSSs on vehicle speed was evaluated for mobile maintenance operations in two multilane maintenance work zones in Oregon. In each case study, two periods of testing were conducted: one with the RSS display turned on (treatment) and one without the RSS display turned on (control), and vehicle speeds were recorded. Descriptive statistics were used to summarize collected data, and a two-sample t-test was applied to each case study to compare the speed difference between control and treatment cases. The findings indicate that vehicle speeds are typically lower and that there is less variation in speeds between adjacent vehicles with the RSS turned on. RSSs are thus promising devices for controlling vehicle speed and making work zones safer for motorists and workers.

Furthermore, workers conducting mobile highway maintenance and rehabilitation operations experience a hazard that is absent in many other types of construction sites: high-speed traffic traveling within a short distance of the construction area. An Occupational Safety and Health Administration fatality investigation reported highway construction to be among the three industries with the highest number of fatalities (2). The risk of death is seven times higher for roadway workers than for the average worker in all work industries combined (3).

Providing sufficient warning of the work zone to the motorists and providing proper safety training to workers are examples of measures taken to prevent work zone injuries and fatalities. For successful mobile operations, the warning area must move with the work area or be repositioned periodically to provide adequate warning for motorists (4). Slowing traffic in a work zone is generally perceived to improve the overall safety of the work zone (5–7). Decreased vehicle speed allows motorists more time to react and reduce their stopping distance and to engage in additional maneuvers to control the vehicle. It also gives more time for workers to move out of the way of the vehicle and reduces the likelihood of serious or fatal injuries to workers, motorists, and passengers (5).

In response to these concerns, the Oregon Department of Transportation (DOT) Research Division investigated highway maintenance project safety enhancements. Types of maintenance work for which Oregon DOT anticipates using traffic control equipped with a mobile radar speed sign (RSS) primarily include sweeping and drainage cleaning operations. Sweeping operations are typically continuously moving and advance at 3 to 5 mph. Drainage cleaning operations are usually not continuously moving but rather stop-and-go, with the work vehicle stopping in front of a drainage inlet for several minutes before proceeding to the next inlet up the highway. In view of these considerations, a study was conducted to quantify the impact of truck-mounted RSSs on vehicle speeds in maintenance work zones and to identify best practices for their use as part of mobile maintenance work operations. The signs are attached to the back of maintenance trucks and deployed as a traffic control measure during maintenance work. Observations of the traffic when the truck moves as part of the maintenance operation are included.

LITERATURE REVIEW

Work zone speed control has been the subject of several research efforts. Various techniques and procedures have been tested and evaluated. Among them are variations of traditional fixed signing,
changeable message displays, radar units with speed sign messages, and a range of electronic devices to sense and display information related to speed. The research indicates that informational measures (e.g., static signage, variable message signage) led to small to moderate speed reductions (8, 9) and that physical measures, such as rumble strips and optical speed bars, were ineffective for transient and moving work zones (9). Enforcement measures (speed camera, police presence) had the greatest effects in reducing work zone speeds (9–13), and educational measures have significant potential for improving public awareness of road worker safety and for encouraging slower speeds in work zones (9).

Past studies have shown that speed monitoring displays with radar have a statistically significant effect in reducing mean speeds and the percentage of drivers exceeding the posted speed limit. McCoy et al. (14) examined the effectiveness of speed displays at a rural Interstate work zone in South Dakota. They used a stationary trailer with speed monitoring display placed at the beginning of the taper. The study indicated that the speed monitoring display reduced mean vehicle speeds by 4 mph.

Garber and Srinivasan (15) used changeable message signs (CMSs) with a radar unit at rural Interstate work zones in Virginia. On the basis of the 85th percentile speed reduction of about 8 mph, the researchers concluded that the CMS system, coupled with a radar unit, reduces speeds for the fastest segment of the driving population. In another study, this technology resulted in a decrease in the mean speed of up to 2 mph and in a 1- to 4-mph reduction in the 85th percentile speed (16).

In addition to police patrol presence, radar speed display has also been shown to influence speeds effectively through work zones (13, 17). For example, a study by the California DOT in 2013 indicated that lane closure, the use of an RSS, and police enforcement together resulted in a speed reduction of 10.5 to 14 mph. In the absence of police enforcement, the radar sign trailer reduced speeds by 8 to 12.5 mph, at least for short-duration work zones (18).

Some research efforts have included RSSs in mobile operations. These studies evaluated the effectiveness of RSSs through the use of focus group surveys to gain insights and to develop guidance for RSS usage in mobile maintenance operations (19, 20).

On the basis of the literature, RSSs have often achieved their objective of a reduction in speeds. Changes in speeds can range from small to significant. The deployment of RSSs does not appear to have worsened operational conditions in any cases, and drivers have shown positive driving behavior toward speed monitoring displays. Some studies have suggested future research on truck-mounted speed display signs to reduce work zone speeds and possibly minimize the severity of crashes (11, 20). The literature review indicates that the effectiveness of mobile RSSs on speed reduction during maintenance and mobile operations has not been evaluated.

RESEARCH METHODOLOGY AND DATA COLLECTION

For the purpose of this research, an RSS was installed on an Oregon DOT maintenance truck in each case study. The truck moved at a low speed (usually 5 to 10 mph) behind the maintenance equipment used to display vehicle speed or provide a warning to approaching vehicles about the work zone.

Four case studies were selected for data collection. In this paper, the results of only two of the case studies, which are similar to the others, are presented. Data on vehicle length, speed, and time of day were collected by NC200 portable traffic analyzers (sensors). The sensor uses vehicle magnetic imaging technology to count the passing vehicles and detect vehicle speed and length (21). The analyzers were secured to the pavement by placing adhesive tape over the analyzer and its protective cover.

In each case study, 14 portable traffic analyzers were placed directly in the traffic lanes. The first analyzers were placed near the “Road Work Ahead” (RWA) sign to capture vehicle speeds before the vehicles entered the work zone. Two analyzers were placed at the beginning of the taper. Other analyzers were placed in the travel lanes at various points in the working area. The location and spacing of the analyzers in the work zone were dependent on the number of travel lanes and the amount and location of work being performed on the given day or night. Before the testing, the analyzers were calibrated to determine their accuracy and adjust collected data before any statistical analysis.

Case Study 1. I-84 Drain Cleaning

The first case study was performed in the westbound direction of I-84, between I-5 and I-205. At this location the highway has three travel lanes in each direction. The posted regulatory speed on this section of roadway is 55 mph. The maintenance operation involved cleaning the drains along the right shoulder of the roadway. There was no lane closure during the operation. A truck with an arrow board directed traffic to the left-hand lanes near the operation. The operation involved frequent short stops near each drain, and a worker exited the vehicle to perform the vactoring (drain cleaning) while standing on the roadway.

Two consecutive nights of maintenance operations were conducted: one without the RSS displaying vehicle speeds (Day 1) and one with the RSS displaying vehicle speeds (Day 2). Every second drain was cleaned each night. On the first night, only odd-numbered drains were cleaned, and on the second night, the even-numbered drains were cleaned. For this case study, in addition to the RSS sign, an advisory speed sign was mounted on the back of the RSS truck or arrow truck. The maintenance operation was conducted for about 1 h on each night. The difference between the hourly traffic volumes between two nights in the corresponding locations was 12% (1,170 on Day 1 and 1,316 on Day 2). The percentage of trucks (vehicles more than 25 ft long) was approximately the same on both days, from 5% to 10%.

Case Study 2. I-205 Sweeping

The I-205 sweeping case study was located in the southbound direction of I-205, west of Oregon City between the Sunset Avenue overpass and 10th Street. The operation consisted of sweeping the left (median) shoulder of the highway with a sweeper. The highway has two travel lanes in each direction. This operation differed from the vactoring operation in Case Study 1 in the number of traffic lanes and the type of mobile operation (intermittent mobile operation in Case Study 1 and continuously moving mobile operation in Case Study 2).

At this location on the roadway, there are 20 light poles in the median. Traffic sensors were placed a consistent distance apart at the location of every fifth light pole. The sweeping was a quick operation, so both control and treatment tests were performed on one night. The maintenance work was performed twice over the same section of roadway without the RSS displaying vehicle speeds. Then the work
was performed two times over the same section of roadway with the RSS displaying vehicle speeds. The first pass of the sweeper through the work zone took approximately 22 min, during which the shoulder was cleaned of any dust and debris. The other three passes of the sweeper took approximately 12 min, since the road was clean and the sweeper could travel faster without any stops. There was a gap of 10 to 20 min between each sweeper pass for preparation and travel time to return to the starting point of the work zone. While the sweeper was returning to the starting point, no maintenance equipment was present in the work zone, and therefore there was a free flow traffic through the work zone.

RESULTS AND DATA ANALYSIS

After data collection on each case study project, the vehicle data were downloaded from the traffic analyzers for analysis. Descriptive statistics were used to summarize the data, and a two-sample t-test was conducted on each case study to compare the speed difference when the RSS was turned on and when it was not turned on. In addition, analyses were only conducted within each case study; comparisons between different case studies were not made. The differences in site conditions, vehicle distribution, test layout, and maintenance work operations between each case study limit confidence in the comparisons because of confounding factors.

Case Study 1. I-84 Vactoring

Figure 1 illustrates how the 85th percentile speed changed from the RWA signs to the end of the work zone at Drain 8 for both cases (with and without RSS turned on). The 85th percentile speeds on both nights were above the 55-mph regulatory speed limit on this section of roadway. As seen in Figure 1, the speeds with the RSS turned on were lower than the speeds without the RSS turned on. The free-flow speed (speed at RWA sign) on Day 2 with RSS was consistently higher than on Day 1 without the RSS turned on during the testing period.

A comparison of the 85th percentile speed at Drain 3 (without RSS turned on) with that at Drain 4 (with RSS turned on) is shown in Figure 2. Drains 3 and 4 were selected for illustration purposes only; similar charts showing comparisons between adjacent drains are provided in the full report (22). Vehicle speeds are lower when work equipment is adjacent. For example, between 22:15 and 22:30 on Day 1 without the RSS turned on, the work took place at Drain 3. At that time, the 85th percentile speed was approximately 55.4 mph. On the second day of testing (with the RSS turned on), the work on Drain 4 took place earlier in the evening. From 22:15 to 22:30 on Day 2 there was no work at Drain 4, and the 85th percentile speed was approximately 54.4 mph, slightly lower than the prior day at the adjacent Drain 3. On Day 2 with the RSS turned on, the 85th percentile speed at the location of the work equipment was less at 53.5 mph. During the whole period of operation, regardless of whether the RSS display was turned on, the vehicles slowed down as they approached the equipment and then sped up downstream of the work equipment. However, comparison of the figures shows that the 85th percentile speed was lower by 7 to 8 mph with the RSS turned on as the vehicles approached the work equipment.

Table 1 shows the decrease in speed from the RWA signs to the work zone for both days of testing. The speeds in the work zone were those recorded by all of the traffic sensors adjacent to all of the drains. For all vehicles (passenger cars and trucks), mean speed decreased from 56.6 mph at the RWA signs to 53.0 mph in the work zone, a 6% decrease, on Day 1 without the RSS turned on. On Day 2 with the RSS turned on, the decrease for all vehicles was greater at 12% (57.2 mph versus 50.5 mph). Separate analysis of cars and trucks yielded similar results: the percentage decrease in mean speed was greater with the RSS turned on. In all cases, the mean speed in the work zone with the RSS turned on was less than without the RSS turned on.
Another comparison of mean speeds within the work zone is shown in Table 2. The mean speed for all vehicles in the work zone on Day 1 without the RSS turned on was 45.5 mph, and the mean speed in the work zone on Day 2 with the RSS turned on was 39.9 mph, a difference of 5.6 mph. This difference was statistically significant ($p < .0001$). A similar statistically significant result was found for cars: mean speeds throughout the work zone were less with the RSS turned on. For trucks, the difference in mean speed was greatest, but the difference was not statistically significant ($p = .269$), likely due in part to the low volume of trucks recorded.

Analyses also focused on the difference in speed between adjacent vehicles as they passed through the work zone. The speed difference between adjacent vehicles is a concern if the difference is large. A faster vehicle approaching a slower vehicle may increase the risk of rear-end crashes. Speed difference was calculated as the difference in speed between a vehicle and the vehicle in front of it. A positive value for speed difference indicates that the vehicle is traveling at a faster rate of speed than the vehicle in front of it. A negative value for speed difference indicates that the vehicle is traveling more slowly than the vehicle in front of it.

Statistical tools were used to analyze the treatment effect of implementing the RSS display. A two-sample $t$-test was conducted to determine whether turning on the RSS display affected the speed difference. In the analysis, a positive value of speed difference was used as the dependent variable. This situation may be hazardous, since it can lead to rear-end crashes. The statistical test was conducted for all vehicles combined, for passenger cars only, and for trucks only.

### Table 1: Percentage of Vehicle Speed Decrease in Work Zone Area, I-84, Vactoring

<table>
<thead>
<tr>
<th>Type of Vehicle</th>
<th>Mean Speed Without RSS (Day 1) at RWA (mph)</th>
<th>Mean Speed Without RSS (Day 1) at WZ (mph)</th>
<th>Decrease in Mean Speed Without RSS (Day 1) (%)</th>
<th>Mean Speed with RSS (Day 2) at RWA (mph)</th>
<th>Mean Speed with RSS (Day 2) at WZ (mph)</th>
<th>Decrease in Mean Speed with RSS (Day 2) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All vehicles</td>
<td>56.6</td>
<td>53.0</td>
<td>6</td>
<td>57.2</td>
<td>50.5</td>
<td>12</td>
</tr>
<tr>
<td>Passenger cars</td>
<td>56.7</td>
<td>53.0</td>
<td>7</td>
<td>57.2</td>
<td>50.6</td>
<td>12</td>
</tr>
<tr>
<td>Trucks</td>
<td>54.5</td>
<td>52.8</td>
<td>3</td>
<td>56.0</td>
<td>50.2</td>
<td>10</td>
</tr>
</tbody>
</table>

**Note:** WZ = work zones.

### Table 2: Effect of RSS on Vehicle Speed, I-84, Vactoring

<table>
<thead>
<tr>
<th>Type of Vehicle</th>
<th>Mean Speed Without RSS (Day 1) (mph)</th>
<th>Mean Speed with RSS (Day 2) (mph)</th>
<th>Difference in Mean Speed (mph)</th>
<th>$p$-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>All vehicles</td>
<td>45.5</td>
<td>39.9</td>
<td>5.6</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Passenger cars</td>
<td>45.3</td>
<td>39.70</td>
<td>5.6</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Trucks</td>
<td>48.6</td>
<td>42.60</td>
<td>6.0</td>
<td>.2692</td>
</tr>
</tbody>
</table>
Table 3 summarizes the results of this analysis. The data used to create the table consisted of all of the data recorded at Drains 3 (without RSS turned on) and 4 (with RSS turned on), as an example. There is no statistical evidence that the RSS display affects speed difference between adjacent vehicles when the speed of the trailing vehicle is greater than the vehicle in front of it for all vehicles combined (\( p = 0.0994 \)) and for trucks only (\( p = 0.292 \)). However, for passenger cars (vehicles less than 25 ft), the difference of 0.85 mph is statistically significant (\( p = 0.048 \)). The table shows that for this case study the speed difference between adjacent vehicles is slightly larger when the RSS is turned on. The difference is significant for passenger cars but not for trucks. In other case studies, the difference in speed between adjacent vehicles was less when the RSS was turned on. For the vactoring case study, the speed difference between adjacent vehicles was less when the RSS was turned on. This could be because of other factors such as the difference in volumes between Day 1 and Day 2. Therefore, the larger mean of speed difference when the RSS was turned on may not be affected by RSS. This could be because of other factors such as the difference in volumes between Day 1 and Day 2. In the vactoring case study, there were three instead of two travel lanes, as in the other case studies. This could be another variable causing a slightly larger speed difference between RSS being turned on and not being turned on.

### Case Study 2. I-205 Sweeping

As in Case Study 1, traffic analyzers provided an opportunity to view vehicle speeds at various locations through the work zone. Figure 3 illustrates how the 85th percentile speed changed from the RWA signs to the end of the work zone at Pole 20 for all cases (with and without RSS turned on and free flow). As shown in the figure, for much of the work zone, speeds with the RSS turned on were lower than without the RSS turned on. The difference ranged from 1 to 3 mph.

An 85th percentile speed over the testing period is illustrated in Figure 4. The 85th percentile speed was consistently lower (by 2 to 2.5 mph) with RSS turned on than without RSS turned on over the course of the testing time period. Free-flow speeds while the sweeping equipment was returning to the start of the work area to make another pass were always higher than during the periods when the sweeping operation was taking place.

A comparison of 85th percentile speeds at Pole 10 with and without the RSS turned on is shown in Figure 5. Pole 10 was selected for illustration purposes only. The figure illustrates the effect of the presence of the work equipment at Pole 10. The vehicles slow down as they approach the work operation and then speed up. Over the same distance, the amount of decrease was greater with the RSS display turned on. For example, from Pole 1 to Pole 10, speeds decreased.
FIGURE 4  Vehicle speed (85th percentile) at Pole 10 during operation time, I-205, sweeping.

FIGURE 5  Vehicle speed (85th percentile) at various distances from operation, I-205, sweeping, Pole 10.
from approximately 67 to 55 mph (a 12-mph decrease) with the RSS turned on and from approximately 64 to 55 mph (a 9-mph decrease) without the RSS turned on.

The data in Table 4 indicate that for all vehicles, mean speed decreased from 60.3 mph at the RWA signs to 55.7 mph in the work zone, 7.6%, without the RSS turned on. During the work periods with the RSS turned on, the amount of decrease for all vehicles was greater at 12%. In addition, the magnitude of the mean speed in the work zone was less. When cars and trucks were analyzed separately, similar results were found: the percentage decrease in mean speed was greater with the RSS turned on, the amount of decrease for all vehicles was greater with the RSS turned on and from approximately 67 to 55 mph (a 12-mph decrease) with the RSS turned on.

Table 5 shows another comparison of mean speeds. The speeds within the work zone adjacent to the poles were compared. For all vehicles, the mean speed in the work zone during the periods without the RSS turned on was 55.6 mph, and the mean speed in the work zone with the RSS turned on was 54.8 mph, a difference of 0.79 mph. This difference was statistically significant ($p = .029$). Evidence suggestive of a difference in mean speeds was found for cars ($p = .058$), while no difference was found for trucks ($p = .360$). For this case study, the difference in mean speeds was less for cars (0.7 mph) than for trucks (1.2 mph).

As in Case Study 1, a two-sample $t$-test was conducted to determine whether turning on the RSS display affected the speed difference between adjacent vehicles. The results of the analysis for positive values of speed difference are shown in Table 6. There is no statistical evidence that the RSS display affects speed difference between adjacent vehicles for which the speed of the trailing vehicle is greater than that of the vehicle in front of it.

### TABLE 4: Percentage of Vehicle Speed Decrease in Work Zone Area, I-205, Sweeping

<table>
<thead>
<tr>
<th>Type of Vehicle</th>
<th>Mean Speed Without RSS at RWA (mph)</th>
<th>Mean Speed Without RSS at WZ (mph)</th>
<th>Decrease in Mean Speed Without RSS (%)</th>
<th>Mean Speed with RSS at RWA (mph)</th>
<th>Mean Speed with RSS at WZ (mph)</th>
<th>Decrease in Mean Speed with RSS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All vehicles</td>
<td>60.3</td>
<td>55.7</td>
<td>7.6%</td>
<td>61.6</td>
<td>54.2</td>
<td>12%</td>
</tr>
<tr>
<td>Passenger cars</td>
<td>60.6</td>
<td>56.1</td>
<td>7.4%</td>
<td>61.4</td>
<td>54.4</td>
<td>11%</td>
</tr>
<tr>
<td>Trucks</td>
<td>56.8</td>
<td>54.5</td>
<td>4.0%</td>
<td>59.4</td>
<td>52.4</td>
<td>12%</td>
</tr>
</tbody>
</table>

### TABLE 5: Effect of RSS on Vehicle Speed, I-205, Sweeping

<table>
<thead>
<tr>
<th>Type of Vehicle</th>
<th>Mean Speed Without RSS (mph)</th>
<th>Mean Speed with RSS (mph)</th>
<th>Difference in Mean Speed (mph)</th>
<th>$p$-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>All vehicles</td>
<td>55.6</td>
<td>54.8</td>
<td>0.8</td>
<td>.0290</td>
</tr>
<tr>
<td>Passenger cars</td>
<td>55.8</td>
<td>55.1</td>
<td>0.7</td>
<td>.0579</td>
</tr>
<tr>
<td>Trucks</td>
<td>53.6</td>
<td>52.4</td>
<td>1.2</td>
<td>.3604</td>
</tr>
</tbody>
</table>

### CONCLUSIONS

The results of this study provide insights into the impacts of a truck-mounted RSS on vehicle speeds during mobile maintenance operations on high-speed roadways. Overall, compared with the situation when speeds were not displayed, the RSS proved to be effective in reducing vehicle speeds in the work zone. The impact occurred for both continuously mobile operations (e.g., sweeping) and intermittent operations (e.g., vactoring).

At the RWA sign location, vehicles travel at normal highway speeds. Passenger cars tend to travel faster than trucks. However, all vehicles begin to slow down as they enter the active work area. There is a gradual decrease in speed to the end of the taper. In the work zone, vehicles typically travel at a lower speed when they pass by the work equipment as described above. After they pass the equipment, the vehicles typically increase their speed. These results are similar to those observed in previous Oregon DOT studies (13, 23).

Limitations on the use of radar speed displays are recognized. The effectiveness of the speed monitor display could decrease over time. Although the displays are an effective speed control countermeasure, speed reductions attained with the radar speed display are usually less than what is desired. These limitations may be mitigated in part by the mobile and intermittent nature of maintenance work (i.e., the RSSs are not stationary and are not present on the roadway when the maintenance equipment is absent). In addition, the use of RSSs is not a panacea; they should be used in combination with other accident prevention and mitigation measures.

### ACKNOWLEDGMENTS

This study was made possible through funding from the Oregon DOT. Special appreciation is expressed to the Oregon DOT Research Unit and Technical Advisory Committee for input into the study. The authors thank all Oregon DOT and construction personnel involved in the case study project for their interest and input into the study and for their efforts in assisting the researchers.
REFERENCES


The Standing Committee on Work Zone Traffic Control peer-reviewed this paper.