ABSTRACT
Highway construction and maintenance crews are often forced to work adjacent to high volumes of traffic and in many cases fast-flowing traffic. This exposure is hazardous and evident from the high number of work zone crashes that occur in the US. Current work zone traffic control measures used to improve motorist and worker safety include positive protection measures such as concrete and steel barriers, as well traditional measures such as variable message signs, flaggers, cones, flares and law enforcement presence at work sites. For short term maintenance operations of duration less than one work shift, the implementation of positive protection measures is not feasible and work crews need to work with minimum protection from errant vehicles that might cross into the work zone.

A recent advancement in work zone safety includes the use of a mobile barrier system (MBS) that can be transported to a work zone and provides positive protection to maintenance crews, with minimum effort and in a very short time. The Oregon Department of Transportation (ODOT) recently purchased such a barrier and, with the limited independent literature available as to the effectiveness of its use in work zones, contracted with researchers at Oregon State University to evaluate the MBS. The research team investigated the barrier during five case studies that were representative of ODOT maintenance activities for various performance metrics such as time of setup, limitations/enhancements to work operations, worker safety and safety perception, worker productivity, and motorist safety perception. The same performance metrics were also investigated in similar maintenance operations without the MBS present.

The results show that the MBS provides enhanced protection to the workers by reducing and eliminating hazards and providing a positive barrier between the work area and passing traffic. The barrier facilitates work operations by enhancing work sites with additional lighting, noise protection, power capabilities, and storage compartments. Additional training is needed for the work crews so that they can fully seize the true potential of the barrier for efficiency.

Key Words
Road Maintenance and Construction, Mobile Barrier System, Safety, Work Zones

INTRODUCTION
Work performed by highway maintenance and construction crews often times
mandates that workers perform their work tasks adjacent to vehicles traveling at very high speeds. The hazardous exposure to this risk is evident by the large number of fatalities that occur in work zones on US roads. The National Highway Traffic Safety Administration (NHTSA) maintains a database of all fatal incidences on US roads, including work zone accidents. There were 667 work zone fatalities in 2009, 576 in 2010, and 587 in 2011 (NHTSA 2013).

The various Departments of Transportation (DOTs) and construction companies in the US that participate in roadway construction operations utilize a variety of traffic control measures such as concrete and steel barriers, variable message signs, and flaggers. For maintenance operations, current practices commonly include the use of truck mounted attenuators (TMA), spotters, cones, and signs. These traffic control devices provide protection from errant vehicles that encroach into work zones yet still require workers to be exposed to a high number of roadway hazards. In addition, the nighttime nature of maintenance operations is an additional risk to workers and motorists alike.

A recent advancement in work zone safety is the use of highly mobile work zone barriers which provide positive protection for workers. Positive protection devices have been defined by the Federal Highway Administration (FHWA) as devices that reduce the risk to workers by containing and directing vehicles away from work zones. These devices must also meet crashworthiness criteria as described in National Cooperative Highway research Program (NCHRP) Report 350 (FHWA 2013). The Oregon Department of Transportation (ODOT) recently purchased such a barrier and contracted with researchers at Oregon State University to evaluate the effectiveness of its use in work zones.

BACKGROUND

The types of accidents that occur in and around work zones have been identified to be of predominately two types: rear-end collisions and sideswipes (Upchurch 2000; Khattak et al. 2002; FHWA 2003; Tsyganov et al. 2003; Sun et al. 2006; Muttart et al. 2007). Other types of accidents include: joint vehicle collisions, vehicles running into materials and equipment, vehicles driving into pits and potholes, vehicles running into pedestrians, and vehicles colliding with road-building machines and equipment (Tsyganov et al. 2003). Literature also suggests that the most effective method in deterring motorists from speeding is by placing police cars visible to the drivers, and/or the use of radar to monitor driver speeds (Antonucci et al. 2005). Police presence is not always practical or economically feasible, and suggestions for additional work zone safety enhancement include: high-visibility apparel and signage, effective communication of work zone start times, clear driver expectations, improved traffic control systems, the employment of competent employees for accountability and oversight, public information campaigns, and full lane closures (Upchurch 2000; FHWA 2003; Antonucci et al. 2005).

Positive protection measures for highway maintenance and construction work zones are gaining popularity and state DOTs have started developing guidelines for their use (Ullman et al. 2007; CDOT 2010). These measures can be separated into two categories: systems/devices for long-term construction/maintenance operations, and systems/devices for short-term construction/maintenance operations. This
distinction is based on the ease of their mobility. For this research, short term operations were considered to be activities which require road closures of no more than one or two days (crew shifts), which is a common duration of maintenance activities performed by DOTs. Due to this short activity window, positive protection measures are not usually implemented for maintenance.

Highly mobile work zone barriers have the capability of being deployed quickly and implemented by maintenance crews. Two examples of mobile barrier systems (MBS) are the Balsi beam (Caltrans DRI 2007; Jewell et al. 2008), developed by Caltrans, and the MBT-1® (Mobile Barriers 2010) that was developed by Mobile Barriers Inc. These consist of a semi-truck cab towing a trailer assembly acting as a barrier between active traffic and the workers.

Research Objectives
The researchers developed the following objectives for the research study:

• Evaluate the use of a MBS in representative ODOT maintenance operations with emphasis on the time required for deployment, limitations/enhancements to work operations, worker safety perceptions, and worker productivity.
• Evaluate and compare the same characteristics in work zones without an MBS.
• Develop guidelines for ODOT and construction contractors for the use of an MBS.

To achieve the above objectives five maintenance projects were selected for investigation. The case study projects were selected by ODOT according to the ODOT maintenance schedule. The following sections discuss the case study projects, observations made, and data collected. Table 1 describes the case study projects and their characteristics.

METHODOLOGY
The researchers utilized several tools to investigate the effectiveness of the MBS in the selected case studies. These tools included the use of surveys to gather viewpoints and opinions from ODOT/contractor workers and supervisors, speed sensors to measure the vehicle speeds traveling in the approach and adjacent to the work zone, and the use of five-minute sample surveys of the worksite conditions and work activities in and around the work zones.

The worker/supervisor surveys consisted of questions that asked for the responders to state their preference of either the traditional safety measures, the inclusion of the MBS, or both equally on the following topics: ease of movement within the work zone; access to equipment; ability to see the worksite; ability to complete their work tasks with quality, efficiency, safety and productivity. Survey participants were also given the opportunity to expand on their answers and give additional input if they wanted, especially on the limitations of the MBS and methods to enhance its capabilities. The five-minute surveys were conducted several times during each case study. For each survey, the researchers closely observed worker and motorists’ actions and exposures. Additional observations about the work zone
conditions and work activities were also recorded if they were observed outside the timeframe of the five minute survey.

<table>
<thead>
<tr>
<th>Project</th>
<th>Location</th>
<th>Work Type</th>
<th>Comparison with/without MB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I-405, Fremont Br., Port., OR</td>
<td>Bridge Joint Repair</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>I-5, Brownsville, OR</td>
<td>Concrete Repl.</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>I-5, Inter. Bridge, Port., OR</td>
<td>Bridge Upgrades</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>I-5, MP 304 – 307.5, Port., OR</td>
<td>HOV Marker Repl.</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>I-205, MP 3, Port., OR</td>
<td>Bridge Joint Repair</td>
<td>Yes</td>
</tr>
</tbody>
</table>

The speed sensors used in the case studies were NC-200 Portable Traffic Analyzers (PTA) produced by Vaisala Nu-metrics. The devices are battery powered, programmable, and can detect vehicles traveling between 8mph and 120mph. The sensors are placed on the traveling lanes at the locations where the speeds need to be investigated and can record for up to 21 days or 300,000 vehicles (Vaisala 2010).

**CASE STUDIES**

**Case Study #1 – I-405 Fremont Bridge**

The first case study project was at the Fremont Bridge (I-405 northbound) in Portland, OR. The work involved the replacement of expansion joints at several locations on the bridge. During the first night of work, the MBS was used in addition to the traditional safety measures, while during the following night the MBS was not used. PTAs were placed on the approach to the work zone, at the cone taper near the work zone, and on the active lanes adjacent to the work zone.

![Figure 1. Joint Repair with MBS (left) and without MBS (right) (Case Study #1)](image-url)
lane and the A-lane shoulder. On the second night, work was performed on both the A-lane and B-lane. Work started on the A-lane at 9:40pm and lasted until 1:20am. Work on the B-lane started at 1:46am and ended at 2:55am. Pictures of the work performed during both nights are shown in Figure 1.

**Case Study #2 – I-5 Brownsville**

The second case study was located on I-5 close to Brownsville, OR. This project involved the replacement of a section of concrete on the road on the northbound and southbound lanes of the highway. The work took place in both directions of the highway on the B-lane at the same time. The MBS was used for a period of three days. The research team performed surveys and placed PTAs on the road in both directions for comparison. Heavy rainfall in the area displaced the PTAs from the road, and no measurable speed data was recorded.

The work that was performed included the demolition and replacement of a segment of concrete pavement. Present at the site were five workers and two ODOT personnel. The equipment present included two jackhammers, an excavator, and two generators. While the MBS was parked overnight it was struck at least once by a passing semi-truck and sustained minor damage (scrapes) to its side wall, variable message sign, and warning light.

**Case Study #3 – I-5 Interstate Bridge**

The third case study took place on the I-5 Interstate Bridge in Portland and involved the replacement of several electrical systems along the bridge’s length. The work took place on two nights. On both nights, implementation of the traffic control plan began at 9:15pm, was completed by 10:15pm, and the crews started work at around 11:00pm. On the first night, traditional measures were implemented and the work required the closure of the A and B lanes allowing the traffic to flow on the C lane. On the following night the MBS was used and the work required the closure of the B and C lanes while vehicle traffic was present on the A lane. Heavy rainfall did not allow the placement of the PTAs on the first night. The PTAs were used on the second night and placed on the approach and at several locations on the bridge.

![Figure 2. Maintenance Work without MBS (left) and with MBS (right) (Case Study #3)](image-url)
The MBS was assigned to work with an electrical crew that required a boom truck and a crew of three workers. The MBS was moving alongside the boom truck from location to location occupying the B lane while the boom truck occupied the C lane. When work was completed at one location, both vehicles would move alongside each other to the next work location. Pictures of the work performed with and without the MBS are shown in Figure 2. The MBS was observed at seven work locations. Work started at 11:15pm and was competed at 4:30am.

Case Study #4 – I-5 MP 304 – MP 307.5

The fourth case study involved the placement of high occupancy vehicles (HOV) markers on the northbound section of I-5 in Portland between MP 304 and MP 307.5. This work required the implementation of a “rolling” work zone where a convoy of maintenance vehicles closed the A lane of the highway to perform work at several locations. The work started with the implementation of the traffic control plan at 9:15pm. The research team placed a total of six PTAs at three locations on the B and C lanes: MP 304, MP 304.5, and MP 305. Work started on the road at 9:40pm. Involved in the operation were the MBS, three trucks with an attenuator attachment, and a truck carrying the three-member striping crew. All of the equipment and materials required for the work were stored on the MBS.

The research team observed the installation of 15 HOV markers. The distance between consecutive work locations was approximately 149 meters (488 ft.), and once again surveys were conducted as in the previous case studies. A picture showing the striping crew installing an HOV marker is shown in Figure 3. Work was completed at 2:35am with the release of all the lanes to the public and the return of the crews to their base of operations.

Figure 3. Striping Crew Placing HOV Marker (Case Study #4)

Case Study #5 – I-205 MP 3

The last case study involved the repair of a seal joint on the northbound lane on I-205 near MP 3, over the Tualatin River close to Portland. The work took place over two nights. Traditional safety measures were used on the first night and work was performed on the B lane. On the second night the MBS was incorporated and work was performed on the A lane.
On both nights the research team and the traffic control crew started the installation of the PTAs at around 9:25pm and they were placed on the approach to the work, at the end of cone taper and adjacent to the work zone. On both nights, traffic control and PTA placement finished at 10:00pm and work started promptly after that.

Present at the site of the work on the first night were several vehicles that included: a pickup truck with a generator, a tool van, a pickup truck with a trailer carrying materials, a portable light post and generator, a truck with all sandblasting material, and two crash trucks. On the second night the same crew and vehicles were present with the exception of the portable light post and generator. Pictures showing the work performed with and without the MBS are shown in Figure 4. Work on both nights finished at around 4:40am.

![Figure 4. Joint Repair without MBS (left) and with MBS (right) (Case Study #5)](image)

### RESULTS

The investigation revealed several potential hazards present during maintenance operations that became more apparent in the case studies where the MBS was used for comparison. Specifically in case studies #1 and #5, without the MBS there was a high noise level coming from passing traffic. The level of noise made it difficult to conduct a conversation without shouting. With the barrier, the noise level was tolerable and conversations were possible in a normal voice. In addition, without the barrier, while standing in the work zone it was possible to feel the wind from passing vehicles traveling at high speeds and in close proximity to the cones and the ongoing work. After analysis of the PTA data, in many instances vehicles were traveling at an excess of 95 km/h (65 mph) next to the active work zones.

Without the MBS, there was a constant need for a spotter to watch out for errant vehicles. This was particularly evident when work was carried out close to the active lanes (Figure 1, Figure 4). With the MBS, there was no need for a spotter, freeing a crewmember to perform other duties. In addition, with the MBS in place workers tended to remain within the work zone, decreasing their exposure to hazards. In contrast, without the MBS the workers were observed moving around the cones and into the active lanes.

The MBS was found to enhance worker safety according to the work crew.
survey responses. Out of the 35 responses from all the case studies, 31 stated that they felt safer with the MBS, three indicated that they felt safe with both, and only one said that they felt safer with traditional measures. Many of the workers stated that with the MBS they did not have to always “look over their shoulder” for errant vehicles, allowing them to focus on their tasks and perform their work better.

The design of the barrier allowed the work zone to be enhanced in other aspects besides safety. In case study #3, it was very clear that there was a need for increased illumination. During the first night that the MBS was not used, the workers used headlamps and flash lights, and the work zone was not very visible. With the MBS and its built-in work lights, the work zone was adequately illuminated (Figure 2). Similarly in case study #5 there was no need for the light source on the night the MBS was used (Figure 4). In case study #4, all the equipment necessary for the installation of the HOV markers were stored within the MBS’s storage compartments making them accessible to the workers (Figure 3).

The presence of the barrier was also beneficial to the traveling public. In the cases where welding was required (case studies #1 and #5), welding glare was highly visible to the motorists. In case study #1 the welding screen was carried into the active lane by the wind (Figure 1) and in case study #5, a worker was standing in front of the welding process to shield the vehicles from the glare (Figure 5).

![Figure 5. Welding during Case Study #5](image)

Vehicles traveling adjacent to the MBS were found to have smaller reductions in speed. This was observed clearly in case study #5, where at the same location and conditions, the differences in vehicle speed between the end of taper and the work zone were seen to have a reduction of 20.4 mph without the MBS (95% CI 19.6 – 21.2) and a reduction of 14.4 mph with the MBS (95% CI 13.2 – 15.5) (Welch two sample t-test). Vehicle speeds were obtained by downloading the vehicle data from the various PTAs placed on the roadway. Possible outliers, erroneous data, and information recorded during non-free-flow periods, were removed prior to the analysis. The Welch two sample t-test was selected because it allows for the comparison of two normally distributed samples with unequal standard deviations (Ramsey et al. 2002).
CONCLUSIONS

Based on the researcher observations, and the analysis of the vehicle speeds and survey responses collected from the case studies, the MBS was found to be effective and beneficial to ODOT maintenance workers and the traveling public. The barrier eliminated and reduced safety concerns such as errant vehicles. The MBS creates a “wall of steel” around the work zone that allows workers to concentrate on the work without constantly being concerned about their safety from external factors beyond their control. It was also observed that the noise level was greatly reduced with the presence of the barrier, allowing workers to carry on a conversation in a normal voice and thus enhancing communication between the work crews.

The barrier provides enhancements to the work zone that traditional safety measures cannot. The various compartments present in the barrier provide storage for materials. The barrier also enhances the site by supplying additional lighting and electrical power for the tasks at hand. These features allow the elimination of additional vehicles and equipment to be present on site, such as portable light sources and generators.

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REFERENCES


