FUNCTIONAL REQUIREMENTS FOR HIGHLY-PORTABLE POSITIVE PROTECTION TECHNOLOGIES IN WORK ZONES

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ABSTRACT

Many work zone devices, such as truck-mounted attenuators, cones, and barrels, are used to separate workers from the traveling public during construction and maintenance activities. However, these devices do not provide lateral impact protection. Conversely, concrete barriers are often used to physically separate workers and moving traffic at long-term construction projects. Unfortunately, many work activities are of shorter duration or require continuous movement along the roadway, and so cannot be protected through concrete barrier placements.

This paper describes a set of functional requirements developed for highly-portable positive protection technologies that protect highway workers. These requirements were based on an assessment of a large number of construction and maintenance work activities that are highly mobile and thus would potentially benefit from such a system. Specific roadway design features believed to have the most significant impact upon the functional requirements of a highly-portable positive protection system were also considered.

While it is desirable to have a protective device that covers a wide possibility of work zone conditions, this preliminary study shows there are some practical limits to activities that can be accommodated by a single type of highly-portable positive protection device. As defined, a protection system meeting the stated requirements could accommodate about two-thirds of the construction and maintenance activities considered. Perhaps a highly-portable positive protection system could be used during some of the remaining activities if work crews were to adopt slightly different procedures for those activities.

INTRODUCTION

Many work zone devices, such as truck-mounted attenuators (TMAs), cones, and barrels, are used to separate workers from the traveling public during construction and maintenance activities. However, these devices do not provide lateral impact protection. Conversely, concrete barriers are often used to physically separate workers and moving traffic at long-term construction projects that remain stationary for long periods of time. Unfortunately, many work activities are of shorter duration or require continuous movement along the roadway, and so cannot be protected through concrete barrier placements.

The risk to highway workers from errant vehicles entering the work area is not insignificant. Recent data from New York indicates that worker injuries and fatalities due to vehicle intrusions account for about seven percent of all serious worker injuries that occur in work zones (*1*). In addition, it does appear that vehicle intrusions may be overrepresented in mobile work activities as compared to more stationary work zones. In New York, vehicle intrusion crashes into mobile work zones accounted for 20 percent of all intrusion crashes that occurred. Although actual work zone exposure data are not available, the researchers believe that mobile work zones make up a much smaller percentage of total work activities that occur on public roadways.

Recently, the Texas Transportation Institute (TTI) conducted a research project for the Federal Highway Administration (FHWA) to investigate the feasibility of developing a highly-portable lateral protection system. The specific objectives for the project were to:

- define elements of typical highway maintenance and construction work activities that require workers to be on the roadway with traffic, and
- establish functional requirements and performance specifications for a highly-portable positive protection system to protect workers under such conditions.

HISTORICAL PORTABLE WORKER PROTECTION SYSTEM DEVELOPMENT

In the early 1980s, TTI crash tested a 100 ft long “centipede” barrier made of a train of old cars (*2*). This portable construction barrier was comprised of five station wagons connected together by tow bars and strut assemblies. Thrie-beams were attached to the side of the station wagons and lapped in anticipation of an impact with the side of the system from rear to front. The system successfully redirected a 4400 lb passenger vehicle traveling 48 mph and at an impact angle of 15 degrees.

Around the same time, TTI crash tested a box beam barrier suspended between two dump trucks (*3*). This truck-mounted portable maintenance barrier was fabricated from rectangular structural tubes welded together and supported on two standard five cubic yard Texas Department of Transportation (TxDOT) dump trucks. Additional modifications were made to mate the barrier to the trucks. Mobilization of the system involved the use of a separate transport dolly that towed behind one of the support trucks. Some deployment of the system was required upon reaching the destination. The system successfully redirected a 4400 lb passenger sedan traveling 50 mph and at an impact angle of 15 degrees.

While there was some field testing of these two units, efforts did not result in fully operational devices. In 1993, TTI completed National Cooperative Highway Research Project

(NCHRP) Project 17-8 (*4*), which resulted in a user's manual for guidelines of barrier treatments in work zones but does not directly address the protection of workers in short duration work zones. Consequently, additional research and testing has still been needed to address positive protection needs for highly-mobile work operations.

CONSTRUCTION AND MAINTENANCE ACTIVITIES POTENTIALLY PROTECTED BY A HIGHLY-PORTABLE POSITIVE PROTECTION SYSTEM

Work activities that last only a short time at any one location or which move slowly or intermittently along the roadway and involve some level of worker exposure (i.e., workers on foot in the roadway) create the most difficulty for worker protection as well as for traffic control. Through a review of current practices and interviews with selected state transportation agency personnel, researchers identified the following construction and maintenance activities that meet these criteria and thus would benefit most from a highly-portable worker protection system:

- litter pickup,
- bridge clearance measurements,
- pavement profiling,
- pavement core sampling,
- edge/guardrail repair,
- short-line striping,
- signal installation/maintenance,
- lighting installation/maintenance,
- rumble strip installation,
- raised pavement marker installation/removal,
- crack seal,
- pothole patching,
- asphalt milling,
- sealcoat,
- asphalt overlay,
- level up, and
- traffic control setup/removal.

The specific characteristics of these activities were identified so that each activity could be categorized along three key roadway and environmental dimensions believed to be most critical for ultimately defining highly-portable positive protection functional requirements:

- mobility needs,
- spatial requirements, and
- access requirements.

Researchers then established formal category definitions for those activities within each dimension in order to assess the impact to the functional requirements. These categorizations are summarized in Tables 1 through 3.

Mobility requirements were assessed as one of three types of operations (following the standard work duration definitions included in the Manual on Uniform Traffic Control Devices [MUTCD] [*5*]):

- constantly/intermittently moving at approximately 3 miles per hour (mph) (walking speed),
- short duration stationary (less than one hour at a location), and
- short-term stationary (less than 12 hours at a location).

As shown in Table 1, this categorization illustrates that the majority of mobile work activities that occur move continuously at speeds somewhat less than 3 mph or intermittently along the roadway.

TABLE 1 Mobility Requirements of Mobile Activities

Constantly/Intermittently Moving	Short Duration Stationary (less than 1 hour)	Short-Term Stationary (less than 12 hours)
Litter pickup Pavement profiling RPM installation/removal Crack seal Longitudinal shoulder texture Asphalt milling Sealcoat/asphalt overlay Level-up tab installation crew Traffic control setup/removal	Bridge clearance measurements Pavement core sampling Short-line striping Signal/lighting install/maintenance Pothole patching	Edge/guardrail repair Lateral rumble strips Traffic control flagger

Table 2 contains the spatial requirements that researchers categorized by work location and the number of separate work crews likely to be present during the construction or maintenance activity. Researchers estimate that each work crew (not including litter pickup or bridge clearance measurements) typically utilizes a work space 20 to 50 foot (ft) long. The upper end of this range reflects situations where the work area (and crew) is between two work vehicles following each other. Consequently, it is possible that the specific actions taken by each crew in those situations could be accomplished in a somewhat smaller distance. Researchers could not determine by simple visual inspection whether all of those types of activities could be accomplished within the lower bound of the range (i.e., 20 ft).

TABLE 2 Spatial Requirements of Mobile Activities

Single or Multiple Crews All Lanes/Roadside	Single Crew [a] One or More Lanes	Multiple Crews [a] One or More Lanes
Litter pickup Bridge clearance measurements	Pavement profiling Pavement core sampling Edge/guardrail repair Short-line striping Signal/lighting install/maintenance [b] Lateral rumble strips RPM installation/removal Pothole patching Longitudinal shoulder texture Asphalt milling Level up tab installation crew	Crack seal - Blowout crew - Sealing crew Sealcoat/asphalt overlay - Paper/prep crew - Spreader/overlay crew - Tab install crew

[a] Could also include a traffic control crew.
[b] This includes installation of inductive loop detectors in the travel lane.

As denoted in Table 2, most of the activities take place in a single travel lane that is moved longitudinally as work progresses. However, if multiple lanes are first closed in a stationary traffic control set-up, a few activities (such as loop detector installation or short-line striping) are sometimes accomplished by moving laterally across the travel lanes in a sequential manner. For these types of activities, the ability of the protection system to move laterally or to expand laterally to incorporate as much as an additional lane of traffic may be beneficial in some situations. However, such capabilities do not appear to be an absolute necessity for the majority of work activities being considered for protection by a highly-portable positive protection system.

Finally, access requirements refer to the need of workers to bring equipment and tools into the active work area, or to somehow access the equipment and tools while working. For some operations, access to additional equipment beyond what the workers typically carry to complete the work is not required. In contrast, other activities require rather large objects or materials, hand-operated equipment, or even heavy equipment to be brought into and out of the work space. As Table 3 implies, the ability to bring fairly large pieces of equipment into the actual work area, as well as access materials and equipment contained on the back of a lead vehicle, are is seen as a critical functional requirements for a highly-portable positive protection system.

TABLE 3 Access Requirements for Mobile Activities

None	Hand-Carried or Rolled Equipment	Vehicle/Heavy Equipment
Bridge clearance measurements Litter pickup ground crew Sealcoat/asphalt overlay tab installation crew Level-up tab installation crew Traffic control flagger	Short-line striping Signal/lighting install/maintenance Lateral rumble strips RPM installation/removal Pavement profiling	Litter pickup bag crew Pavement core sampling Edge/guardrail repair Signal/lighting install/maintenance Lateral rumble strips RPM installation/removal Crack seal Pothole patching Longitudinal shoulder texture Asphalt milling Sealcoat/asphalt overlay - Spreader/overlay crew - Paper/prep crew Traffic control setup/removal

ROADWAY CHARACTERISTICS INFLUENCING HIGHLY-PORTABLE POSITIVE PROTECTION SYSTEM DESIGN

Generally speaking, the highly-mobile construction and maintenance activities described above can be required to occur on essentially all types of public roadways nationally. Roadway design standards are established by the American Association of State Highway and Transportation Officials (AASHTO) (*6*) and by state departments of transportation, and vary by functional classification of roadway and other factors. The specific roadway design features believed to have the most significant impact upon the functional requirements of a highly-portable worker protection system are discussed below.

Lane and Shoulder Width

Current design standards establish 12-ft lanes as the norm for most roadways. Slightly smaller widths (typically down to 11 ft) are sometimes used even on high-speed freeways in urban areas, if space availability was a concern at the time of roadway design or if the roadway segment was re-striped to increase the number of slightly-narrowed travel lanes available to traffic. Furthermore, some low-speed facilities in urban areas may have lanes as narrow as 10 ft. A highly-portable positive protection system must be designed so as to allow full access to an entire lane cross section, as many of the operations involve repairs right up to the lane or edge lines. A bigger potential concern, however, is the amount of encroachment that may be required of the protection system into an adjacent lane to accommodate the work area. The smaller the width of the travel lanes, the greater the effect of an adjacent-lane encroachment by the protection system upon the ability of approaching traffic to safely pass by the work area.

Traffic Speeds

Operating speeds on roadways where a highly-portable positive protection system might be employed could vary from as low as 30 mph on urban collectors to 70 mph or more on rural facilities (with higher speeds obviously representing the more sever constraint from a portable protection system design perspective).

Vehicle Type

With regard to vehicle types, most roadway facilities are used by both automobiles and by large trucks. Whereas the protection against an intrusion by a truck would represent the most severe protection device design condition, it is possible that truck intrusions do not represent enough of a potential safety concern to mobile work zone activities to justify using them as a design vehicle (especially given that test requirements in National Cooperative Highway Research Program [NCHRP] 350 do not use truck characteristics as part of the crash test impact conditions [*7*]). Unfortunately, researchers were unable to uncover any crash data as to the relative risk of truck intrusions into mobile work zones.

Number of Travel Lanes

The number of travel lanes on a given roadway segment influences the portable worker protection system design not only in terms of requiring protection on either side of the work area (i.e., a work crew in the left lane of a multi-lane facility will require protection on the right side, whereas a crew in the right lane requires protection on the left side), but also in defining whether protection on both sides of the work area will be required at the same time (for any middle lane work activities). It should be noted that although long-term middle lane traffic-splitting techniques have been used by some agencies on multi-lane facilities, such techniques are currently not used very extensively for mobile work activities because of safety concerns. Therefore, the need for simultaneous protection from both sides of the work area is likely to be quite small.

The number of travel lanes on a roadway segment is also a factor in defining the potential side impact condition of an errant vehicle into the work area; the greater the number of travel lanes present, the greater the potential initial offset or lateral separation between the vehicle and the work area and the greater the possible impact angle into the highly-portable positive protection system.

Vertical Curvature

Vertical alignment is defined by the algebraic difference in grades on a roadway segment and the length of the curve used to bridge that difference in grade. These curves are designed to provide adequate stopping sight distance by a passenger automobile to a 0.5-ft object in the travel lane. These vertical curves require that a highly-portable positive protection system be designed to accommodate small changes in elevation through appropriate hinged connections to anchor vehicles, minimum clearance heights to the bottom of the barrier, etc. A review of the AASHTO design standards (*6*) suggests that a portable protection device 50 ft long will need to accommodate only about 6 inches (in) of elevation change (i.e., will need at least 6 in of ground clearance) over a vertical curve, regardless of the operating speed of the roadway. However, severe vertical alignment changes can create potential “hang-up” problems, depending on the particular design of the highly-portable positive protection system. Vehicles and equipment with overhangs greater than 15 ft and wheelbases 40 ft or longer may be more prone to hang-up problems (*8*). Fortunately, software has been developed to evaluate specific vehicle or equipment configurations for hang-up potential (*9*).

Horizontal Curvature

Horizontal alignment is defined by curve radius and superelevation rate, both of which are selected based on roadway classification and design speed (*6*). The most significant implications of horizontal curvature upon a highly-portable positive protection system are in terms of the lateral encroachment over the adjacent lane that will occur as the work convoy traverses a curve, and in the possible worse-case impact conditions that can develop between by an errant vehicle approaching the work convoy positioned on a curve. With regards to the issue of lateral encroachment, Table 4 provides estimates of extent of encroachment of a highly-portable positive protection system into an adjacent lane as a function of curve radii and corresponding maximum design speed for which a curve of that radius would be allowed (*6*). As Table 4 illustrates, encroachment values would be minimal at all but only the very sharpest of horizontal curves if the protection system length is kept to about 50 ft. Such minor encroachments would still allow traffic to continue to operate in the adjacent lane. However, if the protection system approaches 100 ft in length, significantly larger encroachments can be expected. In fact, for curve radii less than 1000 ft, it is likely that a work convoy would need to require traffic in the adjacent lane to vacate that lane into the next lane over or possibly onto the shoulder.

Theoretically, worse-case oblique-angle side impacts could occur on horizontal curves, as the impact angle (Ω) increases slightly from what would be capable of occurring on a tangent, as depicted in Figure 1. As shown, an approaching vehicle begins to lose control prior to reaching the work area, and its travel path carries it into the work area. Meanwhile, the location of the work activity in the horizontal curve has oriented the side of the proposed protection system slightly towards the approaching errant vehicle.

TABLE 4 Possible Highly-Portable Worker Protection Device Lateral Encroachment into Adjacent Lanes on Horizontal Curves

Curve Radius (ft)	Maximum Design Speed (mph)	Lateral Encroachment into Adjacent Lane for 50-ft Barrier Length (in)	Lateral Encroachment into Adjacent Lane for 100-ft Barrier Length (in)
300	30	12.5	50.0
400	30	9.4	37.5
500	40	7.5	30.0
750	50	5.0	20.0
1000	50	3.8	15.0
1250	60	3.0	12.0
1500	60	2.5	10.0
1750	70	2.1	8.6
2000	70	1.9	7.5
2500	70	1.5	6.0

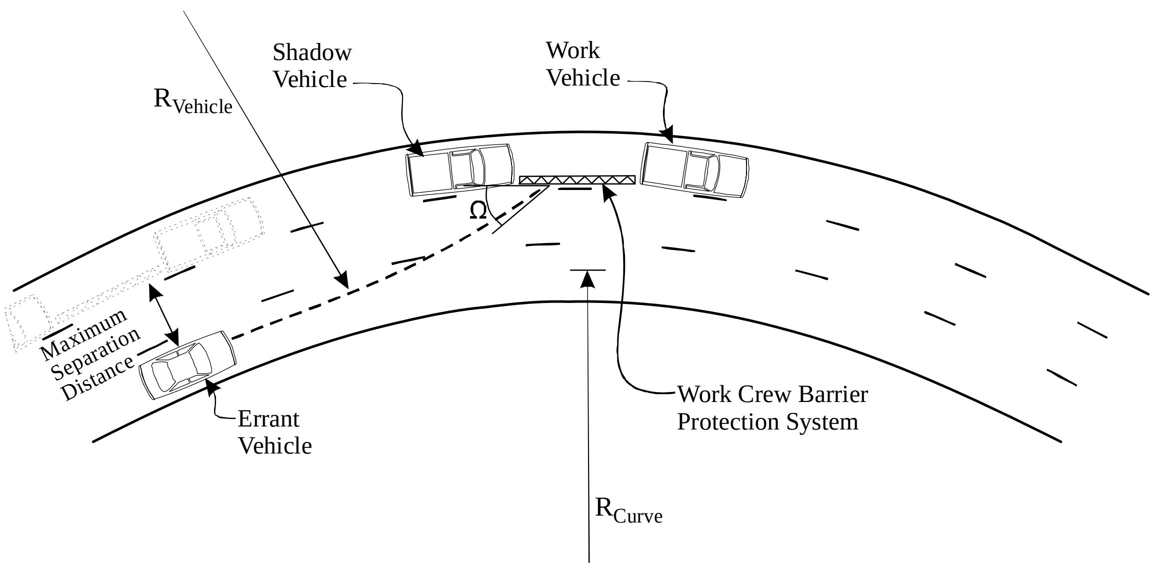


FIGURE 1 Illustration of impact condition on a horizontal curve.

Characteristics of the horizontal curve that influence the calculated impact angle include its radius (R_{curve}), the number of lanes of the roadway (which defines the maximum separation distance between the errant vehicle and the work activity), and the superelevation rate used (e). Superelevation is included on most horizontal curves on high-speed roadways to counter the effects of centripetal force on the vehicle traversing the curve, and can range from 0.04 up to 0.10, depending on the design speed of the roadway (*6*). The impact angle (Ω) is actually the sum of the angle of rotation of both R_{Curve} and $R_{Vehicle}$ between the location where the errant vehicle begins its circular path towards the outside of the curve and the point where it meets the portable system protecting the work crew. Figure 2 illustrates the resulting impact angles computed as a function of the assumed speed of the errant vehicle, the radius of the curve

(R_{Curve}), and lateral separation between where the errant vehicle began and the lane where work activity is occurring. At a lateral separation of 6 ft (i.e., the errant vehicle begins in the lane immediately adjacent to the lane that work activity is occurring), computed impact angles are all less than 15 degrees regardless of the errant vehicle speed assumed. For a 42-ft separation distance (i.e., the errant vehicle is four travel lanes over from the work activity travel lane), impact angles as high as 40 degrees could potentially occur at lower errant vehicle speeds. At higher errant vehicle speeds (60 and 70 mph), however, impact angles of 20 to 25 degrees are calculated to be possible.

MARKING AND TRAFFIC CONTROL REQUIREMENTS

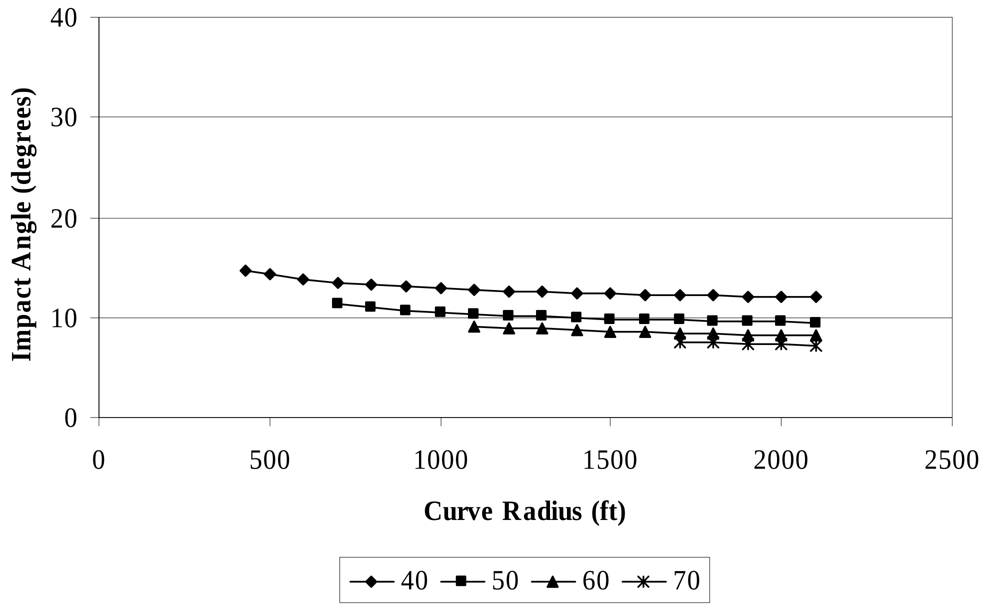
The MUTCD sets forth the basic principles and standards for traffic control on all public roadways in the U.S. (*5*). Part VI of the manual provides standards for temporary traffic control, including construction and maintenance work zones. The manual is fairly explicit with regards to advance signing requirements, channelizing device design and placement, and pavement delineation for temporary traffic control situations. Requirements for vehicle and equipment delineation are less defined. Generally speaking, vehicles and equipment on or next to travel lanes for the purposes of construction, maintenance, or service are simply required to have at least one flashing or rotating beacon as delineation. Research is currently underway by AASHTO (*10*) to provide better guidelines regarding warning lights to be used on work vehicles and equipment.

FUNCTIONAL REQUIREMENTS OF A HIGHLY-PORTABLE POSITIVE PROTECTION SYSTEM

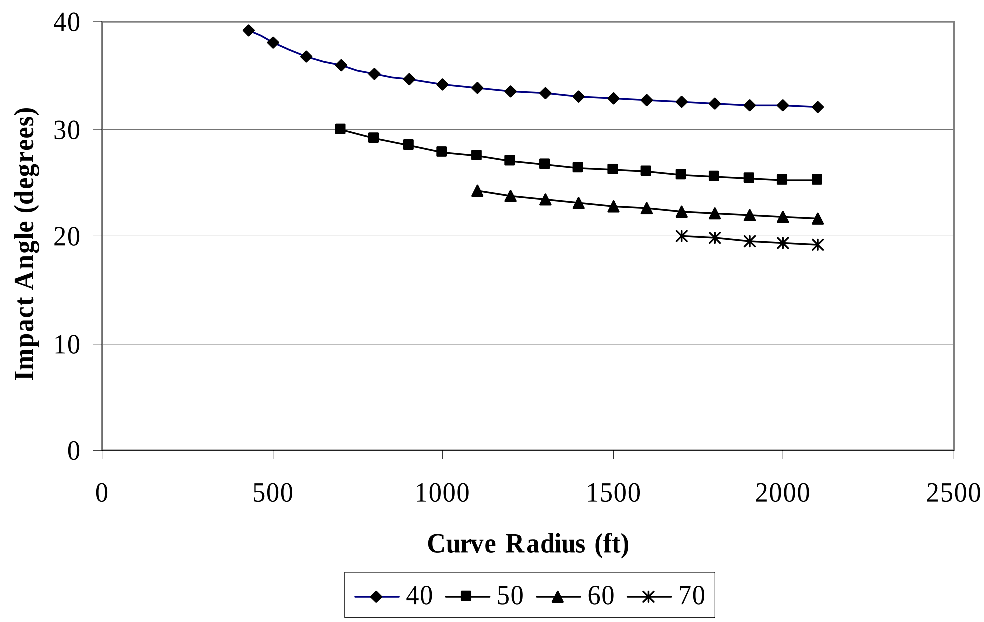
Table 5 contains the minimum and desirable functional requirements for a highly-portable positive protection system that researchers prepared based on the results of the assessments of work activities and impact conditions summarized in the previous sections. These requirements were developed based on the three dimensions previously identified, as well as two ancillary dimensions:

- spatial requirements,
- access requirements,
- mobility needs,
- transportability, and
- traffic control and illumination.

Minimum requirements were defined by the researchers as those which were essential for a highly-portable positive protection system to meet in order to have any type of applicability to the types of work activities being considered. Failure to meet the minimums would negate the ability of a work crew from using the system in most of its potential applications. Desirable requirements, on the other hand, were defined as those which could further increase the applications and conditions under which the system could be deployed or which could reduce the difficulties associated with deploying the system under constrained conditions.



(a) Impact angles for maximum separation distance of 6 ft.



(b) Impact angles for maximum separation distance of 42 ft.

Figure 2 Effect of errant vehicle speed upon possible impact angles.

TABLE 5 Functional Requirements of a Highly-Portable Positive Protection System

Dimension	Minimum Requirement	Desirable Requirement
Spatial	• The system must be capable of allowing workers to access the entire width of a single travel lane. • The system must adequately protect the typical work area lengths required for mobile and short-duration construction and maintenance activities. Limited observations indicate that these activities are currently accomplished within 20 to 50 foot lengths. • The system must be capable of protecting either side (left or right, depending on the lane where work is occurring) of a work area.	• The system should be capable of accommodating varying travel lane widths from 10 to 12 feet in order to minimize the encroachment of the system into adjacent travel lanes. • The system should be capable of being configured so as to protect both sides of the work area when activities occur in the middle lane of multi-lane roadways.
Accessibility	• While deployed, the system must allow rolling equipment such as thermoplastic and bitumen heaters and hand equipment to be brought into the work area. • Once deployed, the system must continue to allow workers to access truck-mounted equipment and materials (i.e., air compressor hoses, pothole patching material, etc.) normally used in mobile maintenance operations.	• None.
Mobility	• Once deployed, the system must have the ability to protect a work area that progresses continuously or intermittently along the roadway at speeds less than 3 mph.	• The system should be deployable into a travel lane in less than 30 minutes. • The system should be capable of being picked up and ready for transport to another location for deployment within 30 minutes.
Transportability	• When configured in its "transport" mode, the system must operate within the design template of a WB-50 (semi-tractor trailer) design vehicle with regards to horizontal and vertical clearances, turning path radii, vehicle hang-up potential, etc.	• None.
Traffic Control and Illumination	• The system, when deployed, must comply with the *Manual of Uniform Traffic Control Devices (MUTCD)* with regards to delineation and warning light requirements for on-roadway work equipment. • The deployed system must have rear-end crash protection.	• The system should be flexible enough to accommodate special flashing warning light and delineation requirements for work equipment as defined by each state's motor vehicle code, Department of Transportation special vehicle warning light and delineation policies, or similar local requirements. • The system should be capable of accommodating artificial lighting that may be needed in the work area at levels defined by recent AASHTO guidelines (*10*, *11*, *12*).

Table 6 cross-references the identified construction and maintenance activities to the functional requirements and thus shows which activities do and do not meet the functional requirements. A discussion on the development of the functional requirements follows.

As Table 6 illustrates, a majority of the construction and maintenance activities being considered for protection by a highly-portable system take place in a single travel lane and can typically utilize a work space 20 to 50 ft long (and is why the minimum length and width requirements were developed around these values). However, a few activities (bridge height measurements, loop detector installation, and some short line striping) are sometimes accomplished by moving laterally across the travel lanes in a sequential manner. In addition, activities such as milling and overlay tend to encroach into the adjacent travel lanes and typically need a longer space, since the equipment works right next to the edge of the travel lane and the operation includes trucks delivering materials, large equipment, and several crews of workers in the immediate vicinity of the equipment. In most cases, litter pickup would also not be accommodated by the minimum spatial requirements since multiple workers are typically spread out over long distances along the roadside. These exceptions are noted where appropriate in Table 6.

In addition to the minimum width and length requirements, the system must be capable of protecting either side (left or right, depending on the lane where work is occurring) of a work area. However, in order to make the system more versatile and applicable to more constrained width situations, it is desirable for the system to be capable of being configured so as to protect both sides of the work area. Such a need would exist when activities occur in the middle lane of multi-lane roadways, for example. However, a system that protected only one side of a work area at a time could still be used in this type of situation (presumably to protect the side considered to be at most risk to workers), and thus why this type of requirement is considered only desirable. Finally, another desirable requirement of a system would be for it to accommodate varying travel lane widths from 10 to 12 ft in order to minimize the encroachment of the system into adjacent travel lanes.

The two minimum functional requirements pertaining to accessibility were included in Table 5 in order to meet the needs of the workers to bring equipment and tools into the work area, and continue to access them while working. In general, the few activities (signal/lighting installation/maintenance, longitudinal shoulder texture, asphalt milling, and overlay) that cannot be accommodated by these minimum accessibility requirements typically require large amounts of heavy equipment and multiple vehicles to complete the work, such that it was not possible to identify any type of desirable functional requirement that could accommodate one or more of these activities in any reasonable fashion.

TABLE 6 Assessment of Functional Requirements Per Work Activity

Dimension	Meets Minimum Requirements	Meets Desirable Requirements	Does Not Meet Requirements
Spatial	Pavement profiling Pavement core sampling Edge/guardrail repair Short-line striping [a] Signal/lighting install/maintenance [b] Lateral rumble strips RPM installation/removal Crack seal Pothole patching Longitudinal shoulder texture Sealcoat/asphalt overlay - Tab installation crew Level up - Tab installation crew Traffic control		Litter pickup Bridge clearance measurements Short-line striping [s] Signal/lighting install/maintenance [b] Asphalt milling Sealcoat/asphalt overlay - Paper/prep crew - Spreader/overlay crew
Accessibility	Litter pickup Bridge clearance measurements Pavement profiling Pavement core sampling Edge/guardrail repair Short-line striping Lateral rumble strips RPM installation/removal Crack seal Pothole patching Sealcoat/asphalt overlay - Tab installation crew Level-up - Tab installation crew Traffic control		Signal/lighting install/maintenance Longitudinal shoulder texture Asphalt milling Sealcoat/asphalt overlay - Paper/prep crew - Spreader/overlay crew
Mobility	Litter pickup Pavement profiling RPM installation/removal Crack seal Longitudinal shoulder texture Asphalt milling Sealcoat/asphalt overlay Level-up - Tab installation crew Traffic control - Setup/removal	Bridge clearance measurements Pavement core sampling Edge/guardrail repair Short-line striping Signal/lighting install/maintenance Lateral rumble strips Pothole patching Traffic control - Flagger	

[a] Short-line striping such as in-lane markings can be accomplished by closing one travel lane; however, other activities such as crosswalk markings and stop bars may require that more than one travel lane be closed.
[b] Most signal/lighting installation and maintenance activities can be accomplished by closing one travel lane; however, loop detector installation generally requires more than one lane to be closed.

The minimum mobility requirement was included since a majority of the identified mobile activities move continuously or intermittently along the roadway at speeds somewhat less than 3 mph. In order to better accommodate the remaining activities, which can take less than one hour to complete, it is desirable to be able to deploy the system into a travel lane in less than 30 minutes, and for the system to be capable of being picked up and ready for transport to another location for deployment within 30 minutes. Such a requirement ensures that the sum of the deployment and pick-up time does not take more than expected activity time at a particular location.

The transportability minimum requirement ensures that the system could be transported on typical roadways without special permits. In addition, minimum and desirable requirements for traffic control and illumination were included to address the need for delineation, rear-end crash protection, and night work.

CURRENT PORTABLE WORKER PROTECTION SYSTEMS

Recently, the California Department of Transportation (Caltrans) developed a mobile work zone protection device called the Balsi Beam (*13*). This system is carried on a tractor-trailer, and was designed to enhance worker safety when carrying out shoulder repair in work zones adjacent to guardrails, bridge rails, and sound walls. Each side of the trailer consists of high-strength steel box section beams. Using hydraulic power, each beam can rotate to either side (left or right), depending on which side of the road a protective barrier is needed. The Balsi Beam protects up to 30 ft of work area longitudinally. Actual crash data are forthcoming; however, lateral deflections in the event of an impact appear to be less than 6 inches. The system reverses the procedure for transport. The Balsi Beam cannot be moved continuously down the road while workers are within the protection area, nor can it be moved or extended laterally across lanes.

Each of these three previously discussed portable systems are intended to prevent side intrusions into a work zone. Obviously, these devices themselves could constitute a hazard to the motoring public and would require shielding from rear-end impacts. A number of manufacturers have developed and tested TMAs for attachment to the rear of work zone vehicles. In many states, TMAs are used quite extensively on shadow vehicles used to protect many of the mobile construction and maintenance activities previously described.

A number of quasi-portable barriers have been developed and are currently used in the highway safety industry. Water filled barriers that have been reinforced with steel can perform as crashworthy positive protection devices. These barriers can be easily loaded, unloaded, and moved when empty. Once positioned in place, they are filled with water to provide weight and stability. The water is removed prior to loading or moving to a new location. Depending on the environmental laws governing the roadway, the water is released onto the ground or pumped from the unit back into the storage vehicle. The length of area protected is dictated by the number of barrier segments linked together. Extent of lateral deflection depends on the specific barrier design and whether the barrier is anchored at its ends or not. Tests of these types of systems have typically been performed with linked sections totaling 140 ft or more. Lateral deflections in excess of 12 ft appear to be typical (*14*).

At least two vendors have developed heavily-reinforced portable steel barriers that can be quickly unloaded at a worksite and linked together to provide longitudinal crash protection (*15, 16*). Some designs include retractable wheels that can be lowered so that the steel sections can be moved by hand. Thus, unlike portable concrete barrier, these systems can typically be unhinged and moved to allow vehicle and equipment access and egress. According to one vendor, these wheels also allow the linked barriers to be towed at very low speeds (less than 10 mph) behind a vehicle to provide protection adjacent to work zones that move down the roadway. In addition, these types of barriers can be moved laterally across travel lanes as needed to create protected work spaces. The length of area protected is dictated by the number of barrier segments linked together. Minimum lengths are required to achieve various crash test performance levels. Extent of lateral deflection depends on the specific barrier design and whether the barrier is anchored at its ends or not. Both vendors report lateral deflections of 6 ft under test level 3 when the system is anchored.

SUMMARY AND CONCLUSIONS

A large number of mobile construction and maintenance work activities were identified and categorized along three key dimensions believed to be the most critical for defining functional requirements for highly-portable positive protection technologies. Specific roadway design features believed to have the most significant impact upon the functional requirements of a highly-portable worker protection system were also considered. Based on the results of these assessments, researchers prepared minimum and desirable functional requirements for a highly-portable positive protection system. In general, a system would need to be highly portable, highly maneuverable, easily deployed, should be adjustable for various lane widths, and capable of redirecting ¾ ton pickup trucks at angles and speeds up to 25 degrees and 60 mph if test level 3 is the selected performance level.

While it is desirable to have a protective device that covers a wide possibility of work zone conditions, this preliminary study shows there are some practical limits to activities that can be accommodated by a highly-portable work zone protective device. As defined, a system meeting the stated requirements could accommodate about two-thirds of the construction and maintenance activities considered. Perhaps a highly-portable positive protection system could be used during some of the remaining activities if work crews were to adopt slightly different procedures for those activities.

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