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Proposed Positive Protection Guidance for Kansas: Synthesis of Work Zone Positive Protection Devices and State of Practice

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The University of Kansas

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The United States experiences over 700 fatalities and over 37,000 injuries each year in temporary construction and maintenance work zones. The Federal Highway Administration (FHWA) has implemented Temporary Traffic Control Devices 23 CFR 630 Subpart K, which specifies a state highway agency must amend their state safety and mobility plan by 2008 to include a description for positive protection in work zones and implementation guidelines for federal funded highway projects. This research study first investigated temporal trends in national and Kansas work zone related crash trends, specifically crashes involving striking a construction vehicle or fixed object. Additionally, current work zone TL-3 and TL-2 approved positive protection devices were summarized including longitudinal barriers, mobile barriers, vehicle arresting systems and end protection systems. Next, a nation-wide survey of state highway agencies was conducted to summarize current guidance relating to positive protection or changes in guidance to comply with Temporary Traffic Control Devices 23 CFR 630 Subpart K. Finally, the research study provided preliminary work zone positive protection guidance for the Kansas Department of Transportation based on the findings of the survey and currently available products.

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THE KANSAS DEPARTMENT OF TRANSPORTATION
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and
THE UNIVERSITY OF KANSAS
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PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

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Abstract

The United States experiences over 700 fatalities and over 37,000 injuries each year in temporary construction and maintenance work zones. The Federal Highway Administration (FHWA) has implemented Temporary Traffic Control Devices 23 CFR 630 Subpart K, which specifies a state highway agency must amend their state safety and mobility plan by 2008 to include a description for positive protection in work zones and implementation guidelines for federal funded highway projects. This research study first investigated temporal trends in national and Kansas work zone related crash trends, specifically crashes involving striking a construction vehicle or fixed object. Additionally, current work zone TL-3 and TL-2 approved positive protection devices were summarized including longitudinal barriers, mobile barriers, vehicle arresting systems and end protection systems. Next, a nation-wide survey of state highway agencies was conducted to summarize current guidance relating to positive protection or changes in guidance to comply with Temporary Traffic Control Devices 23 CFR 630 Subpart K. Finally, the research study provided preliminary work zone positive protection guidance for the Kansas Department of Transportation based on the findings of the survey and currently available products.

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Chapter 1: Background

Highway agencies have recognized work zone crashes are a serious and a growing concern with an increased demand for infrastructure repair in the United States. The ability to protect workers from vehicles using positive separation greatly reduces the risk of a major injury or fatal crash involving the driver or work zone crews. The Federal Highway Administration (FHWA) in 2003 defined positive protection as "a device which contains and redirects vehicles in accordance with NCHRP report 350, preventing their intrusion into the work space" (FHWA 2003). Common positive protection devices used in work zones include portable concrete barriers with end crash cushions, sand or water filled barriers, truck-mounted attenuators, and vehicle arresting systems.

Engineering manuals such as the American Association of State Highway and Transportation Officials (AASHTO) Roadside Design Guide and Chapter 6 of the Manual on Uniform Traffic Control Devices (MUTCD) have listed permanent and temporary positive protection devices. Many highway agencies have noted that these manuals do not provide standardized guidelines for positive protection, and current federal rulings give generous freedom to state agencies to implement positive protection guidance and policy. This ruling has resulted in many highway agencies creating a designated state MUTCD or specific policy on the design and examples of use of specific positive protection devices in work zones. Many state highway agencies have noted that specific guidelines can be very beneficial to the worker and driver, especially with unique features such as tunnels, bridges, or large transportation roadway networks. This research project provides a summary of common positive protection devices, a synthesis of state highway agency guidance and policy for the use of these common devices, and recommendations for the Kansas Department of Transportation to strengthen their safety and mobility policy to include specific language to address positive protection.

Chapter 2: Temporal Trends in Work Zone Crashes

Vehicle crashes in work zones are a serious safety concern and one method to reduce these crashes is the appropriate use of positive protection creating a separation between traffic and work activities. The Federal Highway Administration reports that over 700 fatalities and over 37,000 injuries occur in work zones annually in the United States (National Work Zone Clearinghouse, 2011 and Khattak et al. 2002). Many agencies promote that victims of work zone related crashes are the construction workers. However, it was found between 1994 and 1998 that 84 percent of work zone related crashes involved the vehicle occupants (Schmitz 2000).

A large body of knowledge exists which have investigated causes of work zone related crashes. Garber and Zhao (2002) and Mahoney et al. (2006) found through a synthesis of work zone crash studies that rear-end collisions account for 35 to 52 percent of all work zone crashes. Similar results were reported by Nemeth and Migletz (1978) which investigated 21 work zones sites spanning 384 miles in Ohio. A total of 151 crashes were observed over a two year period. Crashes were found to increase significantly as compared to before construction conditions. Rear-end and single-vehicle fixed-object crashes were found to be the most frequent. The authors also noted that excessive speed was listed in 88 of 151 crashes as a contributing factor. A before and after work zone crash study in New Mexico by Hall and Lorenz (1989) found crash experience increased by 26 percent during construction at 177 sites and run-off-road and fixed object crashes to be the most common.

The National Highway Traffic Safety Administration (NHTSA) Fatality Analysis Reporting System (FARS) maintains current fatal crash counts for the United States. The database can be searched based on the presence of a construction zone or not, then can be further broken down by cause of the crash. Table 1 summarizes two sources of related information which include the number of nationwide fatal crash in work and outside of work zones, and the number of fatal crashes in Kansas work zones between 2001 and 2009.

TABLE 1
Number of Fatalities Occurring in and Outside of a Work Zone

Year	Not in a work zone		In a Work Zone		Total		Number of Fatalities in Kansas Work Zones
	Number	Percent	**Number**	**Percent**	Number	Percent	
2001	41,207	97.7%	**989**	**2.3%**	42,196	100%	**13**
2002	41,819	97.2%	**1,186**	**2.8%**	43,005	100%	**16**
2003	41,789	97.4%	**1,095**	**2.6%**	42,884	100%	**12**
2004	41,773	97.5%	**1,063**	**2.5%**	42,836	100%	**20**
2005	42,452	97.6%	**1,058**	**2.4%**	43,510	100%	**7**
2006	41,704	97.6%	**1,004**	**2.4%**	42,708	100%	**14**
2007	40,428	98.0%	**831**	**2.0%**	41,259	100%	**6**
2008	36,707	98.1%	**716**	**1.9%**	37,423	100%	**6**
2009	33,141	98.0%	**667**	**2.0%**	33,808	100%	**1**

(Source: NHTSA 2011; Kansas Traffic Accident Facts 2008; KDOT 2011)

As shown in Table 1, between 1.9 and 2.8 percent of the total number of fatal vehicle crashes in the United States occurs in work zones. Although these percentages are low, it remains constant over the eight year study period as the total number of highway fatalities decrease. Additionally, it can be seen that the number of fatal vehicle crashes in Kansas are decreasing overall and are generally following national fatal crash temporal trends. However, at the time of this study, preliminary 2010 work zone crash data in Kansas indicated there were 7 fatal crashes. Generally, the state of Kansas observes between 1,400 and 2,100 crashes annually in work zones and the main contributing factor was driver inattention (KDOT 2008).

To understand how work zone fatalities relate to the presence or absence of positive protection, additional search criteria were inputted into the FARS database. This included investigating such variables as if the motor vehicle strikes a construction worker or stopped/operating construction vehicle. This may mean that positive protection or an arresting system was not present to capture or redirect an errant vehicle. Additionally, the variable “strikes a traffic barrier” was inputted which means an errant vehicle lost control or ran off the road and struck positive protection device or fixed object in the work zone. Table 2 summarizes the number of nationwide fatal crashes where a vehicle struck a construction worker either in or outside of a work zone between 2001 and 2009.

TABLE 2
Work Zone Fatalities Where Vehicle Struck Worker

Year	Not in a work zone		In a Work Zone		Total	
	Number	Percent	**Number**	**Percent**	Number	Percent
2001	6	27.3%	**16**	**72.7%**	22	100%
2002	7	22.6%	**24**	**77.4%**	31	100%
2003	7	33.3%	**14**	**66.7%**	21	100%
2004	5	23.8%	**16**	**76.2%**	21	100%
2005	5	23.8%	**16**	**76.2%**	21	100%
2006	3	12.0%	**22**	**88.0%**	25	100%
2007	4	16.7%	**20**	**83.3%**	24	100%
2008	5	23.8%	**16**	**76.2%**	21	100%
2009	4	16.7%	**20**	**83.3%**	24	100%

(Source: NHTSA 2011)

As shown in Table 2, the number of fatal crashes in which a construction worker was struck both inside and outside of a work zone has remained relatively constant. However, it can be seen the number of fatal crashes occurring in work zones between 2006 and 2009 are higher than fatal crashes between 2001 and 2005. Table 3 summarizes fatal vehicle crashes in and outside of work zones where crashes in the FARS database were coded as collision with work construction, maintenance or utility vehicle between 2001 and 2009.

TABLE 3
Work Zone Fatalities Where Vehicle Struck Construction/Maintenance Vehicle

Year	Not in a work zone		In a Work Zone		Total	
	Number	Percent	**Number**	**Percent**	Number	Percent
2001	17	47.2%	**19**	**52.8%**	36	100%
2002	14	42.4%	**19**	**57.6%**	33	100%
2003	18	54.5%	**15**	**45.5%**	33	100%
2004	1	4.2%	**23**	**95.8%**	24	100%
2005	2	9.1%	**20**	**90.9%**	22	100%
2006	1	5.3%	**18**	**94.7%**	19	100%
2007	3	12.0%	**22**	**88.0%**	25	100%
2008	3	15.0%	**17**	**85.0%**	20	100%
2009	1	5.9%	**16**	**94.1%**	17	100%

(Source: NHTSA 2011)

A fatal crash was reported if a moving vehicle struck a construction, maintenance, or utility vehicle while working in transport. Working "in transport" is defined as a vehicle performing its intended task and not driving to or away from a work zone site. It should be noted that prior to 2004, vehicles not in a work zone consisted of vehicles such as garbage trucks, mail delivery vehicles, and police cars. Crashes outside of work zones decreased significantly after 2003 and it is speculated that this was in response to the change in database coding.

However, assuming a change in the database did occur, it is speculated that the numbers of fatal crashes in work zones have remained constant between 2001 and 2009 with between 15 and 23 crashes. Considering that the numbers of fatal crashes outside of work zones are much lower than those within work zones, it is speculated that a lack of or inappropriate selection of positive protection may have influenced these numbers. However, it should be noted that there is a reduction in crashes indicating that positive protection may be helping the crash risk within the work zone. Table 4 summarizes the number of fatal vehicle crashes between 2001 and 2009 where a vehicle struck a traffic barrier or object in and outside of a work zone.

TABLE 4
Work Zone Fatalities Where Vehicle Struck Traffic Barrier/Object

Year	Not in a work zone		**In a Work Zone**		Total	
	Number	Percent	**Number**	**Percent**	Number	Percent
2001	383	94.6%	**22**	**5.4%**	405	100%
2002	419	93.1%	**31**	**6.9%**	450	100%
2003	410	93.4%	**29**	**6.6%**	439	100%
2004	376	93.1%	**28**	**6.9%**	404	100%
2005	372	94.4%	**22**	**5.6%**	394	100%
2006	408	92.9%	**31**	**7.1%**	439	100%
2007	439	95.0%	**23**	**5.0%**	462	100%
2008	436	95.0%	**23**	**5.0%**	459	100%
2009	361	95.0%	**19**	**5.0%**	380	100%

(Source: NHTSA 2011)

A traffic barrier or object for this database search was defined as one of the following: concrete barrier, other barrier, or other fixed object (not including trees or identified hazards). All barriers were either permanent or temporary. The concrete barrier was located either on the outside of the roadway, in the gore area, or in the roadway median.

As shown in Table 4, the numbers of fatal vehicle crashes that involved striking a traffic barrier or fixed object were much higher outside of work zones. These high values are most likely due to the number of longitudinal miles of permanent concrete barriers in cities. However, the number of fatal crashes in which a vehicle struck a traffic barrier in a work zone was constant at around 19 to 23 crashes after a decrease from 31 to 28 crashes indicating that improvement is occurring.

While the number of highway fatal crashes occurring in work zones is a small percentage of the total number of fatal crashes in the U.S., it is a significant number and in many cases could have been reduced with positive protection devices. Appropriate guidelines and recommendations by state highway agencies and engineers are needed to protect work zone crews. Positive protection is one of many possible safety layers that can easily be implemented through guidance and policy. Positive separation between work zones and traffic can lead to both societal and state highway agency benefits with the reduction in the number and severity of crashes in work zones.

In 2012, the Moving Ahead for Progress in the 21st Century Act (MAP 21) was signed into law. Section 1405 of the bill "Highway Worker Safety" states that at a minimum, positive protection measure should be used in all work zones that offer no means of escape for workers unless an engineering study determines otherwise. Additionally, longitudinal barriers should be used for long-duration work zones with high travel speeds and within 1 lane-width from the edge of the travel way. This does not apply to work zones outside of urban areas and the traffic volume is less than 100 vehicles per hour. Finally, MAP 21 states positive protection devices used for work zones are paid for on a unit-pay basis.

Chapter 3: Summary of Information in the Report

The study objective was to aid the Kansas Department of Transportation (KDOT) in developing and implementing positive protection guidance that complies with Temporary Traffic Control Devices 23 CFR 630 Subpart K and compliments the Kansas Department of Transportation's 2008 safety and mobility policy. To achieve this objective, the research team summarized currently available positive protection devices that meet either test level 2 or 3 (TL-2 or TL-3) that are not considered experimental. To determine where these devices are used, and if any existing guidance has been approved or in the process of being approved, a summary of state highway agencies' positive protection policies was conducted.

The research team summarized the information in tabular format from 27 state highway agencies. Policy and guidance were found through an internet search and phone interview survey to determine if positive protection information is publically available and also if it meets and or exceeds Temporary Traffic Control Devices 23 CFR 630 Subpart K guidelines. Finally, based on the state highway agency survey and available positive protection devices, work zone positive protection draft guidance was developed based on the needs of multiple highway divisions within KDOT. The outcome of this research project is expected to assist KDOT in seeking final approval from the FHWA that KDOT has met or exceeds the requirements of 23 CFR 630 Subpart K to increase work zone safety by reducing exposure and using appropriately selected positive protection devices.

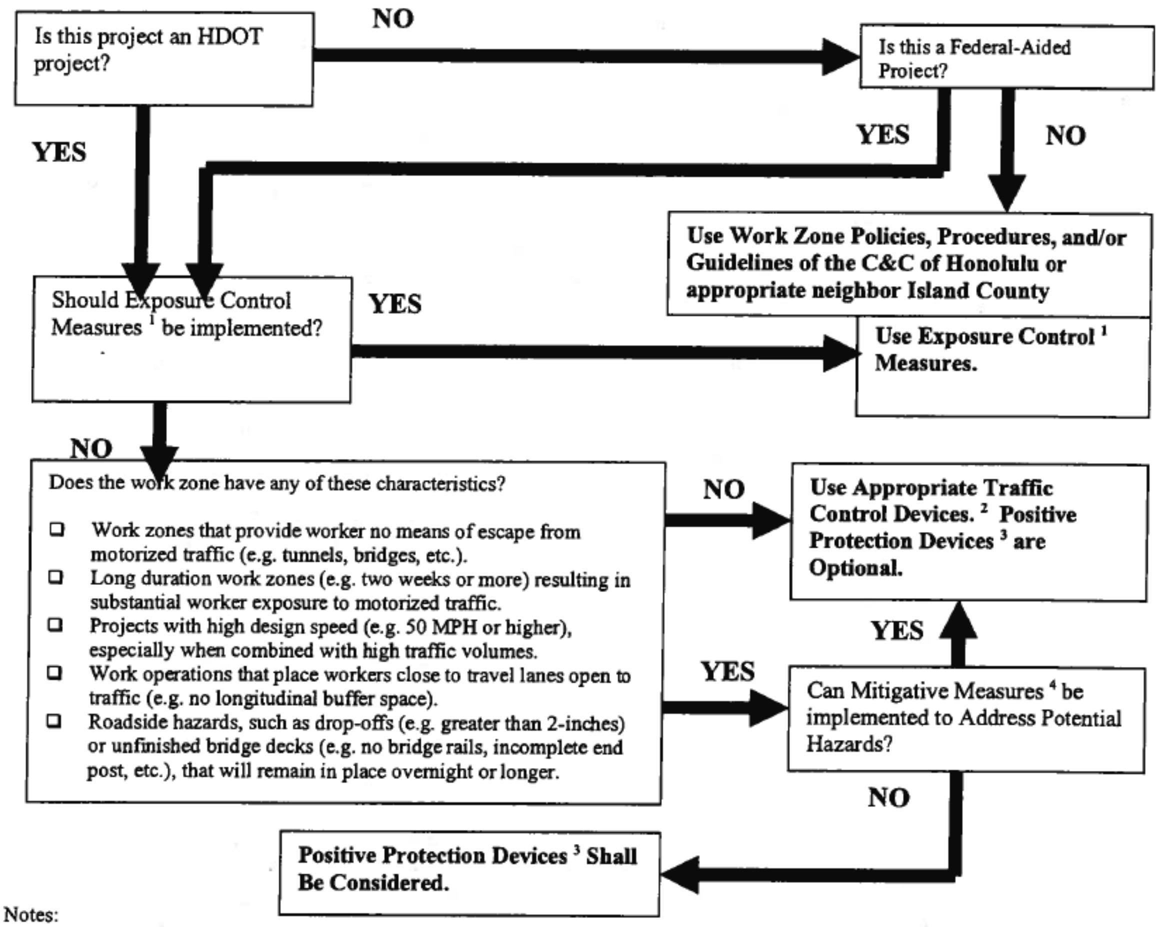
Chapter 4: Federal Guidelines and Resources

In 2004 the Federal Highway Administration (FHWA) published the Work Zone Safety and Mobility Rule (Subpart J) which addressed the country's changes in congestion, infrastructure, safety issues, and overall increase in work zones. The rule also charged state highway agencies (by 2007) to develop long-term plans to help with mobility in work zones and implementation of strategies to help manage current and future impacts during project delivery (Federal Register 2004).

A supplement on the FHWA 2004 rule was implemented in 2007 called the Temporary Traffic Control Devices Rule (Subpart K). This rule was in response to section 1110 of the Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) (FHWA 2011). Subpart K addresses work zone topics such as expenditure of funds for uniformed law officers, positive protection measures, and installation of temporary traffic control during construction, utility, and maintenance operations (FHWA 2011). Specifically relating to positive protection in work zones, the ruling gives the following specific guidance:

- The use of positive protection devices shall be based on an engineering study. The strategies and devices to be used may be determined by a project-specific engineering study, or determined from agency guidelines that define strategies and approaches to be used based on project and highway characteristics and factors.
- The use of positive protection shall be considered in work zone situations that place workers at increased risk from motorized traffic and where positive protection devices offer the highest potential for increased safety for worker and road users.

However, the ruling does not provide state highway agencies with requirements or recommended thresholds on positive protection usage. This gives great flexibly in developing guidelines and policies for unique characteristics that a state might have on the roadway system. The ruling also encourages state highway agencies to explore techniques to reduce the likelihood of an errant vehicle entering a work zone. An example of how the Hawaii Department of Transportation has used the new ruling to implement positive protection guidance is shown in Figure 1.



Notes:

1. Exposure Control Measures are considered when appropriate to avoid or minimize worker exposure to motorized traffic and exposure of road users to work activities, while also providing adequate consideration to the potential impacts on mobility. Examples of Exposure Control Measures can be found in the Work Zone Safety Management Guidelines, III B and Appendix III.
2. Appropriate Traffic Control Devices are usually found in all HDOT traffic control plans. These are, but not limited to, cones, arrow panels, signs, etc.
3. Positive Protection Devices are defined as longitudinal barriers and other shielding devices, such as truck mounted attenuators (TMA). All longitudinal barriers and shielding devices shall be NCHRP Report 350 compliant, approved by FHWA, and accepted by HDOT.
4. Mitigative Measures are techniques and/or practices that are utilized to address areas of concern. Examples of Mitigative Measures are as follows: Appropriately designed wedges along with appropriate worker safety devices, such as intrusion alarms, to address drop-offs; Speed management to address speeding or practices that will slow motor vehicle operating speeds (e.g. enforcement; temporary traffic signal or flaggers for one-lane closure on two-lane road); etc.

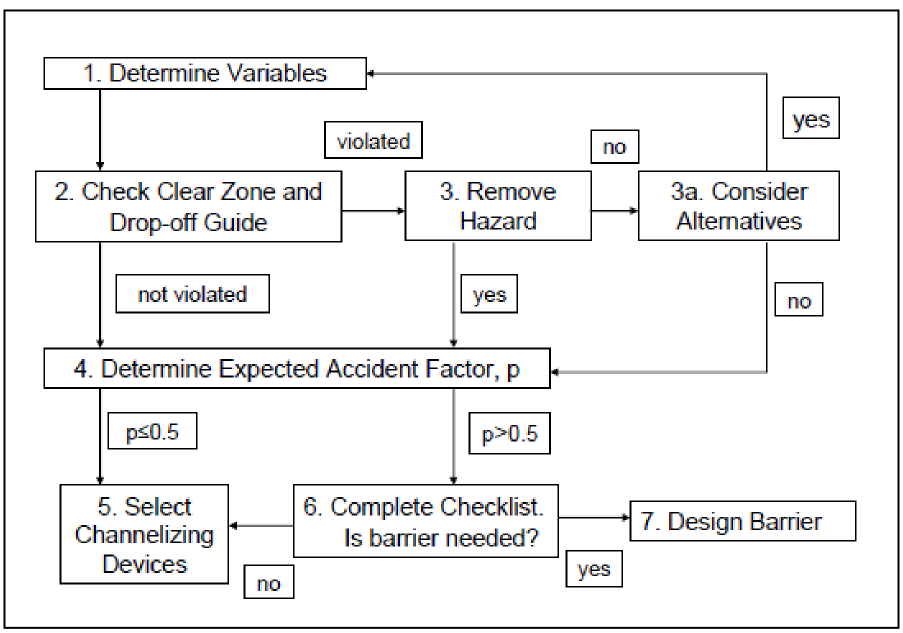
(Source: Hawaii Department of Transportation Highways Division 2008)

FIGURE 1
Use of Exposure Control Measures and Positive Protection on Construction Projects

As shown, determining safety measures at work zones in Hawaii is a multiple step process where engineering judgment is required. Important steps before considering positive protection are exposure control and mitigation measures.

Bryan (2005) defines exposure control as an alternative to reducing worker exposure to traffic. An exposure control method may include work zone planning and design, rolling roadblocks during traffic control setup, a reduction in flagger exposure, or automated cone placement equipment. Other approaches to controlling work zone exposure are mitigation measures. Fitzsimmons et al. (2009) and Maze et al. (2000) summarized many commercially available products that can be implemented prior to and within the work zone to control vehicle speeds in the open travel lane. Along with the presence of a uniformed law officer, devices such as rumble strips, drone radar, automated enforcement, and Autoflagger were found to be effective in alerting drivers.

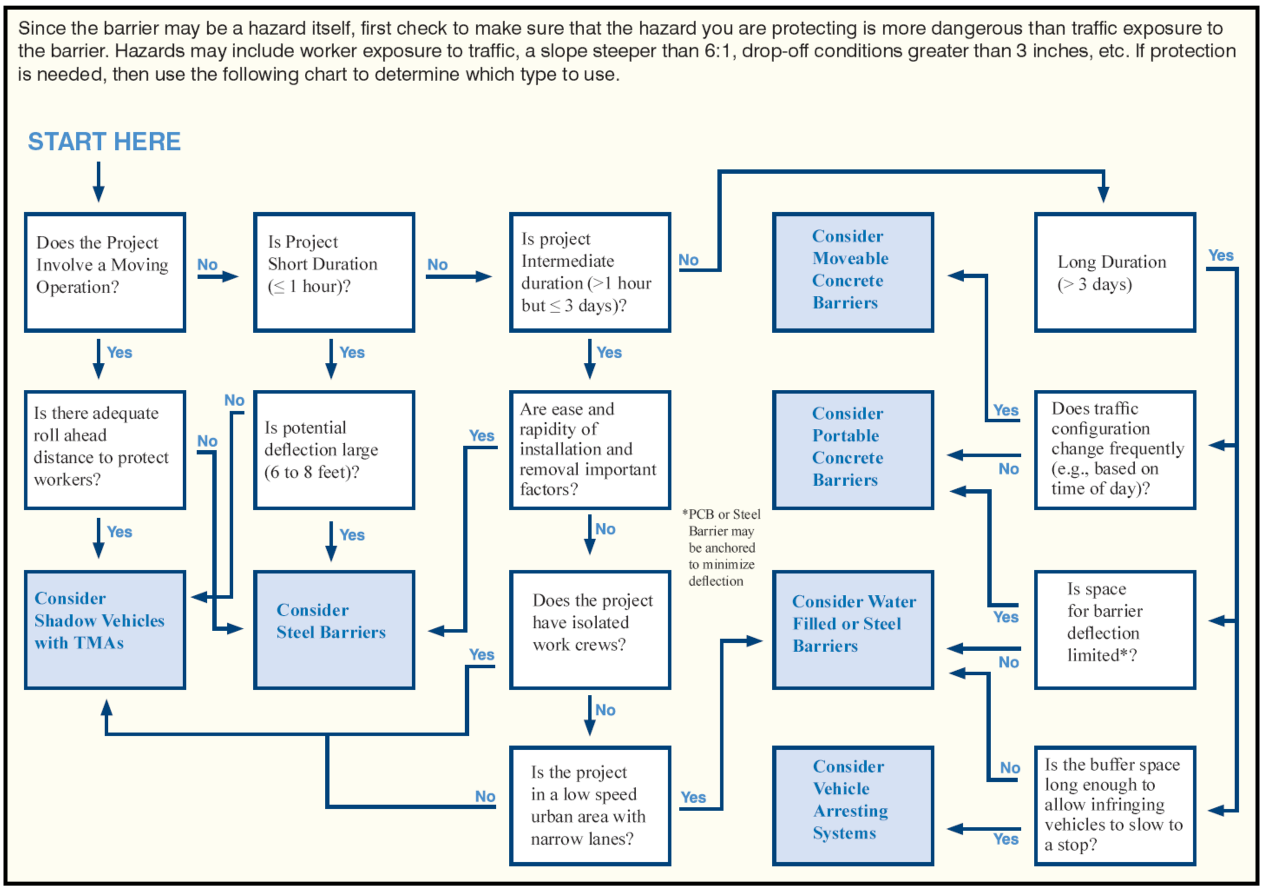
Similarly, the Virginia Department of Transportation developed a flow chart shown in Figure 2, to aid design engineers in determining if barrier or channelizing devices are needed for a temporary work zone.



(Source: VDOT 2010)

FIGURE 2
Virginia Department of Transportation Barrier Selection Process Flow Chart

Figure 2 step 1 of the flow chart, "determine variables" includes pre-construction records of speeds, traffic volume, work zone project duration, roadway type, run-off-road crash frequency and length of the work area. The second part of the flow chart involves evaluating the presence of and size of the clear zone, drop-off, and roadside hazards. The expected accident factor (*p*) is an interim step that multiplies run-off-road crash frequency by fixed object length and by construction time (VDOT, 2010). VDOT stated at the time of this report that this process provides an evaluation for many types of temporary work zone applications. However, the design engineer recommendation is the final decision on a project-by-project basis. A similar positive protection decision flow chart was also developed in 2010 by the American Traffic Safety Services Association (ATSSA) as shown in Figure 3.



(Source: ATSSA 2010)

FIGURE 3
Decision Tool for Selecting Positive Protection Devices

As shown in Figure 3, key steps in the decision process include whether the work zone is moving or not, space needed for device deflection, the duration of the project, and expected speeds. The Alabama Department of Transportation takes the decision process a step further by providing guidance for a specific positive protection device. Shown in Figure 4 is the guidance for the use of a portable concrete barrier.

Portable Concrete Barrier

Warrant Guide (TCP Speed Limit of 45 mph and above)

	Location	Drop off	TCP Offset[1]	Worker Exposure Concentration	Barrier Warranted	Comments
	Bridge/ Tunnel	Any	Any	Any	Yes	Applies to work zones with no means of escape from a vehicle entering the work area. Also applies to any removal of the railing for a drop off hazard.
Worker Protection	Stationary Work (Culvert Extension, etc...)	Any	Less than 20'[2]	High	Yes	Applies to work operations that are labor intensive (such as tying steel, formwork, etc...) and stationary[3]
	Overnight Concrete Slab Repair	Any	2' or Greater	Any	No	Applies to overnight operations that make the placement of barrier impractical. Provide shadow vehicle protection as practical
Drop off Protection	Interstate Lane Addition Long Duration Pavement Drop off	Less than 1.5'	8' or Greater	Any	No	Requires use of Vertical Panels. Include Incentive/Disincentive clause (based on RSAP analysis) in the Contract as an exposure mitigation technique. Limit to 2 lanes in each direction with total Average Daily Traffic of 45,000.
	Pavement Drop off	4.5" - 8"	0'	Any	Yes	Barrier not warranted if a 4:1 wedge is provided
		> 8"	0'	Any	Yes	
		4.5" - 8"	3'	Any	No	Use 3:1 Wedge
		8" - 1.5'	3'	Any	No	Use 4:1 Wedge
		> 1.5'	10'	Any	No	Use 4:1 Wedge
	Separation of Opposing Traffic				Yes	Use a barrier for interstate and for divided high speed facilities with high truck volumes.

[1] The nearest TCP Phase to the drop off. Barrier may be warranted in one phase and not another.

[2] For slopes flatter than 3:1. Steeper slopes should have barrier

[3] Stationary for worker exposure is 2 weeks.

(Source: ALDOT 2011)

FIGURE 4
Alabama Department of Transportation Guidance for Portable Concrete Barriers for Speeds Greater Than 45 mph

As shown in Figure 4, the Alabama Department of Transportation provides guidance for worker protection and/or drop-off protection at different locations, exposure concentration, and use of vertical panels or shadow vehicle. This is just one example of how many state highway agencies are tailoring their safety and mobility policy to address positive protection guidance.

At the time of the report being written, state highway agencies in Colorado, North Carolina, and Virginia provided design engineers an FHWA- and state-approved list of positive protection devices. Shown in Figure 5 is an example of the list of approved concrete barrier systems from the Virginia department of Transportation (VDOT 2011).

FHWA Code	Manufacturer	Device Description	Test Level	Dynamic Deflection	Anchorage (a)
B-41	University of Nebraska - Lincoln	9'- 4" Long F-Shape barrier w/pin & loop connection.	TL-3	6'	11' - 5" Run-on 9' - 10" Run-off
B-40	Barrier Systems, Inc.	Narrow Quickchange Moveable Barrier.	TL-3	2'- 11"	(b)
B-36	Texas A&M (TTI)	Low-Profile Concrete Barrier for Work Zones	TL-2	5"	(c)

(Source: VDOT 2011)

FIGURE 5
Virginia Department of Transportation Concrete Barrier Vendor Selection List

Three VDOT approved concrete barrier types out of a possible 15 are shown in Figure 5. Included in the table is the FHWA reference code for device information and approvals on the FHWA website, device description, NCHRP 350 test level, dynamic deflection, and anchorage are listed.

Chapter 5: Positive Protection in Work Zones

A key aspect to a safe work zone is the ability to separate workers inside the work zone from traffic which may be adjacent to the work area. Positive protection devices are designed to physically prevent vehicles and pedestrians traveling through work zones from entering space occupied by workers, equipment, materials, or roadside hazards.

Bryden (2005) separates positive protection devices into separate categories including devices that redirect errant vehicles before the work space, and devices that bring an errant vehicle to a complete stop before entering the work area. Generally various types of longitudinal barriers will redirect vehicles while devices such as shadow vehicles with truck mounted attenuators or arresting systems will capture the vehicle. The following section explains the current performance measures in place that allows a positive protection device to be deployed in a temporary work zone.

5.1 Performance Measures

Currently, there are many types, sizes, and specified uses of positive protection devices manufactured in both the United State and Europe. Devices designed to be used in the United States must be approved by the FHWA and can be found on their website with the approval letter. The FHWA will approve a barrier device if it has been shown to meet specific test levels designated in NCHRP report 350: "Recommended Procedures for the Safety Performance of Highway Features." Positive protection devices that are tested under NCHRP report 350 are evaluated in terms of three evaluation areas (Ross et al. 1993 and Bryan 2005):

- Structural adequacy – evaluation of the device to contain or redirect the vehicle
- Occupant risk – evaluation of risk or harm to the occupants of a vehicle
- Vehicle trajectory – evaluation of post-impact trajectory of a vehicle to minimize secondary events

Ross et al. (1993) states there are total of six possible test levels under NCHRP 350, however there is limited information or guidance as to what test level is acceptable for a work zone, however many positive protection device vendors will list test level 3 (TL-3). TL-3 is one of six possible tests for longitudinal barriers and has two vehicle impact tests. The first consists of 1,760 pound passenger car impacting a barrier at 20 degree with a velocity 60 miles per hour. The second test consists of a 4,400 pound pickup truck impacting the barrier at a 25 degree angle with a velocity of 60 miles per hour (Ross et al. 1993).

Barriers intended to be used on European roadways will undergo crashworthiness tests similar to NCHRP 350 called EN 1317. A study conducted by Lohse et al. (2007) developed a proposed algorithm to correlate the two studies for CALTRANS which has been used to aid the FHWA in approving devices without a full-scale crash tests, however the process has not been adopted as of 2011.

The following sections provide a brief summary of commonly used positive protection devices by state highway agencies in the United States. Information includes description, costs / benefits, dimensions specialized equipment needs for installation, and if any relevant literature is available as to the effectiveness of each device listed.

Chapter 6: Common Positive Protection Devices

This section summarizes commonly used positive protection devices in work zones that meet or exceed Test-Level 3 guidelines along with providing the results of any effectiveness research that has been performed. The products summarized in this report are not endorsed by the University of Kansas or the Kansas Department of Transportation.

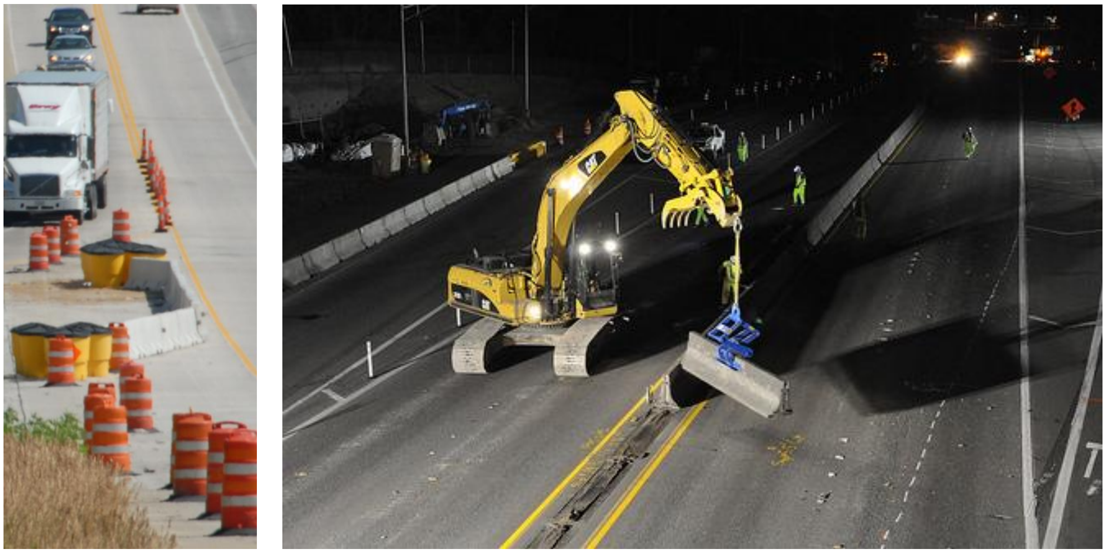
6.1 Portable Concrete Barrier

6.1.1 Background

One of the most widely used longitudinal positive protection devices is the portable concrete barrier. Portable concrete barrier profiles are similar to the profiles of permanent concrete barrier. Portable concrete barriers are segmented units which are attached end-to-end by a load bearing connection. Segmentation of the barriers allows for easy installation, positioning, and removal from the work zone area. Portable concrete barriers have several functions identified by the AASHTO Roadside Design Guide:

- Protect traffic from work areas such as excavations or material storage sites,
- Provide positive protection for workers,
- Separate two-way traffic,
- Protect construction such as falsework for bridges and other exposed objects, and
- Separate pedestrians from vehicular traffic.

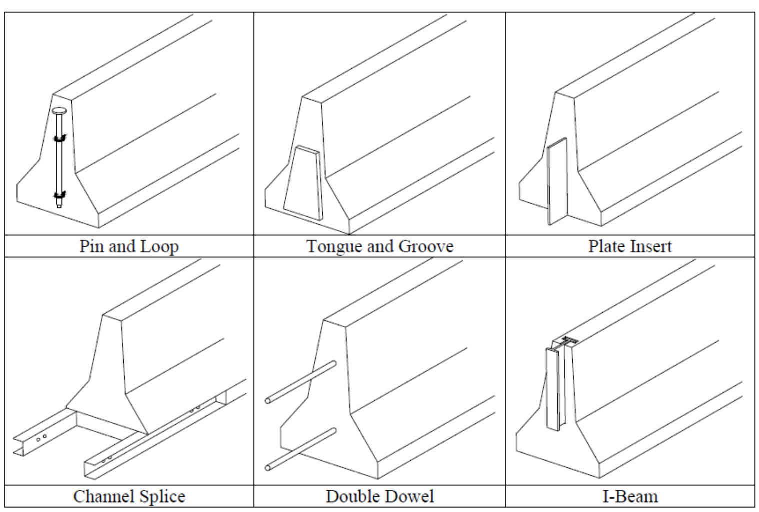
A buffer space is typically needed behind a work zone barrier to accommodate potential deflection by the barrier system (Bligh et al. 2006). The most common types of portable concrete barriers include New Jersey, F-shape, and single-slope safety shape barriers (Marzougui et al. 2007). However, other variations of these common designs can be found with varying height, length, width, and shape. Illustrated in Figure 6 is an example of New Jersey portable concrete barrier system installed and being installed at two highway work zones.



(Source: MoDOT, 2011; WSDOT 2011)

FIGURE 6
(Left) Jersey Barrier with Sand Barrel Crash Cushions; (Right) Jersey Barrier System Being Installed in Medina, Wisconsin

The impact performance of a barrier is influenced by a number of variables including barrier shape, height, segment length, joint rotation slack, joint moment capacity, joint tensile strength and friction between barrier and roadway surface (Bligh et al. 2006). Portable concrete barriers are connected to each other through a variety of possible connections, most of which involve pins, plates, or rods. Illustrated in Figure 7 are six of many possible connections between portable concrete barriers.



(Marzougui et al. 2007)

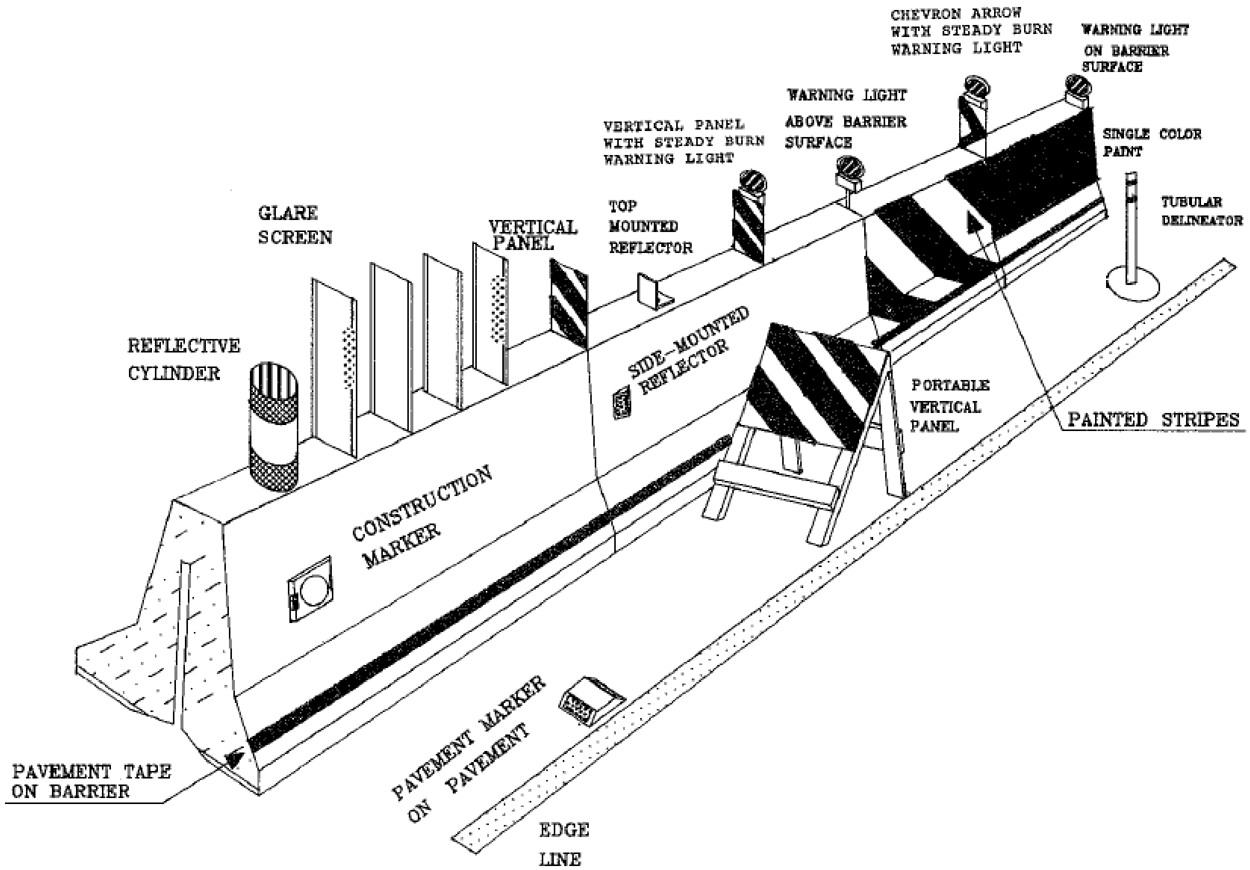
FIGURE 7
Types of Portable Concrete Barrier Connections

As of 2011, the AASHTO Roadside Design Guide listed 15 different portable concrete barriers that met NCHRP 350 TL-3 guidelines. The approved portable concrete barriers' deflection ranged from 6 inches to 76 which met or exceeded FHWA TL-3 guidelines. With small deflection values compared to other devices, portable concrete barriers provide the highest level of containment as compared to other positive protection devices. Minimal deflection values can be achieved by anchoring portable concrete barriers to the roadway or bridge deck using drift pins or anchor bolts. Research has also been conducted to investigate the use of four pin-and-stakes along each concrete barrier segment drilled diagonally through the pavement (Mak and Campise 1990).

6.1.2 Concrete Barrier Delineation

Noel et al. (1989) identified that concrete barriers cannot easily be seen by drivers approaching work zones during the night and adverse weather conditions such as dust, fog, rain or snow.

A study conducted by Mullowney (1978) conducted a crash analysis of work zone crashes in which a vehicle struck a center barrier. A total of 258 crashes occurred in 1975 along a 70 mile segment, 113 crashes occurred at night and 52 occurred during wet pavement conditions at night. Shown in Figure 8 is the result of the synthesis study by Noel et al. and what delineation devices state highway agencies are using to delineate concrete barriers.



(Source: Noel et al. 1989)

FIGURE 8
Identified Devices for Delineating Left-Side Placed Portable Concrete Barriers

Research studies have investigated the effectiveness of various delineating devices for portable concrete barriers. The results of these studies have shown mixed results, however two research studies specifically mentioned vehicle headlight glare and the effectiveness of top and side-mounted delineator devices. Mullowney (1978) over a 16 month study indicated that left handed curves restricted the visibility of side-mounted reflectors, and opposing headlight glare can reduce visibility of top-mounted reflectors and should be used in lighted areas. Similarly, Ugwoaba (1987) studied a state of Washington highway and found devices on top of portable concrete barriers were greatly diminished with headlight glare and side-mounted delineators were much more effective.

6.1.3 End Treatments

The ends of a portable concrete barrier system need to be able to redirect an errant vehicle. The AASHTO Roadside Design Guide provides possible end treatments including the use of crashworthy cushions. Shown in Figure 9 are two examples of crashworthy end treatments, these include a series of sand-filled barrels and a crumpling impact attenuator. It should be noted that many of the proprietary systems are one-time use devices and contractors need to be aware of vehicle hits for expedited repair or replacement.

(Islee.com 2011; Protprotectionservices.com 2012)

FIGURE 9
Examples of Portable Concrete Barrier End Treatments

Additionally, the AASHTO Roadside Design guide lists other candidate treatments including: burying the end of the barrier into the backslope, flaring the barrier away to edge of the clear zone, using a sloped end treatment, or a TL-2 barrier for the first part of the barrier system (AASHTO 2011). It is strongly recommended that design engineers and contractors consider end treatments when designing a work zone.

6.2 Ballast-Filled Barriers

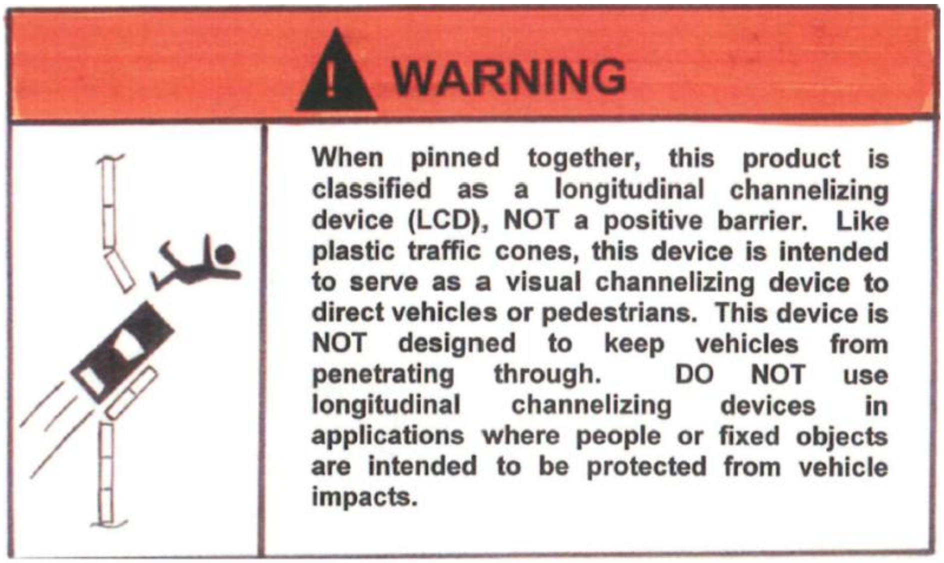
6.2.1 Background

Ballast-filled barriers are large polyethylene containers that are typically filled with either sand or water. They are interlocked together to form a longitudinal barrier or channelizer barrier that can either redirect or provide guidance for vehicles through temporary work zones. Ballast-filled barriers are essentially used in the same capacity as a portable or moveable concrete barrier with between 6 to 22.6 feet of deflection (Ross et al. 1993 and AASHTO 2011).

One advantage to ballast-filled barriers is the empty weight which enables workers to place, move, and tear-down the devices without specialized equipment. Although these devices are becoming more common in urban temporary work zones, a concern that must be considered is the potential for the water to freeze in the barrier. An internet search revealed that many online distributors recommend 12 pounds or 1.5 gallons of calcium chloride is added to each barrier if the temperature falls below freezing (plasticjersey.com 2011). Additionally, many states have implemented environmental protection policies that require water-filled barriers to be emptied and stored off-site (Lohse et al. 2007).

6.2.2 Ballast-Filled Barrier Research

Limited research is available as to the effectiveness of ballast-filled barriers beyond the FHWA TL-3 approval process research. However, many United States highway and contracting agencies have identified a need to warn of the risk of using appropriate ballast-filled barriers for temporary work zone protection. The AASHTO Roadside Design Guide notes that many plastic longitudinal plastic barriers are available commercially, but many ballast-filled barriers do not meet TL-3 guidelines and are not designed redirect errant vehicles. AASHTO reports that unapproved devices should not be confused by design engineers and contractors in the field as a substitute to a TL-3 approved device (AASHTO 2011). To provide guidance for temporary work zones applications, a multi-agency supported guideline was produced in 2007 to recommend warning labels (as shown in Figure 10) be adhered to each ballast-filled barrier warning that the device was to be used as a visual channelizing devices and not as a barrier (ATSSA 2007).



(Source: ATSSA 2007)

FIGURE 10
Recommended Ballast-Filled Channelizing Device Warning

As of 2011, the FHWA has approved four ballast-filled barriers to be in compliance with NCHRP-350 TL-2 and TL-3 guidelines. To meet TL-3 guidelines, the barriers needed structural reinforcement in addition to the weight of the plastic and water / sand. Each of the barriers listed in Table 5 are constructed using various reinforcement systems including external rails to internal cable or steel skeleton system. Additionally, all of the barriers listed are approved to serve as their own end treatments.

TABLE 5
Water-Filled Barriers Meeting NCHRP 350 TL-3 Guidelines (As of 2011)

Guardian Safety Barriers Source: armorcastprod.com		The guardian safety barrier is 42 inch high by 72 inch long water filled low-density polyethylene barrier. The barrier is both NCHRP 350 TL-2 and TL-3 approved and can act as its own end treatment. To meet TL-3 guidelines, each barrier includes four interlocking powder-coated steel bars. Empty weight is 280 pounds and full weight is 1,750 pounds with water. **Estimated Unit Price[a]: $700**
2001M-BM Source: yodock.com		The 2001M-BM is a 32 inch high by 72 inch long with 229 gallons of water or sand filled recycled high-molecular high-density plastic barrier. The barrier is both NCHRP 350 TL-2 and TL-3 approved and can act as its own end treatment. To meet TL-3 guidelines, each barrier includes two external interlocking cross-connected steel barrier rails. Empty weight is 90 pounds and full weight is 900 pounds with water. **Estimated Unit Price[a]: $700**
Sentry Water-Cable Barrier Wall Source: traffixdevices.com		The Sentry barrier wall is a 42 inch high by 72 inch long with 242 gallon water filled polyethylene barrier. The barrier is both NCHRP 350 TL-2 and TL-3 approved and can act as its own end treatment. To meet TL-3 guidelines, each barrier includes four internal 3/8 inch steel cables connected to a 1 1/8 inch steel T-pin between barriers. Full weight is 2,000 pounds with water. **Estimated Unit Price[a]: $685**
Triton Barrier TL-3 Source: energyabsorption.com		The Triton barrier is a 32 inch high by 78 inch long with 145 gallon water-filled polyethylene barrier. The barrier is both NCHRP 350 TL-2 and TL-3 approved and can act as its own end treatment. To meet TL-3 guidelines, each barrier includes an endoskeleton structure along with sitting on mechanically strapped pedestals. Empty weight is 140 pounds and full weight is 1,350 pounds with water. **Estimated Unit Price[a]: $680 - $720**

[a]Unit price and specifications are based on available 2011/2012 internet and company resources, the prices and specifications are subject to change after this report has been published.

6.3 Steel Moveable Barrier

An alternative to portable concrete barriers for short-term work zones are steel barriers. Steel barriers, similar to concrete barriers are brought to the work zone site in sections ranging from 28 feet to 50 feet. This positive protection device can also be used with a concrete barrier system acting as a gate at the end of the work zone. Steel barriers can be towed behind a vehicle, moved easily using wheels or a fork lift, and can easily be taken off the roadway if the work zone has limited operations.

Limited data are available as to the effectiveness of steel barriers; however manufacturers advertise steel barriers as a higher initial cost with a longer lifespan (Hallowell et al. 2009). The decreased weight of the steel barrier also allows for higher deflection unless the system is anchored between the ends (Lohse 2007). Shown in Table 6 are the current mobile steel barriers manufactured in the United States. It should be noted that each of the three companies offer at least two variations of the listed products which include end terminals and variations of the design for specific applications.

TABLE 6
Summary of Currently Available Steel Longitudinal Barrier Systems in the United States (as of 2011)

ArmorGuard Steel Barrier Source: Barriersystemsinc.com		ArmorGuard Steel Barrier is a light-weight towable steel barrier system that makes setting up and tearing down a quick operation. It can also be used for links and gates between portable concrete barriers. Each 28 foot section steel barrier includes a set of wheels and can be deployed at a rate of 200 to 300 feet in 30 minutes. Wheels are lowered and raised using a compressed air or hand crank device. The barrier system was tested and approved according to NCHRP-350 TL-2 and TL-3 guidelines. **Estimated Unit Price[a]: unknown**
Zoneguard Barrier Source: Hillandsmith.com		The Zoneguard steel barrier system consists of 50 foot sections that are installed without hand tools using common construction equipment. Unlike other available steel barrier systems, the Zoneguard does not offer wheels, but does offer rubber padding. The barrier systems can be anchored at the ends, or can be anchored every 33 feet to minimize deflection. The barrier system was tested and approved according to NCHRP-350 at the TL-2 and TL-3 guidelines. **Estimated Unit Price[a]: $0.06 - $0.21 /ft./day rental**
Vulcan Barrier Source: energyabsorption.com		Similar to the ArmorGuard barrier system, the Vulcan Barrier systems is a steel moveable barrier capable of providing protection for straight tangents and horizontal curves. Stackable barriers are available in 13, 26, or 40 foot sections. The barrier system is moved at the site with either a forklift system or optional caster wheels. The barrier system was tested and approved according to NCHRP-350 TL-3 guidelines. **Estimated Unit Price[a]: unknown**

[a]Unit price and specifications are based on available 2011/2012 internet and company resources, the prices and specifications are subject to change after this report has been published.

6.4 Movable Concrete Barrier

6.4.1 Background

The Quickchange movable concrete barrier is a proprietary system designed and sold under Barrier Systems Incorporated that can be used for work zones or permanent applications. For work zone applications, the system is generally leased for between 9 to 12 months for $50 per foot including the barricade and machine. For long length and duration work zones, a movable concrete barrier system may offer a higher benefit to cost ratio over portable concrete barriers if directional flow, frequent openings and closings of lanes and changing work zone widths are needed as shown in Figure 11.

(Source: UDOT 2011; Kozel 2011)

FIGURE 11
Barrier Transfer Machine on an Urban and Interstate Facility

Cottrell (1994) describes the moveable barrier system as 39 inch long by 32 inch high by 24 inch wide concrete barrier sections weighing 1,400 pounds. Individual blocks are connected to each other by steel pins in hinges. A reversible barrier transfer machine lifts the sections off the road and repositions the sections 4 to 18 feet laterally at speeds of 5 mph (Ray et al. 2003).

6.4.2 Movable Concrete Barrier Effectiveness Research

A synthesis of literature conducted by Berg et al. (2010) found limited research in the effectiveness of moveable barrier systems in work zones. However, five highway projects were cited and overall it was reported the moveable concrete barrier system reduced work zone congestion, enabled a faster construction schedules, and reduced user delay. Anderson and

Ullman (2000) stated in NCHRP Synthesis 293 "Reducing and Mitigating Impacts of Lane Occupancy during Construction and Maintenance" suggested a key advantage to the movable barrier system is allowing a smoother transition when closing or opening lanes around work zones. However, Stanley (1993) reported that a movable concrete barrier system in North Carolina was found to capture water on the roadway when repositioned, causing vehicles to hydroplane.

Cottrell (1994) investigated movable barrier systems in Virginia from 1991 to 1992. Forty two collisions involved striking the barrier in which no fatalities were reported and only 33 percent were found to have injuries. One collision involved a tractor-trailer which broke through the barrier system. Berg et al. (2010) conducted a study to evaluate a moveable barrier system in a Utah urban corridor. The authors found that using the moveable barrier system reduced construction time by seven months, an estimated $1.7 to 2.5 million dollar savings in crash costs and travel time delay. A 4 to 1 benefit cost ratio with the potential of a 10 to 1 benefit to cost ratio if variables such as reduced impact to businesses, lower air emissions, and other safety benefits were considered.

6.5 Mobile Barrier Trailer (Emerging Longitudinal Positive Protection Technology)

6.5.1 Background

Mobile barriers are designed to provide positive protection for temporary, mobile, or maintenance work zone sites using a standard tractor-trailer configuration. The modified trailer provides a longitudinal barrier that provides a physical and visual wall between passing traffic and work crew personnel. Depending on the barrier type configuration, rear-end crash protection can be provided by attenuator cushions, and work zone lateral protection to divert errant vehicles can be performed by the rigid steel walls of the trailer.

Ullman et al. (2007) developed a table based on previous literature and the needs of practitioners to implement highly-portable positive protection systems, in which the mobile barrier system is designed to compliment. The authors stated that a failure to meet minimum requirements as shown in Table 7 would not allow work crews to utilize the device in all possible applications and would not provide safe separation from traffic.

TABLE 7
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 ft 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 *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 AASHTO guidelines.

(Source: Ullman et al. 2007)

Two types of mobile barrier systems are currently available. The first one is the Balsi Beam (shown in Figure 12) developed and crash tested by the California Department of Transportation, however not approved by the FHWA. The unit consists of a tractor trailer combination with the trailer converting into a 30 foot long work space between the rear axles of the tractor and the trailer with a collapsible and reversible steel beam barrier. The Balsi Beam was designed for localized activities , such as bridge deck repairs, bridge rail repairs, and bridge joint maintenance.

(Source: CALTRANS)

FIGURE 12
Balsi Beam Mobile Barrier System

The other mobile barrier system is the Mobile Barrier Trailer (MBT-1, as shown in Figure 13) which was developed in 2007 (Mobile Barriers LLC 2009). The MBT-1 system can provide work crews with 42 to over 100 feet of protected work space between the tractor and trailer wheels.

(Source: Mobile Barriers LLC 2012)

FIGURE 13
Mobile Barrier Trailer (MBT-1) System

A study in Colorado (Hallowell et al. 2009) investigated the potential effectiveness of the application of the MBT-1 in work zones. The study focused particular attention on the benefits and limitations of lighting schemes associated with the MBT-1. The authors stated there were significant advantages to the MBT-1's lighting schemes, programmable message board, NCHRP 350 TL-3 crash-tested barrier, and mobility. Since work zone signage and work area lighting systems are integrated with the MTB-1, the systems are always in optimal location relative to the work activity.

A field test in New Jersey performed by Kamga and Washington (2009) found that the MBT-1's functional requirements were state-of-the-art for work zone positive protection against lateral intrusions by vehicles. The authors stated the MBT-1 far exceeded expectations to protect workers from bodily injuries caused by errant vehicles and also protected drivers from possible injuries with its ability to absorb crash energy by crushing upon impact and its integrated TMAs. Additionally, they mentioned that the truck's mobility both to the site and on the site was another attractive feature when considering the implementation of this equipment on a given road construction project, likely due to the decreased setup time compared to more traditional traffic control devices. Furthermore, they found that using the MBT-1 at a temporary work zone required pre-planning as the unit needed to be manually converted from left and right side work zone operations. Finally, the authors noted one of the more preferred applications of the device was on straight roadway sections without ramps in the work zone.

6.6 Shadow Vehicle

6.6.1 Background

Chapter 9 of the American Association of State Highway Officials (AASHTO) Roadside Design Guide describes how construction vehicles can be used as positive protection for work zones. Three types of vehicles are discussed in the Roadside Design Guide including: shadow vehicle, barrier vehicle, and advance warning truck. A shadow vehicle is generally a large construction truck that is a vital component to a mobile temporary work zone. Michie and Bronstad (1992) reported that 90 percent of these vehicles are dump trucks ranging from 22,000 to 38,000 pounds. These types of work zones include installation of pavement markings, asphalt rehabilitation, crack sealing, and highway sign installation. Large vehicles provide substantial protection for work zones; however without a cushion attached to the truck, serious occupant injury can occur if a smaller vehicle strikes the rear of the truck.

Attenuators are constantly evolving with new technologies and plastics being produced and they can cost between $15,000 and $20,000 each (Ullman et al. 2011). Michie and Bronstad (1992) provide a comprehensive overview of the development of truck mounted attenuators in NCHRP Synthesis 182. Modern truck and trailer mounted attenuators must meet federal standards similar to those for positive protection devices such as concrete barriers by meeting NCHRP-350 TL-3 guidelines. Examples of two types of attenuators are shown in Figure 14.

(Source: Energy Absorption Systems 2011)

FIGURE 14
Trailer (Left) and Truck (Right) Mounted Attenuators

Common guidance on when to use a shadow vehicle and/or a truck mounted attenuator has been found for most state highway agencies. Most require a truck mounted attenuator on shadow vehicles for moving temporary work zones. However, guidance for most other applications is based on AASHTO Roadside Design Guide Table 9.3 which was originally based on research reported by Humphreys and Sullivan (1991). Humphreys and Sullivan (1991) developed preliminary guidance for shadow vehicles and truck mounted attenuators and the results of the study are summarized in Tables 8 and 9.

TABLE 8
Recommendations for the Assignment of Shadow Vehicles in Work Zones

Closure / Exposure Condition	Freeway	Non-Free with Speed Limit		
		>=50 mph	40-45mph	<=35 mph
Shadow vehicle for no formal lane closure for operation involving exposed personnel	Very highly recommended	Very highly recommended	Very highly recommended	Very highly recommended
Shadow vehicle for no formal lane closure for operation NOT involving exposed personnel	May be justified	May be justified	May be justified	May be justified
Shadow vehicle for no formal shoulder closure for operation involving exposed personnel	Highly recommended	Highly recommended	Recommended	Recommended
Shadow vehicle for no formal shoulder closure for operation NOT involving exposed personnel	May be justified	May be justified	May be justified	May be justified

TABLE 9
Recommendations for the Application of Truck Mounted Attenuators in Work Zones

Closure / Exposure Condition	Freeway	Non-Free with Speed Limit		
		>=50 mph	40-45mph	<=35 mph
Shadow vehicle for no formal lane closure for operation involving exposed personnel	Very Highly Recommended	Highly Recommended	Recommended	Desirable
Shadow vehicle for no formal lane closure for operation NOT involving exposed personnel	Highly Recommended	Highly Recommended	Recommended	Desirable
Shadow vehicle for no formal shoulder closure for operation involving exposed personnel	Highly Recommended	Recommended	Recommended	Recommended
Shadow vehicle for no formal shoulder closure for operation NOT involving exposed personnel	May be justified	Recommended	Desirable	May be justified

As shown in both Tables 8 and 9, positive protection using a truck and an attenuator device is highly desirable for many for most work zone applications. However, under many conditions where construction crews are not exposed, it may be justified by an engineer or unique features of the work zone site.

Many state highway agencies have developed guidelines and protocols for the drivers of shadow vehicles in mobile work zones. Many shadow vehicles operating on high-speed and high-volume facilities are required to deploy a truck or trailer-mounted attenuator. It was reported by Bham et al. (2010) that the use of truck mounted attenuators is state law in Delaware. An excellent source of training is the Missouri Department of Transportation's "Truck Mounted Attenuator Training" program (MODOT 2010). This training series provides information about attenuator maintenance, emergency planning, and expectations of the truck driver. Most state highway agencies have developed a roll-ahead guide based on the AASHTO Roadside design guide for known truck weights that the agency owns. Roll-ahead distance is the longitudinal distance from the shadow vehicle to the work zone. When an errant vehicle strikes the attenuator, the force will propel the shadow vehicle forward. Shown in Table 10 are recommended roll-ahead distances for mobile and stationary shadow vehicles with truck-mounted attenuators that are used by the Kansas Department of Transportation (Humphresy and Sullivan 1991).

TABLE 10
Roll-Ahead Distance for Mobile and Stationary Barrier Vehicles

	Weight of Shadow Vehicle	Prevailing Speed (mph)	Weight of Impacting Vehicle to be Contained			
			4,500 lbs	**10,000 lbs**	**15,000 lbs**	**24,000 lbs**
(Moving)	10, 000 lbs	60-65	100 ft	175 ft	225 ft	275 ft
		50-55	100 ft	150 ft	175 ft	200 ft
		≤45	75 ft	100 ft	125 ft	150 ft
	15,000 lbs	60-65	75 ft	150 ft	175 ft	225 ft
		50-55	75 ft	125 ft	150 ft	175 ft
		≤45	50 ft	100 ft	100 ft	100 ft
	24,000 lbs	60-65	75 ft	100 ft	150 ft	175 ft
		50-55	50 ft	75 ft	100 ft	150 ft
		≤45	50 ft	75 ft	75 ft	100 ft
(Stationary)	10, 000 lbs	60-65	50 ft	100 ft	150 ft	200 ft
		50-55	25 ft	75 ft	100 ft	150 ft
		≤45	25 ft	50 ft	75 ft	100 ft
	15,000 lbs	60-65	25 ft	75 ft	100 ft	150 ft
		50-55	25 ft	50 ft	75 ft	100 ft
		≤45	25 ft	25 ft	50 ft	75 ft
	24,000 lbs	60-65	25 ft	50 ft	75 ft	100 ft
		50-55	25 ft	25 ft	50 ft	75 ft
		≤45	25 ft	25 ft	25 ft	50 ft

(Source: Humphreys and Sullivan 1991)

6.6.2 Crash Reduction

Advancements in truck and trailer mounted attenuators have provided excellent crash protection and have contributed to the reduction of the number of severe occupant injury rear-end crashes. However, no lateral impact protection is available with truck mounted attenuator devices since they are designed to be impacted from the rear.

Limited research is available on the effectiveness of truck mounted attenuators. Bryden (2007) investigated New York work zone crashes for five years with a total of 461 crashes being identified. The author concluded that the truck mounted attenuators were highly effective in preventing 77 vehicles from entering the work area in which striking a truck mounted attenuator was the primary cause of the crash. Approximately one-third of these crashes resulted in vehicle occupant injury. The author also noted that truck mounted attenuator strikes from the rear as compared to the side was found to be 4 to 1.

Truck mounted attenuators were also found to have a positive benefit cost ratio. A 1985 report prepared for the Texas legislature estimated a savings of $23,000 per accident in injury and damages were found as compared to a vehicle striking a stationary construction vehicle (Humphreys and Sullivan 1991 and Anderson 1985).

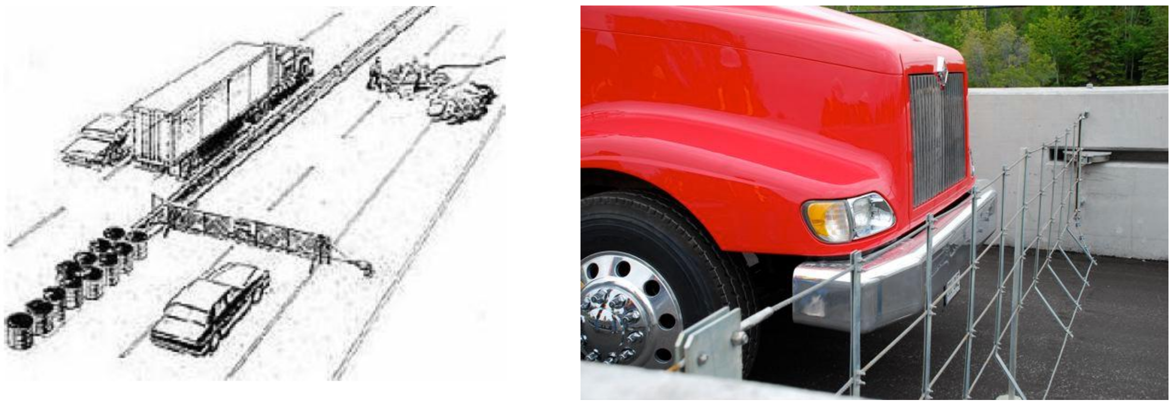
6.6.3 Truck Mounted Attenuator General Research

As shown in the previous sections and specific guidance by state highway agencies in regards to truck mounted attenuators in advance of work zones, recent research has focused on visually enhancing the shadow vehicle and attenuator. Smith et al. (2006) developed new recommendations for truck mounted attenuation systems in New Zealand. The author recommended posting advance warning signs 400 meters (1,312 ft.) upstream of the truck mounted attenuator and shadow vehicle. Flashing strobe lights and retroreflective tape were shown to enhance the size and shape of the attenuator device. These recommendations were found to result in 27 percent fewer drivers merging in the last 300 meters prior to the truck. A complimenting study by Steele and Vavrik (2009) found that the percent of vehicles that merged within 500 feet the truck mounted attenuator was 4.8 percent in a rural area and 12.2 percent in nan urban area.

A research study also investigated the shape and the color of the attenuator warning sign. Bham et al. (2010) evaluated driver perception during day and nighttime conditions of four different attenuator markings using a driver simulator. The markings included green and black inverted “v” pattern, yellow and black inverted “v” pattern, red and white checkerboard pattern, and orange and white vertical stripe pattern. The lane change distance from the attenuator was recorded for 120 participants in the virtual highway with a posted work zone speed of 45 mph. Results of the study indicated the red and white checkerboard pattern was the most effective.

6.7 Vehicle Arresting Systems

A relatively new type of positive protection device is vehicle arresting systems for work zones applications. This system is designed to complement such positive protection devices as portable concrete barriers to prevent vehicle penetration into activity areas such as a closed ramp, runaway truck lanes, or temporary roads where there is a chance of a head-on crash (AASHTO, 2011). Figure 14 shows two examples of vehicle arresting systems.



(Source: CDOT 2011; Ontario Ministry of Transportation 2011)

FIGURE 15
Vehicle Arresting Systems

The AASHTO Roadside Design Guide describes one proprietary vehicle arresting system used for work zone applications called Dragnet as shown in Figure 15. The MUTCD also has a brief description of an arresting system in Section 6F.83. This system is designed to deflect and/or significantly slow a vehicle to a stop with limited damage or injury to the occupants. Dragnet is the only known product at the time of the report that met NCHRP 350 TL-3 guidelines for head-on impact crashes, and approved by the FHWA. The cost of a the Dragnet vehicle arresting system ranges from a rental price of $4,000 to $5,000 with a replacement net after being stuck costing between $3,000 to $4,000. Generally, very limited research and technical information is available for vehicle arresting systems in temporary work zone settings.

Chapter 7: Synthesis of Positive Protection State-of-Practice

In the process of developing proposed work zone positive protection guidance for the Kansas Department of Transportation that would fall into compliance with Temporary Traffic Control Devices 23 CFR 630 Subpart K, the research team conducted a survey of state highway agencies. A total of 27 agencies were sampled across the country. An Internet search and follow-up phone calls with traffic operations offices provided key information on such questions as: (1) does the state have an updated safety and mobility plan or guidance that specifies positive protection? (2) What positive protection devices does the state give guidance for? And (3) what year did the guidance take affect and has it been subsequently revised?

The internet search and follow-up phone calls resulted in key information from 27 states that represent all areas of the country including Hawaii. Guidelines for positive protection and compliance with Temporary Traffic Control Devices 23 CFR 630 Subpart K included one or more of the following:

- A letter from the FHWA office located within the state recognizing that the state highway agency is in compliance with Temporary Traffic Control Devices 23 CFR 630 Subpart K with existing technical drawings, specifications, or work zone guidance.

- Enhanced work zone guidance based on requirements of 23 CFR 630 Subpart K which also included documents that have not been approved by the FHWA. This included a section on engineering judgments or study, work zone characteristics that warrant positive protection, and guidance for available positive protection devices.

- Extensive information and guidance on positive protection including examples of usage, vendor information, cost / benefit analyses, approved devices for certain work zone characteristics, and maintenance requirements for contractors.

Appendix A summarizes the highlights found for each state highway agency in regards to positive protection for work zones. The results of the survey are presented in table format which includes: the name of the state highway agency, document names that specify positive protection in work zones (details, specifications, standard drawings), the date in which the cited documents were created, approved, or in the process of approval, and any unique guidance relating to positive protection in work zones.

During the process of finding survey information, the research team noted that in many cases when a positive protection guidance document or the state highway agency safety and mobility plan was found and downloaded, it was outdated. This resulted in a phone call to the state highway agency work zone safety specialist who provided the documents from the agency internal servers, not accessible to the public. In two cases, draft documents were provided to the research team in which the work zone safety specialist was unsure if the document was even approved by senior personnel.

The results of the survey indicated that many state highway agencies were in the process of updating their safety and mobility plan, specifically addressing positive protection in work zones. Many state highway agencies have dedicated manuals to specifically address work zone positive protection. These agencies included the Colorado, Hawaii, and North Carolina Departments of Transportation. It was found that states such as New Hampshire, Arkansas, and Virginia have extensive positive protection guidance including recommended distances, type, and best practices for varying types of work zone activities and positive protection devices.

The research team found that acquiring information regarding work zone positive protection guidance beyond standard drawings using a state highway agency website was complicated. Many state highway agencies were found to dedicate pages and extensive information on temporary work zones and driver safety, however limited guidance beyond federal and state MUTCD's were found to be available to the public. However, it was found that a number of agencies did have work zone positive protection guidance in the form of technical summaries, brochures, or contractor specifications.

Generally it was found that all state highway agencies had some form of basic guidelines in place and easy to access documents for common positive protection devices (e.g. portable concrete barrier, truck / trailer-mounted attenuator, longitudinal barrier end-treatments). It was found that some state highway agencies have gone as far as recommended certain types of proprietary devices for positive protection and their associated guidelines that can be used under unique or certain conditions. Finally, it was observed by the research team that many state highway agencies have successfully worked together in information sharing on best practices for work zone positive protection and are reflected in their guidance with similar language, references, and noted device limitations.

Chapter 8: Proposed Positive Protection Guidance for the State of Kansas

Working with the Kansas Department of Transportation, the research team developed draft work zone positive protection guidance as shown in Appendix B. Guidance is divided into four sections including:

- Written guidance was developed for work zone positive protection that is expected to meet federal Temporary Traffic Control Devices 23 CFR 630 Subpart K. Guidance is broken down into four sections. The background section provides a short description explaining why guidelines were developed and its intended goals for the State of Kansas. The second section provides a clear definition of what positive protection is for work zones. Exposure control measures define how work crew exposure to open traffic can be limited, reduced, or eliminated using the new decision flowchart. Finally, the Other Traffic Control Measures section provides a list of other measures that can be used to control exposure and which are not considered positive protection devices (as described in this report).
- A decision flowchart was created to assist an engineer in determining and documenting how to limit, reduce, or eliminate exposure in temporary work zones. Additionally, the flowchart provides decision points where work zone positive protection is required.
- A table describing work zone exposure control measures was created. This table describes commonly used KDOT exposure control measures along with approved guidance for each measure that an engineer can reference.
- A table describing possible positive protection devices was created. This report assumes that engineers will be interested in TL-3 approved positive protection devices as well as TL-2 end-treatments and truck-mounted attenuators. The devices listed are devices approved at the time of this report and it is the assumption that future developments or changes to guidelines will supersede this report.

One important aspect KDOT wanted in the development of guidance was to help an engineer with the decision process in determining if positive protection is needed for a temporary work zone. Additionally, the guidance was setup to provide an engineer with existing documents approved by KDOT to limit, reduce or eliminate exposure at work zones through various methods before considering positive protection.

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Appendix A: Positive Protection Survey of State Highway Agencies

State Agency	Referenced Document(s)	Latest Revision Date	Positive Protection in Work Zones: Key Guidance
Alabama (ALDOT)	Guidelines for Operation: Subject – Temporary Traffic Control Devices Section 3.65	2011	1) Positive protection devices shall meet NCHRP-350 crashworthiness tests. Devices include **Portable Concrete Barriers (PCSB), Moveable Traffic Barrier Systems, Water-Filled Barriers, Guardrails, Shadow or Protective Vehicles and Truck-Mounted Attenuators (TMA), and other types of crash cushions and vehicle arresting systems.** 2) The use of positive protection is encouraged for work zones with characteristics such as: no means of escape for workers, duration greater than two weeks, posted speed limited greater than 45 mph, work operations close to the open travel lanes, and identified roadside hazards. 3) **Portable Concrete Barriers**: warranted for work zones with a posted speed limit greater than 45 mph. ALDOT has developed a barrier guidance table for potential situations involving worker and drop-off protection. The exposed ends of barriers shall be treated as specified in the AASHTO Roadside Design Guide. End Treatments shall meet NHRP-350 or MASH approved test guidelines 4) **Protective Vehicles and Truck-Mounted Attenuators**: Recommended for mobile work zones, a shadow vehicle only is also warranted for over-night concrete slab repair work.
Arizona (ADOT)	Traffic Control Design Guidelines: Section D \ Implementation Guidelines for Work Zone Safety and Mobility: Pursuant to	2003 / 2009	1) Positive protection in work zones is based on an engineering study (agency-wide or to determine measures to be applied on an individual project) 2) **Temporary Concrete Barrier**: designed in accordance with ADOT highway design standards. The length of need and offset formulas are found in Chapter 5 of the AASHTO Roadside Design Guide

State Agency	Referenced Document(s)	Latest Revision Date	Positive Protection in Work Zones: Key Guidance
	23 CFR 630 Subpart J&K		3) **Impact Attenuator**: is placed at the end of the temporary barrier, an existing guardrail, or dangerous embankment
Colorado (CDOT)	CDOT Guidelines for the Use of Positive Protection in Work Zones	2010	1) CDOT has developed a complete set of guidelines based on 23 CFR 630 Subpart K for the use of positive protection in work zones. This document includes guidance, vendor information, designer / engineer considerations, and web resources for worker and user safety.
Florida (FDOT)	Plans Preparation Manual, Volume 1 – English: Section 10.11	2011	1) Positive protection is recommended for work zones with the following characteristics: no means of escape for workers, longer than two weeks in one location, anticipated work zone speeds greater than 45 mph, operations that place workers close to open travel lanes, and identified roadside hazards. 2) **Barrier Walls (Temporary)**: Use design standards, Index 414, 415, and 600. The barrier shall be placed on a cross slope of 1:10 or flatter with 2 feet of clearance between the barrier and open travel lane. 3) **Water-Filled Barriers**: should be used in accordance with vendor drawings on the qualified product list, and meet NCHRP-350 crashworthiness tests. 4) **Crash Cushions**: should be used on the exposed ends of temporary barriers to protect motorists. Selection of the systems should be the result of a site analysis, the recommendation of the designer, and from the qualified product list.
Georgia (GDOT)	Work Zone Safety and Mobility Policy – Appendix F: Final Rule on Temporary Traffic Control Devices Title 23 CFR 630 Subpart K / Department of	2008 / 2011	1) The use of positive protection, specifically longitudinal traffic barriers shall be based on an engineering study. At a minimum, positive protection shall be considered in work zone situations that place workers at an increased risk from motorized traffic where position protection offers the highest increased safety for workers. 2) Work zone situations where positive protection would be needed: limited escape routes for workers, long project

State Agency	Referenced Document(s)	Latest Revision Date	Positive Protection in Work Zones: Key Guidance
	Transportation State of Georgia Special Provision: Section 150 – Traffic Control		duration, high anticipated operating speeds, work operations close to open travel lanes, protection from roadside hazards, limited equipment and material staging areas, bridge widening, and culvert extension. 3) **Temporary Barriers**: when located less than 20 feet away from the travel lane, yellow reflectors shall be fixed to the top in intervals not greater than 40 feet. The approach end of the temporary barrier shall be flared and protected an attenuator.
Hawaii (HDOT)	Work Zone Safety Management Guidelines	2008	1) Positive protection devices shall be considered for work zones that: provide no means for worker escape, long duration projects, design speeds greater than 50 mph, work operations close to the travel lane, and the presence of identified roadside hazards. 2) **Portable Concrete Barriers**: are recommended for all roadway work zones. Deflection of barrier can be up to 3 feet. Pinning the temporary barrier to the pavement will lesson deflection. 3) **Quickchange Barriers**: are recommended for all roadway work zones. They are Ideal for dynamic work areas that require shielding at various lane widths. Currently, the Quickchange barriers system is proprietary and cost of operations is high. 4) **Steel Barriers**: are recommended for all roadway work zones. Deflection is usually less than 3 feet and currently the system is proprietary. 5) **Water-filled Barriers**: are recommended for roadways with a work zone design speed less than 45 mph. Since deflection is high, the barrier requires a significant buffer area. 6) **Truck-Mounted Attenuators**: are recommended for mobile work zones where a truck can provide a shield. A roll-forward distance is necessary to allow system to work. 7) All positive protection systems except truck-mounted

State Agency	Referenced Document(s)	Latest Revision Date	Positive Protection in Work Zones: Key Guidance
			attenuators require a crashworthy end treatment. These devices along with the listed positive protection devices shall be approved by the FHWA and HDOT.
Illinois (IDOT)	Safety Engineering Policy Memorandum: Safety 4-08 Work Zone Safety Supplemental Policy, Subpart K to Title 23 CFR Part 630	2008	1) For local roads with an ADT of less than 400, barricades can be used in lieu of positive protection based on engineering judgment. 2) Positive protection is required for either <u>mobile</u> or <u>stationary</u> work zones. All positive protection devices shall comply with NCHRP-350 test guidelines for crashworthiness. 3) <u>Mobile Work Zones</u>: multi-lane highways - if a non-standard lane closure is needed, positive protection such as a **Truck-Mounted Attenuator** shall be used to close the lane in advance of the work zone. Two-lane highways - a **Truck-Mounted Attenuator** is required. 4) <u>Stationary Work Zones</u>: positive protection will be required for areas with no means of escape from motorized traffic based on engineering judgment. Multi-lane highways - **temporary longitudinal traffic barriers** shall be used for work zones lasting longer than 24 hours or require multiple day and nights setups. Two-lane highways - **temporary longitudinal traffic barriers** shall be used for work zones that occupy a location for more than four days per stage. **Truck-Mounted Attenuators**: can be used in instances where workers are present for only short durations (less than 24 hours).
Iowa (IowaDOT)	Work Zone Safety and Mobility Final Report	2010 / 2010	1) The IowaDOT revised numerous sections of the Design Manual to ensure compliance with 23 CFR 630 Subpart K.

State Agency	Referenced Document(s)	Latest Revision Date	Positive Protection in Work Zones: Key Guidance
	/ Highway Design Manual: Sections 9B-9, 8B-9		2) **Temporary Barrier Rail**: concrete barriers are mainly used on highway roadway projects. However steel barriers are typically used on bridge projects with limited cross-sectional space. The use of temporary barrier rail is based on engineering judgment. However, there are cases when temporary barriers are warranted which include: work zones with limited worker escape (e.g. bridge deck / rail), project duration greater than 2 weeks, identified roadside hazards left in place overnight, work zones in place for more than one construction season, and separation of two-way traffic in freeway work zones. A minimum lane width of 14 feet - 5 inches must be maintained between barrier and bridge rail or other barriers. Temporary barriers should be installed at a minimum of 2 feet from the edge of the nearest open travel lane. The maximum flare rate towards traffic is 6:1, and the approach ends must be protected if the temporary barrier terminates in the clear zone. All barriers must meet NCHRP-350 and MASH test guidelines. 3) **Sand-Filled Barrels**: may be used as attenuator end treatments for temporary barrier systems. The designer should specify the number of locations of where the barrels should be placed with 2.5 feet of spacing between the barriers and first set of barrels.
Michigan (MDOT)	Work Zone Safety and Mobility Manual: Chapter 17	2010	1) The use of positive protection in work zones have been an MDOT standard for many years. Project designers / engineers are to follow Chapters 7 and 8 in the MDOT Road Design Manual. 2) **Mobile Attenuators**: MDOT 2003 publication: Guidelines for Using a Truck-Mounted Attenuator on Construction Projects shall be followed for work zone operations. In 2008, trailer-mounted attenuator guidelines were added to the document as a special provision. 3) **Temporary Longitudinal Barriers**: include the use of

State Agency	Referenced Document(s)	Latest Revision Date	Positive Protection in Work Zones: Key Guidance
			concrete barrier wall, moveable barrier wall, or water filled barrier wall that meets NCHRP 350 TL-3 guidelines if constructed after 2006. Longitudinal barriers shall be used on all freeway projects where opposing traffic lanes are adjacent to each other or when dividing bi-directional traffic on roadways where the posted speed limit prior to the work zone is 50 mph or greater. Temporary longitudinal barriers are not required on project where motorist and non-motorized traffic lanes are adjacent to each other when a non-mountable curb is in place. Further guidance can be found in the Michigan Manual of Uniformed Traffic Control Devices (MMUTCD).
Mississippi (MDOT)	Procedure for Managing Traffic Through Work Zones	2008	1) Positive protection devices must meet NCHRP-350 crashworthiness tests, be utilized in work zones with a project duration greater than two weeks, a pavement drop-offs greater than 3 inches, and anticipated operating speeds greater than 45 mph within the work zone.
Montana (MTD)	Work Zone Safety and Mobility Goals and Objectives, Procedures, and Guidelines / Roadside Design Manual- Chapter 15: Maintenance and Protection of Traffic Through Construction Zones	2009 / 2006	1) **Temporary Concrete Barrier Rail**: determined on a project-by-project basis. They are designed to keep traffic from entering the work zone, protect workers and pedestrians, separate two-way traffic, shield obstacles, and protect construction items such as false work or exposed objects 2) **Water-Filled Polyethylene Plastic Shell**: are supported by a wire framework and are capable of 12 feet of deflection if hit. These devices are highly desirable in urban and congested work zones with lower operating speeds. 3) **End Treatments**: must be installed at the ends and pedestrian gaps in temporary barrier system. The QuadGuard CZ is preferred end treatment for temporary barriers. 4) The temporary barrier length is determined by a 15 degree angle from the back of hazard or from the clear zone distance off the travel way.
Nevada	Work Zone Safety &	2009	1) Positive protection devices must meet NCHRP-350 guidelines,

State Agency	Referenced Document(s)	Latest Revision Date	Positive Protection in Work Zones: Key Guidance
(NDOT)	Mobility Implementation Guide		located in work zones that provide no means of escape for the workers, long duration projects, operating speeds greater than 45 mph, work zones that place workers close to travel lanes, and work zones with roadside hazards (drop-offs, unfinished bridge decks) 2) Positive protection at work zones will be based on an engineering study which may be used to develop positive protection guidelines for the agency or for an individual project
New Hampshire (NHDOT)	Positive Protection Guidance for Work Zones	2010	1) New Hampshire uses several types of positive protection: **Portable Concrete Barrier, Guardrail, Traffic Control Barrier, Terminal End Treatments, Impact Attenuators (mechanical), Sand Barrel Arrays, Truck / Trailer Mounted Impact Attenuators** 2) **Portable Concrete Barrier**: are either freestanding jerseys or "F" shaped and precast 10 feet in length with connection devices. A Minimum offset of 2 feet from the line of the travel lane to the barrier is desirable; however 6 feet would accommodate snow removal. For connection between barriers, refer to the AASHTO Roadside Design Guide. Barrier performance level should match expected traffic exposure at the site. The Maximum recommended flare rates include: **Operating Speed** — **Maximum Flare Rate** ≤ 30 mph — 7:1 40 mph — 8:1 50 mph — 11:1 60 mph — 14:1 70 mph — 15:1

State Agency	Referenced Document(s)	Latest Revision Date	Positive Protection in Work Zones: Key Guidance
			3) **Guard Rail**: temporary guardrail consists of a meal beam rail with wood/plastic block-outs and metal or wood posts. Installation and performance is the same as a permanent guardrail system, except the equipment is "like-new" instead of new and are designed for long duration projects. Similar requirements are required for that of a portable concrete barrier in terms of spacing. 4) **End Treatments**: acceptable end treatments include: an approved crashworthy terminal connection to an existing crashworthy temporary barrier, approved impact attenuator, flaring the end of the barrier beyond the edge of the clear zone, burying the end into the back-slope so vehicles avoid direct impact. 5) **Impact Attenuation (mechanical)**: typically connected to the end of a barrier system. Work zone considerations include: use of re-directional or non-redirectional devices. When using non-re-directional devices, a rectangular area of 75 feet behind the terminal and 20 feet perpendicular to the barrier system should be relatively traversable. 6) **Sand Barrel Array**: use of sand barrels in work zones are prohibited between November 1st and April 15th unless they are at least 10 feet away from the travel way. Special considerations are needed if the designer / engineer require barrels during this time period including methods to prevent the sand from freezing. 7) **Truck / Trailer Mounted Attenuation**: cost-effective protection for short-duration work zones. The devices can take small hits, but significant impacts will require that the device and or truck be completely replaced.
New Jersey	Traffic Mitigation	2007	1) Specifies **Temporary Concrete Barriers** can increase worker

State Agency	Referenced Document(s)	Latest Revision Date	Positive Protection in Work Zones: Key Guidance
(NJDOT)	Guidelines for Work Zone Safety and Mobility		and driver safety 2) **Moveable Barrier**: useful when there is strong directional traffic peaking, however safety is a significant issue if the lanes cannot be separated easily by a moveable barrier
North Carolina (NCDOT)	Guidelines for the Use of Positive Protection in Work Zones	2009	1) NCDOT developed a complete set of guidelines based on 23 CFR 630 Subpart K for the use of positive protection in work zones. This document included guidance, vendor information, designer / engineer considerations, and web resources. The guidelines are similar to the ones developed by the Colorado Department of Transportation.
Ohio (ODOT)	Traffic Engineering Manual: Section 605-14 / OHMUTCD	2011 / 2005	1) Positive protection shall be considered for work zones that include: no means of escape for workers, high-speed multi-lane divided highways (>45mph), long-term, workers operating close to open travel lanes, drop-off areas, projects with high operation speed and high volumes, and bridge decks where the parapet or guardrail is removed. 2) **Moveable Guardrail**: applications were the device can be used: (1) the need to close an additional lane during work periods, (2) close an additional lane during off-peak hours to provide extra space, and (3) creating a temporary reversible lane providing unbalanced capacity favoring the major direction of flow. More information can be found in OMUTCD, Section 6G.18. 3) **Portable Concrete Barrier**: delineation on all barriers shall be used with barrier reflectors and object markers. Exposed ends should be located at a distance from the edge of the travel way equal to the clear zone distance. If this distance cannot be achieved, impact attenuators shall be located at the exposed ends of the temporary barrier. Exposed ends shall be tapered, barrier anchoring may be considered, and grade at which the barrier is sitting must be 10:1 or flatter. 4) **Plastic Water-Filled Barrier (as a longitudinal barrier)**:

State Agency	Referenced Document(s)	Latest Revision Date	Positive Protection in Work Zones: Key Guidance
			cannot be used as a direct substitute for a portable concrete barrier due to the potential deflection distance. However, the following situations may have an advantage over portable concrete barriers: (1) Intermediate-term work zones, emergency management, moving operations on low-speed urban roadways, locations with limited vertical clearance, locations requiring restricted dead loads (e.g. bridge decks). 5) **Vehicle Arresting Systems**: can consist of portable netting, cables, and energy absorbing anchors. The use of vehicle arresting systems is determined by the project designer / engineer. 6) **Truck-Mounted Attenuators**: are attached to the rear end of a shadow vehicle and is located in advance of the work area. Guidance should be used from the AASHTO Roadside Design Guide Section 193-12.
South Dakota (SDDOT)	Work Zone Safety & Mobility Plan	2010	1) Work zone management strategies items to be considered but not limited to: **Temporary Barrier Systems** and **Crash Cushions**.
Tennessee (TDOT)	Standard Specifications for Road and Bridge Construction, Supplemental Specifications – Section 700 / Circular Letter 712.07-1	2010 / 2009	1) TDOT stated their guidance for positive protection was in compliance with Subpart K. Additionally, TDOT developed a work zone traffic control inspection form. This checklist enables TDOT inspectors to verify that temporary traffic control (including positive protection) is properly used, maintained, and in compliance with Subpart K. 2) **Portable Barrier Rail**: will be placed as far away from the travel lanes as possible while serving the intended purpose. All portable barriers will be moved or removed as directed by the engineer.
Texas (TxDOT)	Compliant Work Zone Traffic Control Device List / Work Zone Safety and	2009 / 2008 / 2006	1) TxDOT reported future policy changes will be made as per recommendations report in Texas Transportation Institute Publication #0-6163-1. Positive protection at work zones should be determined by the project engineer based on such

State Agency	Referenced Document(s)	Latest Revision Date	Positive Protection in Work Zones: Key Guidance
	Mobility Guidelines / Texas Manual on Uniform Traffic Control Devices (TMUTCD)		characteristics as: speed, volumes, worker exposure, roadway geometry and type of work. Positive protection offers the highest potential increase for safety in situations where workers have no means to escape for traffic, work zones lasting more than two weeks, anticipated operating speed of 45 mph or greater, work operations close to travel lanes, and the presence of identified roadside hazards. 2) **Truck-Mounted Attenuators**: must be NCHRP-350 compliant. TL-2 approved for roadways with posted speed limits of 45 mph or less. TL-3 may be used on any TxDOT facility. Supporting vehicle will have a weight of 20,000 ± 1,000 pounds. If vehicle weight is less, the contractor is responsible to adhere to TL-2 and TL-3 guidelines. 3) **Temporary Traffic Barriers as Channelizing Devices**: may be filled with water as ballast, should not be used for a merging taper except in low-speed urban areas, and should not be used for a constricted / restricted work zone. 4) **Temporary Traffic Barriers**: Type 3 or Jersey concrete barriers are used for work zones and are required to be placed less than 2ft. from a drop-off. Barriers are in 30 feet long segments which weight approximately 14,000 lbs. each. Exposed ends of barriers shall be treated as per AASHTO's Roadside design guide and are crashworthy of NCHRP-350 or MASH-09. 5) **Vehicle-Arresting Systems**: designed to prevent vehicle penetration into a work zone; can either be netting, cable, or energy absorbing anchors. The device should be located so that vehicles are not likely to penetrate the area needing protection.
Vermont (VTrans)	Work Zone Safety & Mobility Guidance Document- Appendix A: Temporary Traffic	2011* (Still in revision)	1) **Positive Barrier**: are to be considered when: the work zone speed is anticipated to be greater than 45 mph, AADT greater than 15,000, projects lasting longer than two weeks, projects evaluated using standards T-25 and T-26, projects with

State Agency	Referenced Document(s)	Latest Revision Date	Positive Protection in Work Zones: Key Guidance
	Control Devices		equipment and material in the clear zone, and interstate and divided limited access facilities. 2) **Barrier Guidelines**: a minimum of 2 feet offset from open travel lanes, if there is no tolerance for deflection then consider anchoring the barrier, unprotected ends of barriers on US and state routes should be tapered at least 10 feet outside the edge of the traveled lane, and follow AASHTO Roadside Design Guidelines. 3) **Truck Mounted Attenuators**: sufficient length is needed between the truck and work zone to account for a vehicle strike. Suggested guidance on use and operation from the Michigan Department of Transportation.
Virginia (VDOT)	Virginia Work Area Protection Manual: Standards and Guidelines for Temporary Traffic Control	2011	1) VDOT has extensive information regarding temporary traffic control devices, below are highlighted guidance for positive protection: 2) **Crash Cushions**: either stationary to mitigate the effects of errant vehicles from striking barriers / hazards or truck-mounted. Truck-mounted attenuators shall be attached to the rear of show trailers or trucks listed on VDOT's approved device list. Truck mounted attenuators shall not be used more than 3 consecutive days to protect a fixed object. The rear panel of the attenuator shall have alternate 6 to 8 inches wide orange and black chevron stripes. All truck-mounted attenuators shall meet the requirements of NCHRP-350 TL-3 or MASH. 3) **Shadow Truck**: shall be used: when closing a lane on a four or more lane roadway with a posted speed of 45 mph or

State Agency	Referenced Document(s)	Latest Revision Date	Positive Protection in Work Zones: Key Guidance
			greater; on shoulders, ramps, and loops of interstates and limited access highways; when mobile operation occupies all or part of the travel lane on a multi-lane roadway with a posted speed limited greater than 45 mph, and other locations where the engineer feels such protection is warranted. The shadow truck shall be position 80 to 120 feet in advance of the work zone, no traffic control devices shall be stored in the shadow truck, and the truck shall be visually inspected daily prior to use. 4) **Portable Water-Filled Devices**: can only be used in lieu of drums and vertical panels and shall not be substituted for temporary concrete barriers. 5) **Temporary Concrete Barriers**: designer / engineer will specify concrete barrier or channelizing device based on an engineering study. Concrete barriers must meet TL-3 or 4 of NCHRP-350 and the MASH testing. Barriers shall be anchored if placed within two feet of a trench/drop-off with a depth equal to or greater than 4ft, equipment and materials parked/stored in the work zone, and site deemed hazardous to workers. Designers and engineers should use the VDOT pin and loop positive connection Precast Concrete Median Barrier 6 ft. dynamic design criteria for temporary traffic control lanes.
Washington (WSDOT)	WSDOT Design Manual: Sections 1010 and 1610-1620	2011* (still in revision)	1) Barriers (**temporary concrete, moveable, portable steel, water-filled**): designed to separate opposing high speed traffic, drop-off protection at work zones, when equipment must remain in the construction work zone, when temporary signs, cones and barricades do not provide adequate protection. Positive protection devices shall conform to NCHRP-350 crashworthiness tests and lateral displacement is expected to be 2 to 4 feet. If the barrier is expected to be displaced greater than 4 feet, it must be anchored or replaced

State Agency	Referenced Document(s)	Latest Revision Date	Positive Protection in Work Zones: Key Guidance
			2) **Impact Attenuators:** Must be installed at the end of temporary concrete barriers at work zones and meet NCHRP-350 crashworthiness tests.
West Virginia (WVDOT)	Design Directives, Manual of Temporary Traffic Control for Streets and Highways: Section F.82-83	2010	1) Temporary traffic barriers shall be supplemented with standard delineation markings and signs. The devices and their use shall be in accordance with the AASHTO Roadside Design Guide. 2) **Movable Barrier System**: can be used to increase the work zone area during off-peak hours. 3) **Truck-Mounted Attenuators**: are attached to any shadow vehicle or trailer and shall be located in advance of the work zone. 4) **Vehicle Arresting Systems**: systems including: netting, cables, and energy absorbing anchors. The system shall be located prior to areas of the work zone and capture vehicles that try to enter restricted areas.
Wisconsin (WisDOT)	Facilities Development Manual: Chapter 11, Section 50-35	2008	1) **Concrete Barrier Temporary Precast in Work Zones**: are specified to: separate bi-directional traffic with posted speed limit greater than 45 mph, isolated work zones, and drop-off or slope greater than 3:1. The barrier must be anchored if: distance to a 2 foot or greater drop-off is steeper than 3:1, deflection distance 2 feet for posted speed of 40 mph or less and 4 feet for posted speed limit greater than 45 mph. 2) **Crash Cushion or Sand Barrels**: both devices must comply with NCHRP-350 crashworthiness tests and required end treatment for temporary two-way bi-directional facilities.
Wyoming (WYDOT)	Standard Specifications for Road and Bridge	2010	1) Positive protection must meet testing requirements of the MASH or NCHRP – 350 2) **Portable Plastic Water Filled Barrier:** (78"x 21"x 32") and

State Agency	Referenced Document(s)	Latest Revision Date	Positive Protection in Work Zones: Key Guidance
	Construction: Section 703		require an end terminal 3) **Temporary Concrete Barrier:** max deflection of 4 feet, class B concrete, grade 40 steel, connecting pins that meet ASTMA 36, and end terminal required.

Appendix B. Proposed Positive Protection Guidance for Kansas

Proposed Kansas Department of Transportation (KDOT) Positive Protection Guidance April, 2012

1.0 Background

On December 5, 2007 the Federal Highway Administration (FHWA) published Temporary Traffic Control Devices 23 CFR 630 Subpart K. This regulation applies to State and local governments that receive Federal-Aid highway funding. Transportation agencies are required to comply with the provisions of the Rule by December 4, 2008. The goals and expected benefits of these guidelines encourage:

- A systematic approach for safety within the work zone;
- Expanded work zone management focus regarding safety and mobility; and
- Innovative thinking for safety in work zones. Thinking outside of the traditional traffic safety and management box by considering alternative/innovative design, construction, contracting, and transportation management strategies.

2.0 Components of KDOT positive protection guidelines

KDOT policy and procedures must address the following components in order to fulfill the requirements of the federal regulation, Temporary Traffic Control Devices, 23 CFR 630 Subpart K.

2.1 Positive Protection

Positive protection devices are intended to minimize motorized traffic intrusion into the work area and other potentially hazardous areas in the work zone. At a minimum, positive protection devices shall be considered in the work zone as outlined by the KDOT Work Zone Exposure Flowchart (Figure B1) to evaluate work zone exposure. The following are examples of conditions that may warrant the consideration for positive protection devices:

- Work zones that provide workers no means of escape from motorized traffic (e.g. bridges);
- Projects with high design speed (65 mph), especially when combined with traffic volumes of greater than 100 vehicles per hour in rural areas;
- Work operations that place workers close to the travel lanes open to traffic (e.g. limited lateral buffer space); and
- Roadside hazards, such as drop-offs greater than 4-inches.

Positive protection device use on a given project should be determined by the using the KDOT Positive Protection Flowchart. Table A provides additional information for each device that is commercially available as of 2012.

2.2 Exposure Control Measures

Exposure control measures are intended to remove and reduce worker exposure to motorized traffic and road user exposure to work activity. Determination of how and when to use these measures on a given project should be determined using the KDOT Work Zone Exposure Flowchart. Examples of exposure control measures are as follows and further explained in Table B:

- Full road closures;
- Ramp closures;
- Median cross-overs;
- Full or partial detours or diversions;
- Performing work when traffic volumes are low; and
- Accelerated construction to reduce project time.

2.3 Other Traffic Control Measures

Other traffic control devices should be considered for use in work zones to reduce work zone crashes and the risks and consequences of motorized traffic intrusion into the work space. The following devices, which are not mutually exclusive, should be considered:

- Temporary traffic signals;
- Pilot car;
- Increased law enforcement presence;
- Speed management;
- Public/traveler information; and
- Temporary pavement markings/rumble strips.
- Lateral buffer space

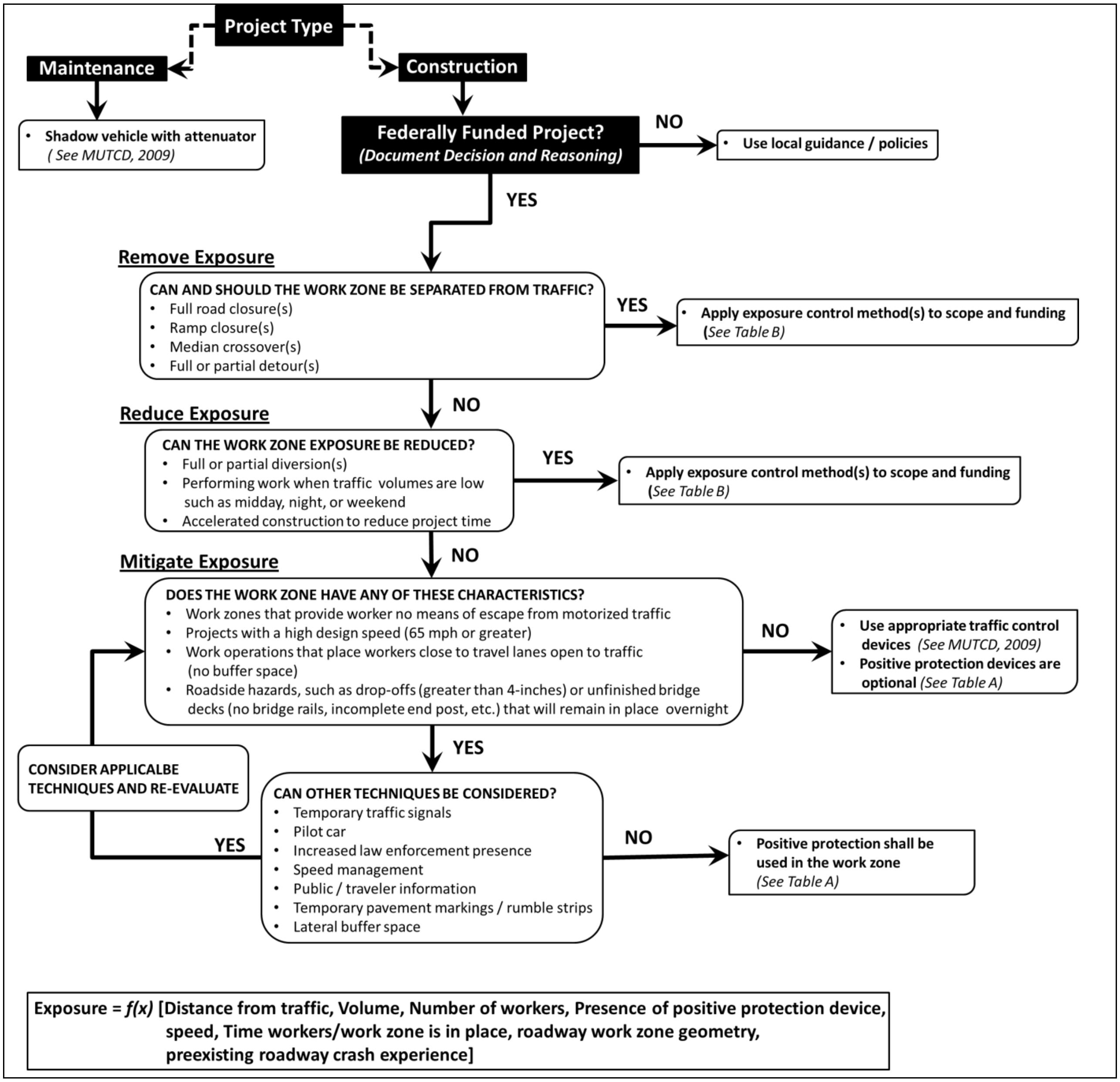

FIGURE B1
KDOT Positive Protection Flowchart for Temporary Work Zones

Kansas Department of Transportation

Table A

Positive Protection Devices

Positive Protection Device	Uses	Requirements and limitations
Portable Concrete Barriers (PCB)	Separates the work area from open traffic	Recommended for use on all roadways. Deflection of barrier is up to 3-feet. Pinning barriers to pavement will lessen deflection.
Ballast-Filled Portable Barriers	Separates the work area from open traffic	Recommended for use on low-speed (design speed of 45 mph or lower) roadways only. High deflection requires large longitudinal buffer area behind barrier. However, as of 2012, TL-3 approved ballast-filled barriers are available for high-speed facilities.
Steel Barriers	Separates the work area from open traffic	Recommended for use on all roadways. Deflection of barrier is usually less than 3-feet upon errant vehicle impact if anchored.
Moveable Barriers	Separates the work area from open traffic	Recommended for use on all paved roadways. Ideal for dynamic a work area that requires shielding for varying widths. Initial cost and on-going operation costs are higher than other barrier types.
Mobile Barriers	Provides longitudinal protection and portable crash cushion for mobile or short-term work zones	Recommended for mobile operations and smaller work areas where a tractor and modified trailer can be used as a longitudinal shield. Work area lateral distance and material / equipment delivery may be limited depending on the location of the project.
Truck Mounted Attenuators	Provides a portable cushion to shield the mobile or short-term work area	Recommended for mobile operations and smaller work areas where a truck can be used as a shield. Roll forward distance is necessary to allow system to perform as intended.
Vehicle Arresting Systems	Captures an errant vehicle prior to entering the work area	Recommended at the entrance of work areas where a flare cannot be created using a longitudinal barrier system. Arresting systems requires attachment to a longitudinal barrier system and a backup arresting net will be needed in the event that a vehicle is captured.

[a]All barriers listed as Positive Protection Devices, except truck mounted attenuators require the use of a crashworthy end treatment

[b]All devices listed, including their end treatments, shall be approved by the FHWA and KDOT prior to use

Kansas Department of Transportation

Table B

Exposure Control Measures

Measure to Remove / Reduce Exposure	Definition	KDOT Policy, Guidance, Standards, or Specifications
Full road closure(s) / detour(s)	Complete closure of the roadway. Only work vehicles and local traffic (where available) are allowed access.	KDOT Detours, SOM 1.11.4
Highway Ramp closure(s)	Similar to "full road closure(s)" except for either an on-ramp or off-ramp of a highway	TE 702
Median crossover(s)	A "break" in the median to access contra-flowed lane(s)	TE 740 and TE 742
Full or partial diversion(s)	Use of a temporary road to divert traffic around the work area.	TE 736 and TE 737
Performing work when traffic volumes are low	Night closures and rescheduling the work hours when errant vehicle occurrences are less likely to occur.	Lane Closure Chart
Accelerated Construction to reduce project time	Reducing the project time to minimize worker exposure to traffic	

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