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Investigation of Truck Mounted Attenuator (TMA) Crashes in Work Zones in Virginia

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Final Report VTRC 16-R7

VIRGINIA TRANSPORTATION RESEARCH COUNCIL
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www.VTRC.net

Standard Title Page - Report on Federally Funded Project

1. Report No.: FHWA/VTRC 16-R7	2. Government Accession No.:	3. Recipient's Catalog No.:
4. Title and Subtitle: Investigation of Truck Mounted Attenuator (TMA) Crashes in Work Zones in Virginia		5. Report Date: October 2015 6. Performing Organization Code:
7. Author(s): Benjamin H. Cottrell, Jr., P.E.		8. Performing Organization Report No.: VTRC 16-R7
9. Performing Organization and Address: Virginia Transportation Research Council 530 Edgemont Road Charlottesville, VA 22903		10. Work Unit No. (TRAIS): 11. Contract or Grant No.: 105843
12. Sponsoring Agencies' Name and Address: Virginia Department of Transportation 1401 E. Broad Street Richmond, VA 23219	Federal Highway Administration 400 North 8th Street, Room 750 Richmond, VA 23219-4825	13. Type of Report and Period Covered: Final April 2014-October 2015 14. Sponsoring Agency Code:
15. Supplementary Notes:		

16. Abstract:

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An email survey of Virginia Department of Transportation (VDOT) and contractor staff was administered to obtain information on the opinions of field forces with regard to the use of TMAs in work zones and their safety in mobile and lane closure operations. Crashes involving TMAs from 2011-2014 in Virginia were compiled and analyzed.

Based on the survey results, driver inattention/behavior, road geometrics/sight distance, mobile operations, and not following the Virginia Work Area Protection Manual are possible contributing factors for TMA crashes. TMA crashes increased from 2011-2014, and most of these crashes occurred on the interstate. A majority of TMA crashes occurred in VDOT's Northern Virginia, Hampton Roads, and Richmond districts. A typical TMA crash involved a contractor TMA vehicle that was struck from the rear by a male driving a passenger vehicle. TMA crashes accounted for less than 1% of all work zone crashes in Virginia from 2011-2014. There is no clear-cut solution to resolving TMA crashes. Although they represent a small number of crashes compared to the overall number of work zones crashes, most of them affect at least two people: the motorist striking the TMA vehicle and the TMA operator.

The study offers a number of recommendations to reduce the incidence of TMA-involved crashes. First, VDOT should require TMA operator training. Second, VDOT's Traffic Engineering Division should share the information with regard to TMA crash experience with the VDOT regions, with particular emphasis on the regions with the highest number of crashes. In addition, VDOT's Traffic Engineering Division should review the benefits of having the first TMA vehicle in a travel lane straddling the lane, as opposed to being fully in the lane, and the spacing of TMA vehicles near ramps during mobile operations. Finally, VDOT should consider working with the Virginia Department of Motor Vehicles and/or others on media and outreach campaigns for distracted driving and include mobile work zones for safer work zones.

17 Key Words: Truck Mounted Attenuators, Trailer Mounted Attenuators, work zone crashes	18. Distribution Statement: No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.		
19. Security Classif. (of this report): Unclassified	20. Security Classif. (of this page): Unclassified	21. No. of Pages: 43	22. Price:

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

FINAL REPORT

INVESTIGATION OF TRUCK MOUNTED ATTENUATOR (TMA) CRASHES IN WORK ZONES IN VIRGINIA

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In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Virginia Transportation Research Council
(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

Charlottesville, Virginia

October 2015
VTRC 16-R7

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ABSTRACT

Truck mounted attenuators (TMAs) are deployed on shadow vehicles in work zones to mitigate the effects of errant vehicles that strike the shadow vehicle, either by smoothly decelerating the vehicle to a stop when hit head-on or by redirecting the errant vehicle. The purpose of this study was to investigate crashes involving TMAs in work zones in Virginia. The objectives of the study were (1) to review trends over the last 3 to 5 years in crashes involving TMAs including a measure of traffic exposure such as the frequency of work zones using TMAs; and (2) to identify the causal factors of crashes in work zones where TMAs are involved.

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Based on the survey results, driver inattention/behavior, road geometrics/sight distance, mobile operations, and not following the *Virginia Work Area Protection Manual* are possible contributing factors for TMA crashes. TMA crashes increased from 2011-2014, and most of these crashes occurred on the interstate. A majority of TMA crashes occurred in VDOT's Northern Virginia, Hampton Roads, and Richmond districts. A typical TMA crash involved a contractor TMA vehicle that was struck from the rear by a male driving a passenger vehicle. TMA crashes accounted for less than 1% of all work zone crashes in Virginia from 2011-2014. There is no clear-cut solution to resolving TMA crashes. Although they represent a small number of crashes compared to the overall number of work zones crashes, most of them affect at least two people: the motorist striking the TMA vehicle and the TMA operator.

The study offers a number of recommendations to reduce the incidence of TMA-involved crashes. First, VDOT should require TMA operator training. Second, VDOT's Traffic Engineering Division should share the information with regard to TMA crash experience with the VDOT regions, with particular emphasis on the regions with the highest number of crashes. In addition, VDOT's Traffic Engineering Division should review the benefits of having the first TMA vehicle in a travel lane straddling the lane, as opposed to being fully in the lane, and the spacing of TMA vehicles near ramps during mobile operations. Finally, VDOT should consider working with the Virginia Department of Motor Vehicles and/or others on media and outreach campaigns for distracted driving and include mobile work zones for safer work zones.

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INTRODUCTION

Truck mounted attenuators (TMAs), energy-absorbing devices attached to the rear of trucks to reduce the severity of rear-end crashes, are deployed on shadow vehicles in work zones to mitigate the effects of errant vehicles that strike the vehicle, either by smoothly decelerating the vehicle to a stop when hit head-on or by redirecting the errant vehicle. The Virginia Department of Transportation (VDOT) has been using TMAs for many years. The *Virginia Work Area Protection Manual* (VAWAPM) identifies the following conditions for their use[1]:

> Shadow trucks with TMAs shall be used:
>
> A. When closing a lane on a four or more lane roadway with a posted speed of 45 mph or greater;
> B. On shoulders, ramps and loops of interstate and limited access highways;
> C. When a mobile operation occupies all or part of the travel lane on a multi-lane roadway with a posted speed of 45 mph or greater;
> D. Other locations where the Regional Traffic Engineer feels such protection is warranted.
>
> When the installation and removal of temporary traffic control devices is performed as a mobile operation meeting the conditions listed in Paragraph 11 [above list], a TMA shall be used on the shadow vehicle.
>
> All TMA units shall conform to the requirements of NCHRP Report 350, Test Level 3 or MASH.
>
> The shadow vehicle with a TMA shall be positioned a sufficient distance (80-120 feet) in advance of the workers or equipment being protected to allow for appropriate vehicle roll-ahead, but not so far that errant vehicles will travel around the vehicle and strike the protected workers and/or equipment.
>
> When all work crews, equipment, or hazards have been sufficiently removed from the lane closure, the shadow truck shall be removed.

Mobile and short duration work zone operations occur nearly daily on Virginia highways from patching potholes to painting pavement markings, spraying chemicals, or performing sweeping operations. These operations are distinguished from standard work zone operations because there are no channelizing devices to delineate the closure and few signs, if any, to warn of the work zones. A mobile operation comprises work moving intermittently (1 to 15 minutes) or continuously, and a short duration work zone occupies a place in one location for 1 hour or less. In the VAWAPM,[1] these operations are called moving/mobile operations. Shadow vehicles with TMAs are used for many of these types of operations and in static lane closures on roadways with four or more lanes posted 45 mph or higher. The sign and arrow board on the TMA vehicles are the means for delineating the closure and warning of the work zone.

In previous years, there were typically about three or four crashes per year involving TMAs statewide based on the perception of VDOT staff. From all 2012–Fall 2013, the number seemed to increase. A contractor informed VDOT staff that he had five TMAs hit from January-August 2013. In September 2013, there was a fatal crash on I-81 resulting in three deaths, including the driver of the TMA shadow vehicle. That same day, a VDOT TMA vehicle was struck by a speeding motorist on a primary route, resulting in the vehicle stopping underneath the crash cushion. As of October 2013, there had been nine TMA crashes in 2013 based on data from five of the nine VDOT districts.

Although there is no evidence to support it, it is speculated that moving/mobile operations are more likely to have TMA crashes. This is partly because in stationary work zones the TMAs are behind channelizing devices and more advanced warning through signing is used.

In December 2013, the Virginia Transportation Research Council (VTRC) Traffic and Safety Research Advisory Committee rated this problem statement as the highest priority.[2]

PURPOSE AND SCOPE

The purpose of this study was to investigate crashes involving TMAs in work zones in Virginia. Two specific objectives were as follows:

1. Review trends over the last 3 to 5 years in TMA crashes including a measure of traffic exposure such as the frequency of work zones using TMAs.

2. Identify the causal factors of TMA crashes in work zones.

Questions to be answered through the evaluation included the following:

1. What is causing the recent increase in the number of TMA crashes?

2. Are TMAs being used properly? What are the issues with proper use? Are shadow vehicle drivers staging the TMAs in appropriate places or operations?

3. Can the safety of the TMAs be improved with respect to greater conspicuity/visibility?

4. Can the design of the work zone be improved to prevent vehicle crashes with TMAs?

5. Do the different brands of TMAs perform differently when struck? Data were not available to answer this question.

6. What opportunities exist for improving safety through education/training of drivers of shadow vehicles with TMAs (TMA operators) and/or motorists?

Answers to these questions were expected to provide insight into improving the operation and safety of motorists in work zones and operators of TMA vehicles by reducing these crashes. With the recent increase in funding for roadway construction and maintenance, there is a significant increase in the number of work zones throughout Virginia, many involving TMA vehicles. By determining the causal factors behind the crashes, it was hoped that improved guidance could be developed.

METHODS

Overview

Six tasks were performed to achieve the study objectives.

1. literature review regarding TMAs in general and specific to safety
2. assessment of use of TMAs
3. data collection, review, and analysis of TMA safety and use in Virginia
4. field reviews work zones
5. identification of potential causal factors and crash characteristics for TMA crashes
6. development of potential alternative actions to improve TMA safety.

Literature Review

A literature search regarding TMAs in general and with regard to safety was conducted using established search engines.

Assessment of Use of TMAs

To assess the use of TMAs in Virginia, an email survey (see Appendix A) was used to obtain feedback on how well TMAs are being used and what issues, if any, exist. The survey was sent to the following eight groups:

1. VDOT work zone safety coordinators
2. VDOT inspectors via area construction engineers
3. VDOT Safety and Health staff
4. Virginia Asphalt Association contractors
5. American Traffic Safety Services Association, Virginia Chapter
6. Virginia Transportation Construction Alliance
7. Hampton Roads Utility and Heavy Contractors Association
8. Heavy Construction Contractors Association.

The survey was sent directly to the first group; for the second group, the inspectors, the survey was emailed to all VDOT area construction engineers to forward to their inspectors. For the remaining six groups, the survey was sent to one contact person to forward to others. At least one follow-up reminder email was sent.

Data Collection, Review, and Analysis of TMA Use and Safety in Virginia

This task was carried out using the following process for crashes involving TMAs in Virginia from 2011-2014.

1. Obtain a report from staff of VDOT's Traffic Engineering Division (TED) using the Oracle database that sorted for crashes in work zones involving Vehicle Type 04 (Truck – Single Unit Truck 2-Axles) OR 23 (Truck – Single Unit Truck – 3 Axles or more) AND Special Vehicle Function is 13 (Maintenance) by year. A list of crash document numbers was provided. Using the crash documents numbers, a report for the crashes was generated in VDOT's Roadway Network System (RNS) (in Excel spreadsheet format) with some details including a description of the crash and the crash diagram.

2. Create two annual reports in RNS: (1) work zone crashes with two-axle trucks, and (2) work zone crashes involving trucks with three or more axles.

3. Review each annual report using RNS reports to determine if the crash record involves a vehicle with a TMA. If yes, record the document number. If not sure, record the document number for additional review; if no, delete the record.

4. Combine the three reports and eliminate redundant records to yield one list for each year.

5. Access the Virginia Department of Motor Vehicles (DMV) Traffic Records Electronic Data System to obtain the crash reports completed by law enforcement officers (FR300) for the crash document numbers. Obtain additional information on each crash that is not available from RNS such as driver information (age and gender), vehicle information, owner of the TMA vehicle as VDOT or contractor, and road and temporal conditions.

6. Create an Excel spreadsheet file of confirmed crashes with TMAs for each year. Confirmed crashes have a TMA shown in the collision diagram or a TMA noted in the crash description. These files were combined into one spreadsheet and then used as input in Tableau (interactive data visualization software) to facilitate the crash analysis.

7. Conduct the crash data analyses: (1) trend analysis by year for changes over time; and (2) all crashes aggregated/combined for causal/correlation analysis in Tableau and Excel.

Several crashes were identified that may have involved a TMA. However, there was no confirmation of the presence of a TMA in the crash report. These unconfirmed crashes were deleted. Therefore, it is possible that there were crashes involving TMAs that were not confirmed through the crash reports.

It would be useful to have information on traffic exposure to work zones such as an estimate of the number of work zones using TMAs in Virginia for the study period. The number of planned work zones each year from 2011-2014 was obtained from VaTraffic, VDOT's roadway condition reporting system. VaTraffic is a web-based application that accepts data entered by VDOT and contract staff located throughout the state related to current events and planned events, such as traffic incidents, congestion, work zones, security events, and weather conditions.[3] VaTraffic disseminates this event information through a data feed service to VDOT staff; partner agencies such as the Virginia State Police; and the public through 511Virginia, Twitter, and other means. VaTraffic has reliable data on interstate work zones. Records of non-interstate work zones are expected to be less reliable in VaTraffic; however, it is the best source available. A possible explanation to be explored for the increase in TMA crashes was that they are simply reflective of a greater number of work zones in Virginia. TMA crash trends were also compared with VDOT's annual construction and maintenance expenditures. A final comparison was made with work zone crashes and all crashes over the same period to determine if the trend was specific to TMA crashes.

The data analysis involved trend analysis as opposed to more rigorous statistical testing because of the relatively low number of crashes expected per year.

Field Reviews of Work Zones

VTRC research staff observed mobile, shoulder, and lane closure work zones across Virginia for TMA visibility and placement of the TMA with respect to VAWAPM[1] guidance.

Identification of Potential Causal Factors and Crash Characteristics for TMA Crashes

From the analysis of the results from previous tasks, the potential causal or contributing factors and crash characteristics for the TMA crashes were identified.

Development of Potential Alternative Actions to Improve TMA Safety

A list of potential alternative actions to improve TMA safety was developed based on the causal factors identified in the previous tasks. Recommendations for alternative actions were developed from this list.

RESULTS

Literature Review

Identification of Hazards Associated With Mobile and Short Duration Work Zones

The objective of the first year of this study by Ullman et al.[4] was to identify the potential hazards associated with mobile and short duration maintenance operations and the probable underlying causational factors. To meet this objective, the researchers used a survey of state department of transportation (DOT) offices, focus groups, and field observations.

The two main hazards identified in the survey were motorist behaviors (e.g., speeding and inattention) and the interaction between work vehicles and traffic. The researchers found that many states have expanded their basic guidelines to provide further direction on how to apply traffic control devices based on additional considerations (e.g., roadway speed or speed of operation). The focus groups identified motorist comprehension of traffic control devices, motorist behavior, and worker safety as the primary hazards associated with mobile and short duration maintenance operations. The motorist behaviors identified included motorist inattention, speeding, entering the convoy or encroaching on the work area, and last minute lane changing. Participants also noted that motorists do not know how to react to a work convoy. Worker safety issues included worker exposure, worker complacency, and the visibility of workers and vehicles.

In the field observations, the primary hazards identified with regard to mobile maintenance operations were apparent motorist misunderstanding of traffic control devices, vehicles entering the work convoy, speed differential between traffic and the work convoy, and visibility of work vehicles. With regard to short duration maintenance operations, the field observations indicated that worker exposure was the primary hazard. It was concluded that many of these concerns could be addressed if motorists were provided more specific information regarding upcoming conditions and/or the appropriate action to take.

Information gathered through all three research methods highlighted the fact that the definitions of mobile and short duration operations and the classification of specific operations as either mobile or short duration were not consistent. Thus, the researchers concluded that there was a need for the following:

- a clearer distinction between mobile and short duration operations
- guidance in applying standards to specific types of operations
- an enhancement of guidelines to provide direction related to roadway conditions (e.g., traffic volume, roadway speed, and speed of mobile operations).

Traffic Control Devices and Practices to Improve the Safety of Mobile and Short Duration Maintenance Operations

The objective of the second year of the study by Ullman et al.[5] was to identify and evaluate new traffic control devices and practices that could be used to improve the safety of mobile and short duration operations.

The researchers conducted a synthesis of previous research, three focus groups, 241 motorist surveys, and a field study to assess motorists' comprehension and the operational effectiveness of current and innovative traffic control devices used to inform motorists about the following:

- the number of vehicles in a work convoy
- the speed differential between the work convoy and traffic
- passing a work convoy on two-lane, two-way roadways with unimproved shoulders
- passing a work convoy on two-lane, two-way roadways with improved shoulders and the LANE BLOCKED sign.

Based on the results of these activities, the researchers recommended the use of several traffic control devices to improve the safety of mobile operations. In addition, based on existing Texas DOT traffic control plans, field observations of mobile and short duration operations conducted during the first year of the study, findings from the second year of the study, and input from the advisory panel, researchers did the following:

- recommended changes to the existing work duration definitions to help maintenance personnel distinguish between mobile and short duration operations
- developed maintenance traffic control plans for select mobile and short duration operations
- developed guidance for the use of trail and shadow vehicles for selected operations based on the roadway volume and posted speed
- developed quick reference tables that directed maintenance personnel to the appropriate mobile and short duration practice(s).

Improving the Safety of Mobile Lane Closures

Hadayeghi and Malone[6] synthesized practices employed by transportation agencies during mobile lane closures and summarized research carried out on different components of mobile lane closure. They found that there are a number of successful mobile lane closure traffic control devices and techniques currently being used by transportation agencies to ensure the safety of workers and motorists.

A review of innovative and experimental devices and technologies revealed that none of the devices evaluated was capable of simultaneously meeting all of the most desirable criteria for mobile operations protection.

These criteria were as follows:

- Reduce exposure of workers to vehicles.
- Warn motorists and work crew to minimize the likelihood of a crash.
- Minimize the severity of crashes once they occur.
- Provide separation between work crew and traffic.
- Improve work zone visibility and presence.

According to the findings of the literature review, even remotely driven vehicles, which remain experimental as of this writing, only partially satisfy these criteria. Literature discussing innovative safety devices, and assessing the effectiveness of the existing safety devices and practices, were reviewed. Other emphasis areas in the research were as follows:

- identification of hazards associated with mobile operations

- provision of improved road-user guidance in the presence of mobile operations (advance warning; work vehicle identification; and the provision of information supporting rapid, error-free, and appropriate behaviors)

- a review of the current mobile lane closure definition.

The survey consisted of 74 questions that were designed to gather information on regulatory and guidance documents, policies, practices, equipment, and technology used; field experiences; and further technology and research needs. The great majority of respondents were not regularly using work zone safety intrusion alarms.

Results showed that only 20% of the respondent states were aware of any technology/device developments or research in progress that could increase the safety of mobile lane closures. In addition, some states cited the difficulty isolating mobile lane closure crashes in the crash data as the reason they do not analyze crash data.

Although extensive research has been done on the different aspects of mobile lane closures, such as the effectiveness of specific traffic control devices in such operations, there is still a number of other issues upon which research information is either limited or unavailable. For example, there is a need for additional research information on optimal vehicle spacing (i.e., between buffer vehicles and work vehicles), placement of workers within the mobile lane closure work area, and training of workers on mobile lane closure procedures.

Improving the Safety of Moving Lane Closures

To improve the safety of moving lane closures for workers and motorists, Steele and Vavrik[7] studied driver behavior around moving lane closures and the effect of different components of current traffic control scenarios, including the number, configuration, and spacing of shadow vehicles and the effect of various traffic control devices and sign messages. Full-scale field tests were conducted at four locations representing a range of roadway and traffic conditions. Three of the sites were high-volume, urban settings; two of these sites were tested during the day, and the other was tested at night. The fourth site was a rural interstate, and data collection was performed during the day. At each location, 2 to 3 days of testing was conducted using multiple traffic control configurations.

Urban vs. Rural Settings

The type of setting (urban vs. rural) had a significant effect on traffic characteristics, driver behavior, and as a consequence, traffic control practices used by the local maintenance personnel. In general, urban motorists drove more aggressively than their rural counterparts, approaching the work zone closer before vacating the closed lane and reentering the lane quickly after passing the work area. Traffic volumes were higher in urban areas, and congestion occurred quickly after a lane was closed. Many work activities were scheduled for nighttime in urban areas to avoid congestion, exposing workers to hazards such as fatigued drivers. Current traffic control standards do not necessarily distinguish between urban and rural settings; however, it may be beneficial to do so.

Cut-in Distance and Work Area Length

In terms of cut-in distance (the distance beyond the work area where drivers reenter the lane) in urban areas, drivers began returning to the lane at 50 ft beyond the work area and the peak cut-in distance was 100 ft. Cut-in distances for rural motorists were slightly longer, beginning at 100 ft and peaking at 225 ft. This reflects the relatively higher aggressiveness of urban vs. rural drivers, as well as factors such as traffic volumes and congestion. The implication for workers is that traffic returns to the lane at very short distances beyond the perceived end of the work area. Work crews have adapted by working very close to the lead TMA (usually within 50 to 100 ft downstream), which protects them from lateral intrusions but leaves them vulnerable if a large collision occurs with the TMA.

An effective way of extending the work area length is adding an additional truck downstream from the work area in the lane just past the work crew. This “lead truck” can be a TMA, a work truck with an arrow board, or a foreperson’s pickup truck with strobe bar. In any case, the lead truck should be highly visible so that vehicles are able to see it as they are passing the lead TMA and understand that it is not yet safe to return to the closed lane. On I-90, tests were performed with and without a lead truck. In the case of no lead truck, no vehicles attempted to swerve into the closed lane when the work zone length was less than 150 ft. At 200 ft, vehicles began swerving into the work area. By placing a TMA downstream of the work area, no incursions were attempted for the 200-ft work area length. Swerving into the work area did not happen with the lead truck until the work area length reached 300 ft.

At the rural test site on I-88, the practice of parking the supervisor’s pickup 300 ft downstream of the lead TMA and on the shoulder was effective in delaying the return of vehicles to the closed lane. Without the pickup, traffic began reentering the lane at 100 ft, with the majority of users cutting in at 150 to 450 ft. With the supervisor's pickup, traffic delayed until 175 ft before reentering the lane, with the majority of vehicles cutting in at 250 to 600 ft downstream.

Truck Configurations

Another frequent comment was that mobile work zones do not have the same public perception as traditional construction work zones; therefore, highway users do not respond with the appropriate level of care. For example, much publicity and public education are conducted to encourage drivers to slow down in construction zones and make them aware of the fines and penalties that exist for breaking work zone speed limits. However, motorists generally do not view the same rules applying to moving closures. They are correct in the sense that speed limit reductions posted for moving closures (on Portable Changeable Message Signs and/or orange signs) are only suggested and are not enforceable. On the other hand, Illinois' Scott's law (the "move over" law) is a very beneficial regulation that can prevent crashes with maintenance crews and be used to ticket motorists that drive unsafely through moving closures.

The balance between safety and mobility is a major policy issue not only at the national level, but also at the local level. For example, maintenance crews prefer working in congestion because of low traffic speeds. Obviously, this is not acceptable to the driving public. To accommodate motorists, many maintenance activities are performed at night, exposing workers to hazardous conditions such as impaired drivers operating at high speeds.

When asked what could be done to make moving lane closures safer, universally traffic control crews stated: "more trucks and more police." The benefits of both of these resources are confirmed by the results of this study; however, their availability is highly dependent on agency funding.

Improving the Safety of Moving Lane Closures: Phase II

In this phase II report, Steele and Vavrik[8] recommended revisions to existing traffic control standards. In addition, they proposed six optional components to be used when resources were available and conditions merited:

1. additional traffic control vehicles in the transition area
2. use of a lead truck downstream of the work space
3. use of a blocker truck to prevent shoulder passing
4. use of an additional warning truck in the advance warning area
5. insertion of a buffer truck to increase spacing between the shadow vehicle and workers
6. use of a spotter within the work space to alert workers of upstream traffic conditions.

In addition, recommendations for three special cases were provided:

1. working at or near horizontal and vertical curves
2. working near ramps
3. continuously moving operations.

Finally, guidance was provided for selecting appropriate spacings for advance warning and transition vehicles, taking into account factors such as traffic density, speed, roadway geometry, driver nature, and setting (Figure 1).

Minimum Recommended Spacing	Condition and Effect on Spacing			Maximum Recommended Spacing
	Decreases Spacing	⟷	Increases Spacing	
Advance Warning = 1,000 ft Truck Spacing = 200 ft	Congested	**Traffic flow** ⟷	Free-flow	Advance Warning = 2,500 ft Truck Spacing = 500 ft
	Low	**Traffic speed** ⟷	High	
	Flat, straight	**Road geometry** ⟷	Curves	
	Aggressive	**Driver nature** ⟷	Passive	
	Urban	**Setting** ⟷	Rural	

Figure 1. Guidance for Selecting Advance Warning and Truck Spacings. *Source:* D.A. Steele and W.R. Vavrik, *Improving the Safety of Moving Lane Closures: Phase II*, Illinois Center for Transportation, Rantoul, 2010.

Horizontal and Vertical Curves

Horizontal and vertical curves present a specific hazard for moving lane closures because of decreased line of sight relative to tangent or flat sections. This gives motorists less time to see and react to the work zone. An effective countermeasure used by field crews is to space the vehicles farther apart than normal. This means using advance warning and transition lengths near the upper end of the range recommended for tangent sections. The buffer and work space lengths are not affected. The exact spacing used will depend on the site conditions, including length and radius of the curves. In general, longer curves require greater spacing. If the spacing between trucks becomes too great, or if the duration of the work activity is very long, it may be necessary to insert additional vehicles into the convoy, such as a second advance warning truck or a third transition TMA. Left-hand horizontal curves are particularly hazardous, as motorists are not accustomed to having lane closures in the left lane, which typically carries faster moving traffic. In at least one maintenance yard, left-lane closures in left-hand curves are now performed with stationary closures because of the difficulty of safely performing moving closures in these areas.

Ramps

It is also important to provide guidance on performing moving closures on the mainline roadway in the vicinity of ramps. An effective practice is to shorten truck spacings as the convoy approaches the ramp, remain in a tight formation while passing the ramp, and then lengthen truck spacings once beyond the conflict area. In these cases, the trucks would be using the lower end of the spacing ranges recommended for normal operations. In effect, the convoy acts similar to an "accordion" as it compresses and decompresses while alternately encountering areas of roadway with and without ramps.

Work Zone Crashes Involving Traffic Control Devices, Safety Features, and Work Vehicles and Equipment

For the New York State DOT, Bryden[9] examined 461 work zone crashes involving Category 3 and Category 4 work zone safety features, portable traffic signs, and work vehicles and equipment. Category 3 devices include crash attenuators and temporary traffic barriers. Category 4 devices include trailer mounted arrow boards, changeable message signs, and light towers. Both work zone attenuators and temporary barriers were involved in a substantial number of crashes and injuries. These crashes emphasize the importance of deploying the devices in accordance with accepted work zone practices and limiting their use to situations in which they are warranted to protect more serious hazards. Worker injuries reported in a number of these crashes emphasize the importance of safe work practices such as restraint use by vehicle occupants, even at slow speeds in work zones, and effective separation of workers from traffic in work zones.

Of 27 primary shadow vehicle / truck mounted attenuator crashes resulting in injuries, 9 resulted in injuries to workers. One of the 9 resulted in injury to a worker in the truck bed, 7 resulted in injury to the shadow vehicle driver or other worker in the truck cab, and 1 resulted in injury both to the driver and to pedestrian workers near the truck who were struck by the impacting vehicle. The manner of injury to the worker occupants of the shadow vehicle was not examined in detail. However, the significant number of these injuries seems to support the case for safety features to protect workers in shadow vehicles. Such features typically include seat belt and shoulder harness systems, head restraints, and interior padding. Although 8 of the crashes categorized as secondary or side impacts resulted in injuries, none of these injuries involved workers.

NHTSA Traffic Safety Facts Research Note: Distracted Driving 2013

Distraction is a specific type of inattention that occurs when drivers divert their attention from the driving task to focus on some other activity instead. Oftentimes, discussions regarding distracted driving center on cell phone use and texting, but distracted driving also includes other activities such as eating, talking to other passengers, or adjusting the radio or climate controls, to name but a few. A distraction-affected crash is any crash in which a driver was identified as distracted at the time of the crash. Distraction is a subset of inattention (which also includes fatigue and physical and emotional conditions of the driver). However, although the National Highway Traffic Safety Administration (NHTSA) may define the terms in this manner, inattention and distraction are often used interchangeably or simultaneously in other material, including police accident reports. It is important that NHTSA and NHTSA's data users be aware of these differences in definitions.[10]

There are negative implications associated with distracted driving—especially in conjunction with a crash. Survey research shows that self-reporting of a negative behavior is lower than the actual occurrence of that negative behavior. There is no reason to believe that self-reporting of distracted driving to a law enforcement officer would be different. The inference is that the reported driver distraction during crashes is lower than the actual occurrence.[10]

Worker Safety During Operations With Mobile Attenuators

In this study, Theiss and Bligh[11] compared truck mounted and trailer mounted attenuators in terms of worker safety. In terms of crash performance, the researchers found no differences between truck mounted and trailer mounted attenuators. The researchers also found that the safety of workers is improved when the heaviest recommended support vehicle is used because this results in reduced accelerations of the support truck driver and shorter roll-ahead distances. Based on these findings, the researchers recommended that the Texas DOT maintain its existing mobile attenuator support vehicle weight requirement of 20,000 lb.

Survey Analysis and Results

As discussed in the "Methods" section, a survey with five open-ended questions (see Appendix A) was emailed to eight groups. A total of 36 responses were received. It is not possible to determine the percentage return because it is unknown how many potential respondents received the survey. No surveys responses were received from three groups: VDOT Safety and Health staff, the Hampton Roads Utility and Heavy Contractors Association, and the Heavy Construction Contractors Association. Survey responses were categorized into three groups: work zone safety coordinators (10), inspectors (15), and contractors (11). All responses were combined for the analysis that focused on Questions 1 through 3.

Table 1 provides a summary of the survey responses. For Question 1, driver inattention/behavior was cited as a causal factor for crashes with TMAs by 23 respondents (64%). Road geometrics / sight distance was noted by 6 respondents (17%). Mobile operations was chosen by 5 respondents (14%), and 4 (11%) each noted TMA placement in work zone / proper work zone setup and higher volumes. For safety concerns with TMA use (Question 2), proper work zone layout using TMAs was noted by 7 respondents (19%). Three (8%) each noted improper use of TMA trucks (as work vehicles with riders for setup/removal of work zones / for storage / as terminal end treatment), training on use and operations of TMAs, and safer TMA truck operator seat and restraint. With the exception of the driver seat, these responses may offer a case for more training and education.

Table 1. Survey Results and Number of Respondents (of 36) Providing Particular Response

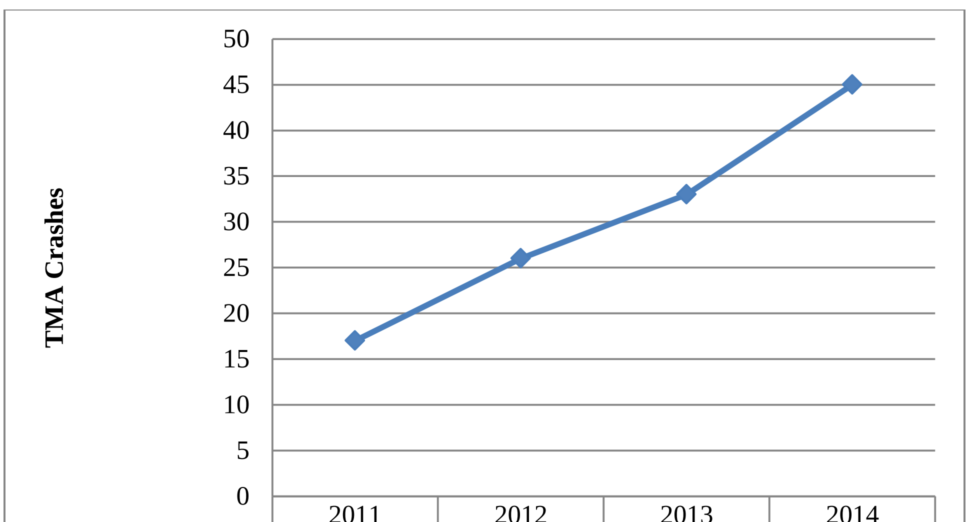
1. Based on your experience, what are causal factors for most crashes with TMAs?
driver inattention/behavior: 23 road geometrics / sight distance: 6 mobile operations: 5 [near ramps: 1] TMA placement in work zone / proper VAWAPM setup: 4 higher volumes: 4 (added high speed: 1) time of operations: 3 [nighttime: 1, daytime: 1] inexperienced TMA operators / training: 2 limited access road/multi-lane roads: 2
2. What are some of your safety concerns with TMA use?
proper VAWAPM layout: 7 [include improper spacing of TMA / proper spacing between TMA vehicles in a mobile operation] improper use of TMA trucks: 3 [as work vehicles with riders for setup/removal of work zone / for storage / as terminal end treatment] training on use and operations of TMA: 3 safer TMA truck operator seat and restraint: 3 lack of respect by public / driver behavior: 2 proper arrow board display: 2 1st TMA in road fully in lane not straddling it: 1 TMA lateral position: Too close to travel lane or slightly outside the work zone into the travel lane: 1 visibility: 1 TMA on narrow shoulders: 1 mobile operations: 1 internally—communication between drivers, ensuring drivers paying attention and not distracted (by use of music headsets for example): 1
3a. What changes do you think are needed to address your safety-related concerns about the use of TMAs in moving or mobile work zones?
TMA operators need to have safe practices stressed / education of operators: 5 use police presence: 3 2nd TMA should straddle the edgeline of the shoulder instead of being fully in the lane for a taper effect.: 2 lack of shoulder space for 1st TMA: 2 educate the drivers on work zones: 2 proper spacing of TMAs: 1 add a 3rd TMA: 1 need good planning and communication during the actual work: 1 adequate traffic control posted on ramps (traffic not aware they are entering work area as mobile operation passes the on ramp): 1 avoid high-volume time periods: 1 mobile ops during the day only: 1 use audio warning devices (intrusion alarm): 1 proper inspection by qualified staff as a best practice: 1 increased advance warning to deter late merge: 1
3b. What changes do you think are needed to address your safety-related concerns about the use of TMAs in stationary work zones?
training: 3 TMAs not being relocated 80 to 120 ft in advance of the first work crew. [Lack of buffer space available downstream of the TMA in most work zones. Road geometry prevents the implementation of a full work zone (or provides an excuse not to install correctly). Roll-ahead distance should be stressed more than buffer space when lack of space to fully install a work zone is an issue.]: 3 not following VAWAPM: 2 [signs and proper tapers] educate drivers on work zones: 2 proper spacing of TMAs: 1 installation and removal of work area signs with only one TMA: 1 TMAs not close enough to the centerline markings to better protect workers and to help push traffic over away from the centerline: 1 police presence especially with setup and removal of closures:1 at signalized intersections above 45MPH, not possible to get buffer zone of 80-100 ft. Buffer zone may be longer due to length of intersection: 1

For Question 3a, changes needed for safety-related concerns for moving or mobile operations, the need for better training and education of TMA operators with respect to safe practices was mentioned by 5 respondents (14%) followed by use of police in the work zone with 3 respondents (8%) responses. Two respondents (6%) each addressed the need for the second TMA to straddle the edgeline of the shoulder to provide a taper effect; the challenge of a lack of shoulder space for the first TMA; and the need to educate drivers on work zones. For Question 3b, changes needed to address safety-related concerns for stationary work zones, 3 respondents (8%) noted enhanced training and 2 respondents (6%) each noted a need for stricter adherence to the VAWAPM [signs and proper tapers]; provision of sufficient buffer space downstream of the TMAs (relating to TMA placement relative to the first work crew); and improved education for all drivers about safe driving in and around work zones.

Analysis of TMA Crashes

As illustrated in Figure 2, TMA crashes have been increasing from 2011-2014 with annual percentage increases from 2011-2012, 2012-2013, and 2013-2014 of 52.9%, 26.9%, and 36.4%, respectively. The highest increase in the number of crashes occurred from 2013-2014. There were a total of 121 crashes involving TMAs in the 4-year period.

The actual number of work zones using TMAs during this time period is not available; VDOT does not maintain records on this. A surrogate measure is the number of planned work zones logged into VATraffic to obtain a rough estimate of the possible exposure. From Figure 3, the number of planned work zones also increased from 2011-2013 but then decreased from 2013-2014 while TMA crashes continued to increase.



	2011	2012	2013	2014
TMA Crashes	17	26	33	45

Figure 2. TMA Crashes From 2011-2014

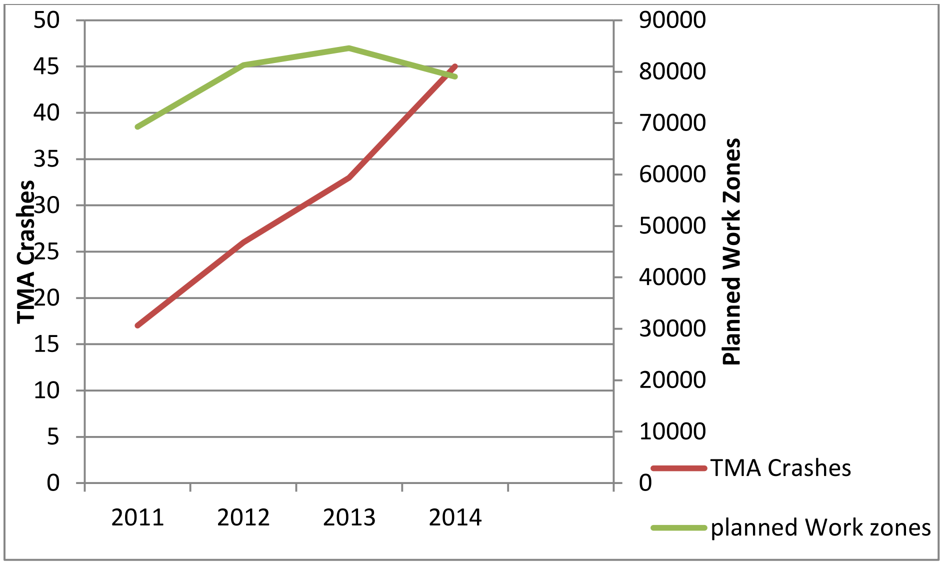


Figure 3. TMA Crashes and Planned Work Zones From 2011-2014

Figure 4 plots the number of TMA crashes alongside construction and maintenance expenditures. As with the planned work zones, the trends seen in these data points are not the same, with VDOT construction and maintenance expenditures decreasing from 2012-2013 then slightly increasing from 2013-2014.

Figure 5 compares the trends of TMA crashes with all work zone crashes (Figure 5, *top*) and all crashes (Figure 5, *bottom*). For the 4-year period, the TMA crashes represented less than 1% (0.84%) of all work zone crashes. From 2011-2014, this percentage increased from 0.49% to 1.1%. Although TMA crashes are a concern, they appeared to represent a very small portion of all work zone crashes. The TMA crash trend was quite different from the trend for all work zone crashes and for all crashes. All crashes trended downward from 2012-2014, whereas work zone crashes were somewhat level then trended upward from 2013-2014.

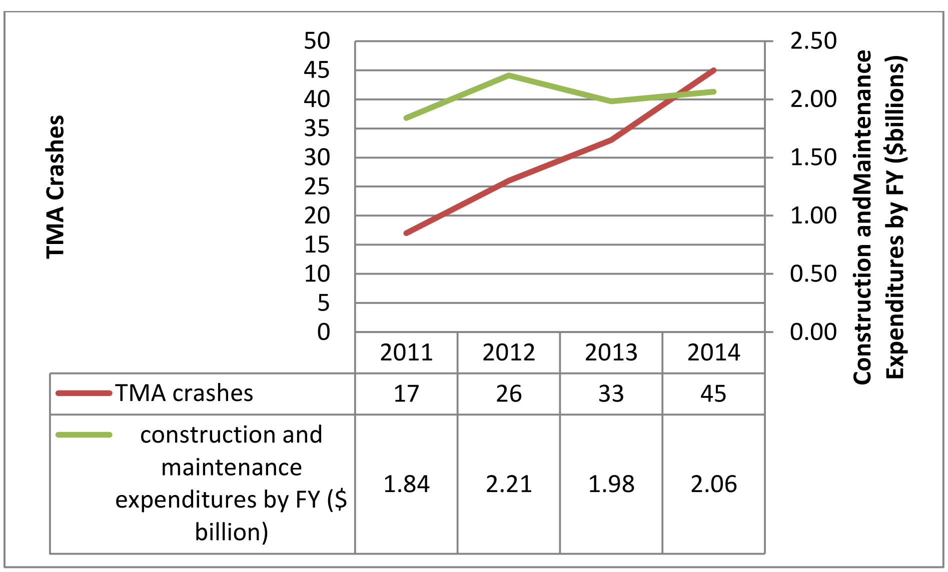
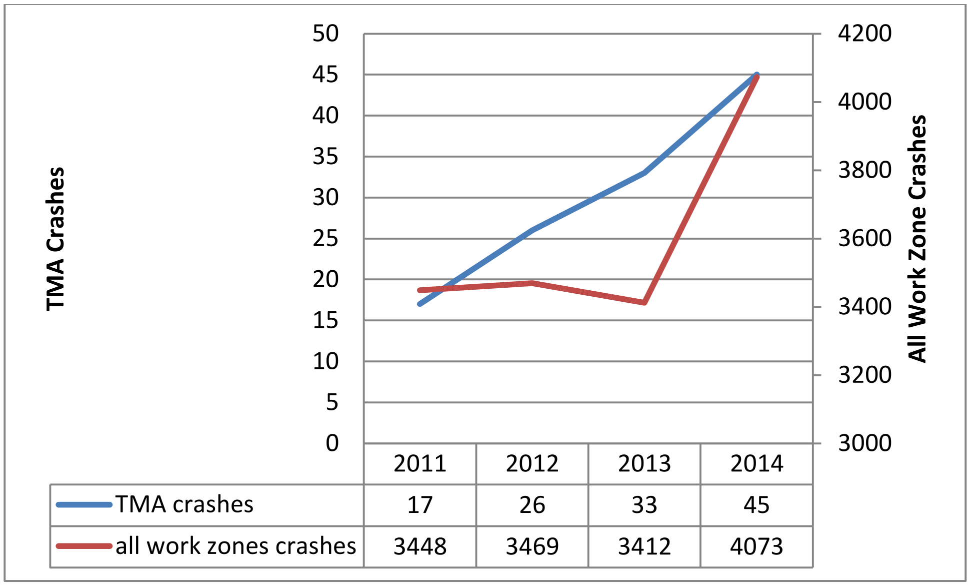


Figure 4. TMA Crashes and VDOT Construction and Maintenance Expenditures From 2011-2014



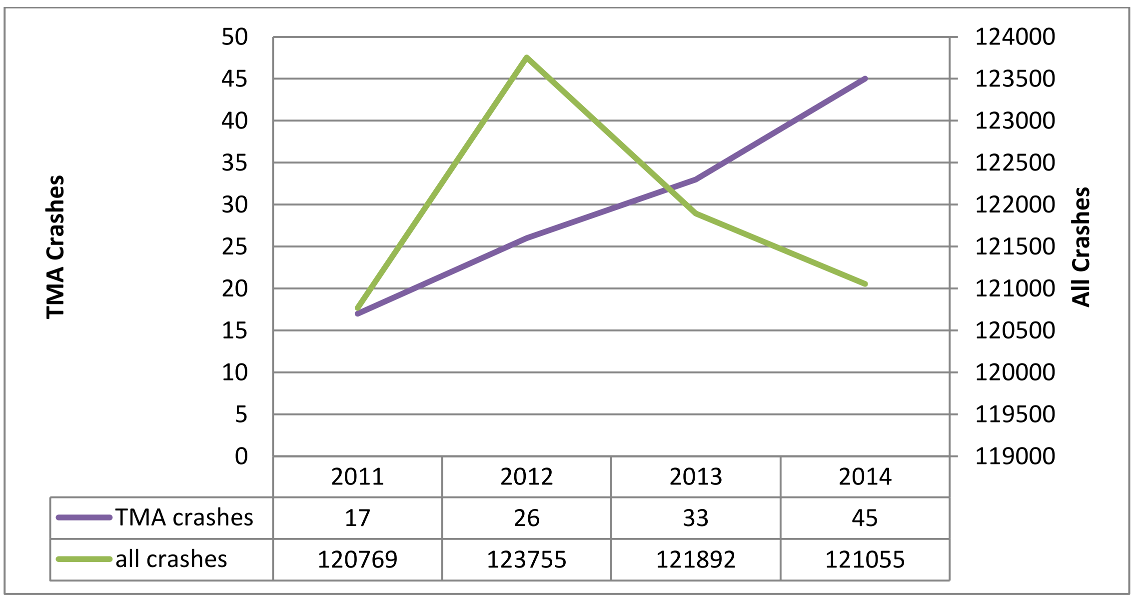


Figure 5. ***Top:*** **TMA Crashes and All Work Zone Crashes by Year;** ***Bottom:*** **TMA Crashes and All Crashes by Year**

Figure 6 displays the TMA crashes by VDOT district by year. The three districts with the larger urban areas, Northern Virginia (NOVA), Hampton Roads, and Richmond, had the higher number of TMA crashes and accounted for 69.4% of all TMA crashes. When the Bristol District was added, these four districts had 81% of the crashes. With regard to the trend over 4 years, the NOVA District had a large increase from 4 in 2011 to 9 in 2012; then, 2013 and 2014 each had 13 crashes; in the Hampton Roads District, crashes decreased in 2013 and then spiked in 2014; in the Richmond District, crashes peaked in 2013 and then decreased.

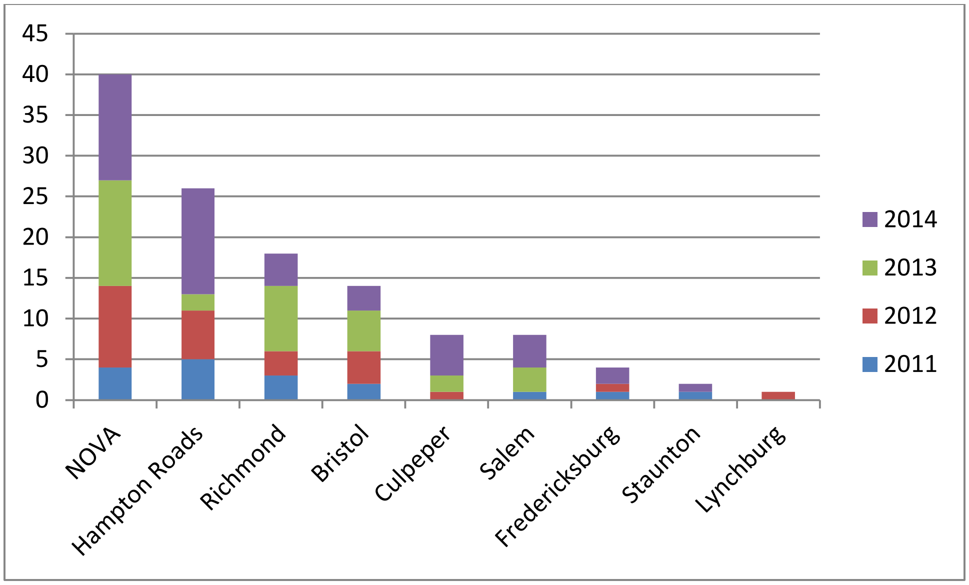


Figure 6. TMA Crashes by VDOT District by Year

The TMA crashes by work zone type by crash severity, Figure 7, revealed that 75.2% of the TMA crashes occurred during mobile operations (and short duration) work zones; 11.6% during static lane closure; 7.4% during static shoulder closure; and 5.8% during setup and removal. Technically, setup/removal is a special type of mobile operations. When this was added to mobile operations, the total was 81% of crashes. Combined lane and shoulder closures accounted for 19% of TMA crashes. All four fatal crashes occurred during mobile operations / short duration work zones.

When TMA crashes were examined by work zone type by year (Figure 8), it was evident that crashes during mobile operations accounted for much of the trend of increasing crashes over the 4-year period. Shoulder closure and setup/removal crashes increased from 2013-2014.

Figure 7. TMA Crashes by Work Zone Type by Crash Severity

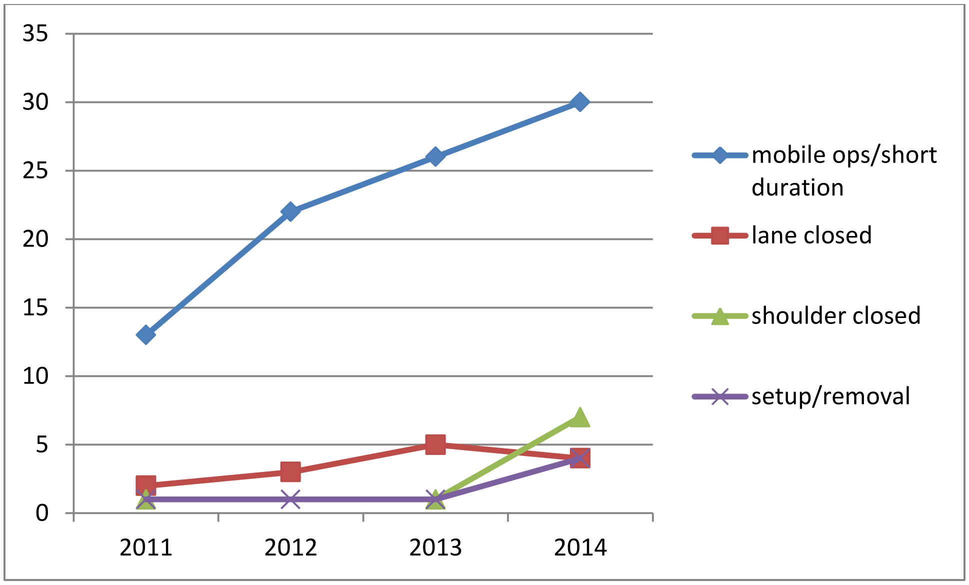


Figure 8. TMA Crashes by Work Zone Type by Year

For TMA crashes by collision type by severity (Figure 9), 76% of the crashes were rear end crashes and 15% were sideswipe same direction crashes. All of the fatal crashes were rear end crashes.

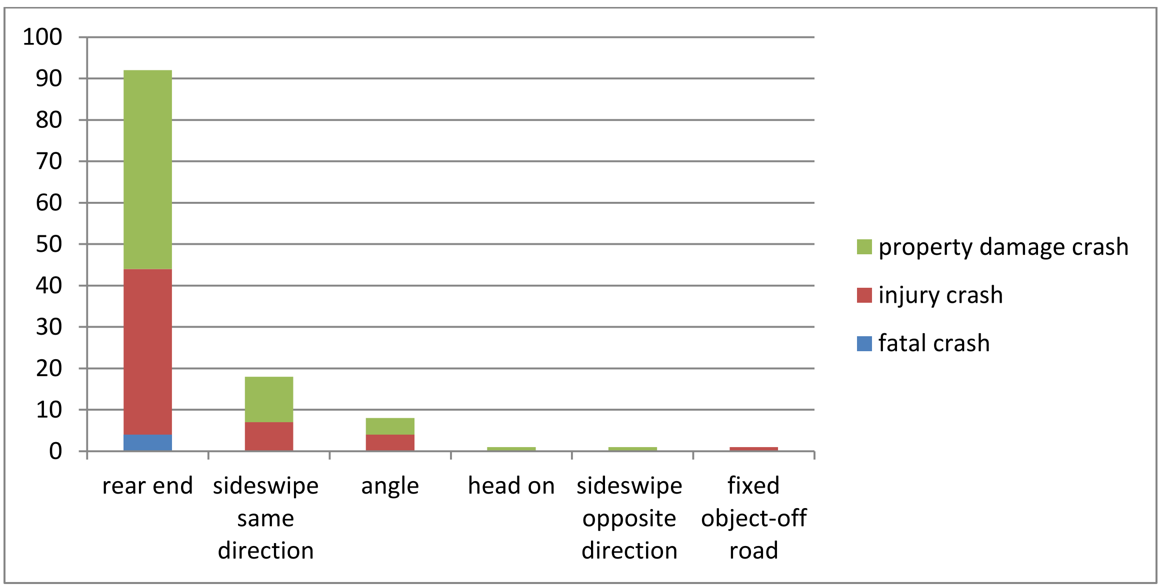


Figure 9. TMA Crashes by Collision Type by Severity

TMA Crash Characteristics

General

In this section a number of attributes available from the crash records are reviewed for possible correlations with the crash data.

From Figure 10, the increase in TMA crashes over time is seen primarily in an increase in contractor-related crashes; VDOT-related crashes were relative stable and low over 2012-2014. The contractors' exposure was likely much greater given that the majority of road work is done by contract.

Figure 11 displays TMA crashes by day of week by year. Wednesday, Tuesday, and Friday are the days when TMA crashes occur more frequently, followed by Thursday and Monday. Sunday had the larger percentage increase in 2014.

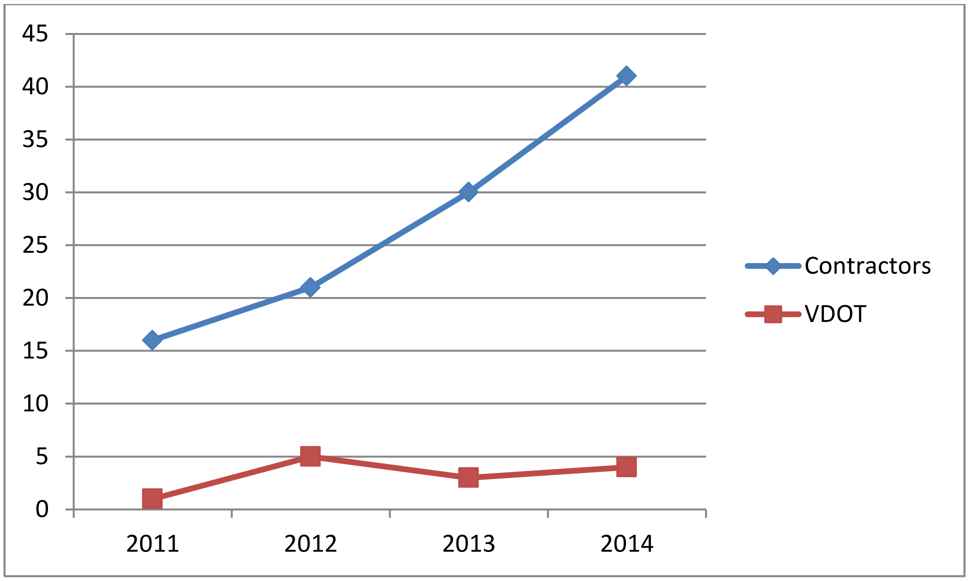


Figure 10. TMA Crashes by Contractor or VDOT by Year

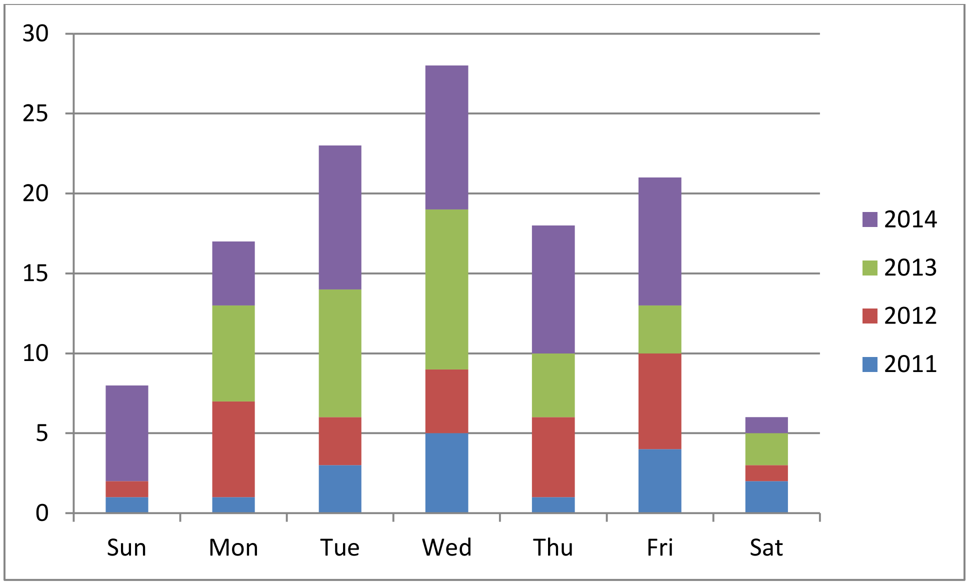


Figure 11. TMA Crashes by Day of Week by Year

Most TMA crashes, 63%, occurred during the daylight followed by 25% occurring in darkness on lighted roads (most likely urban interstate routes) and 9% occurring in darkness on unlighted roads (Figure 12).

When TMA crashes were sorted by light condition by district, the majority of crashes under darkness occurred in the NOVA and Hampton Roads districts (Figure 13). This was likely due to the allowable work hours in these two districts that limit daytime closures on some road sections because of high traffic volumes.

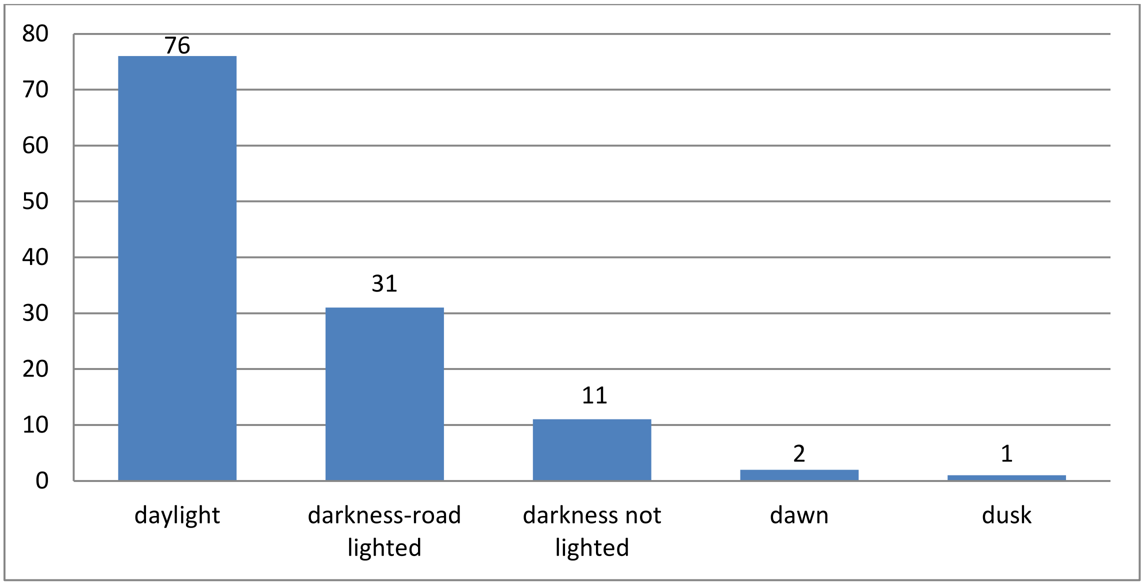


Figure 12. TMA Crashes by Light Conditions

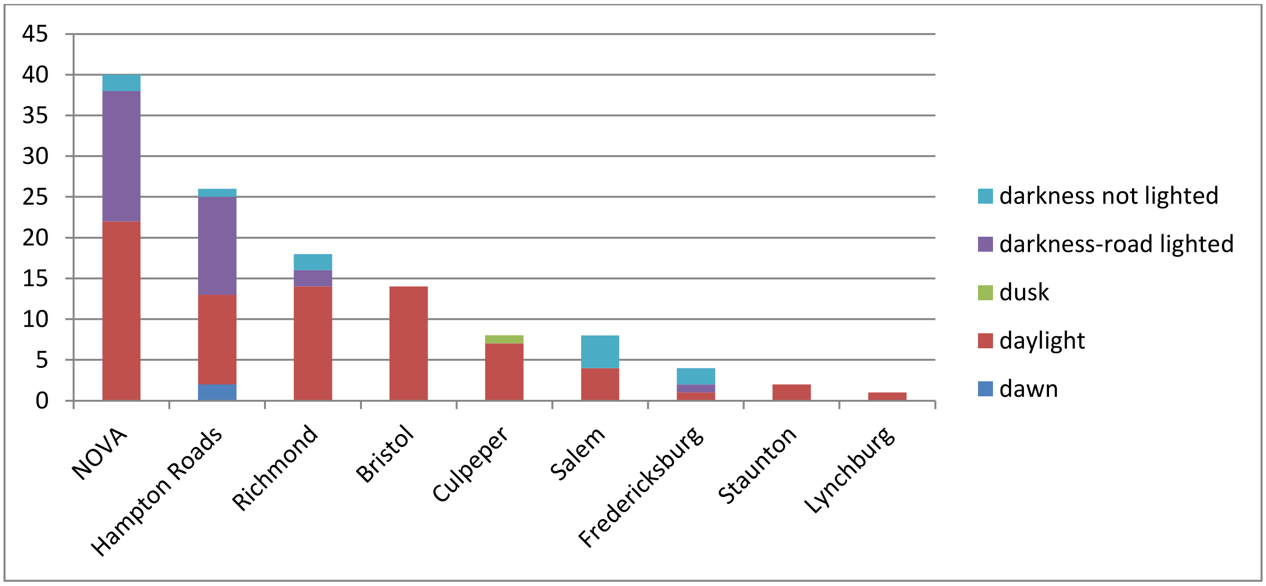


Figure 13. TMA Crashes by Light Conditions by District

Interstate routes 64, 95, 81, 495, 66, 264, and 77 are represented in decreasing order of TMA crashes for routes with five or more TMA crashes; these routes have 64.5% of the TMA crashes (Figure 14). Eighty-nine (73.6%) of the crashes were on interstate roads.

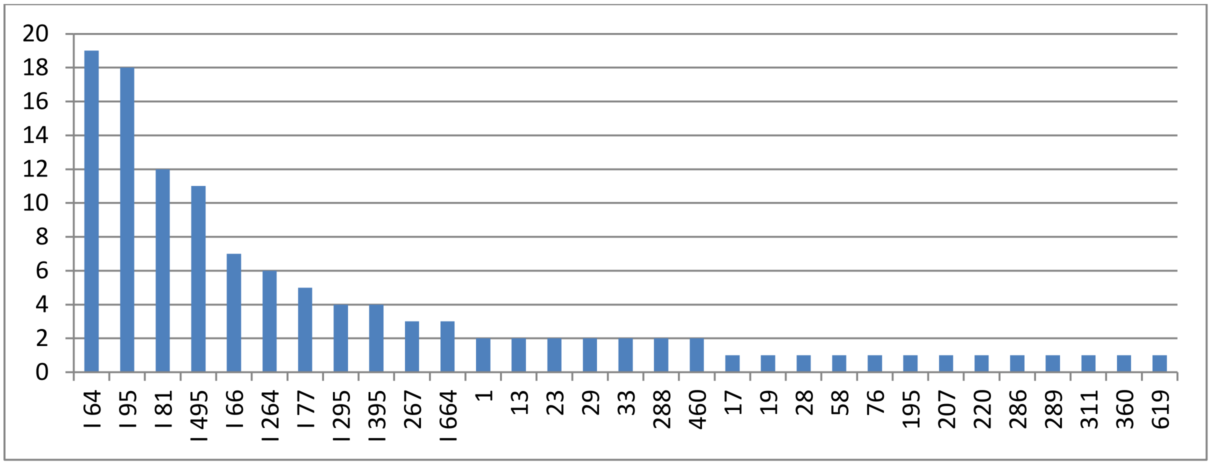


Figure 14. TMA Crashes by Route Number

Driver/Vehicle

With regard to the birth year of the driver hitting the TMA (Figure 15), there was no clear pattern to suggest that a particular age group had a higher crash experience. There was a minor cluster from 1971-1996.

With regard to the gender of the driver hitting the TMA (Figure 16), males were the drivers 72% of the time. The frequency of TMA collision by females was constant from 2012-2014, whereas males accounted for the increase in TMA crashes during that period. Males were the TMA drivers 75.2% of the time (Figure 17), and the number of crashes with male TMA operators increased over time from 2013-2104. It is likely that the vast majority of TMA operators are male.

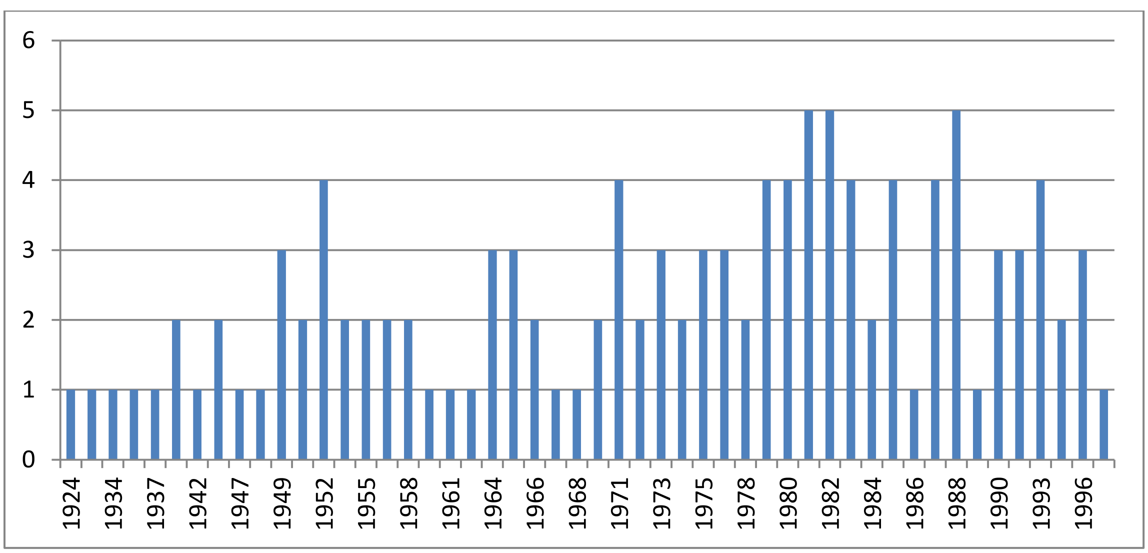


Figure 15. TMA Crashes by Birth Year of Driver Hitting TMA

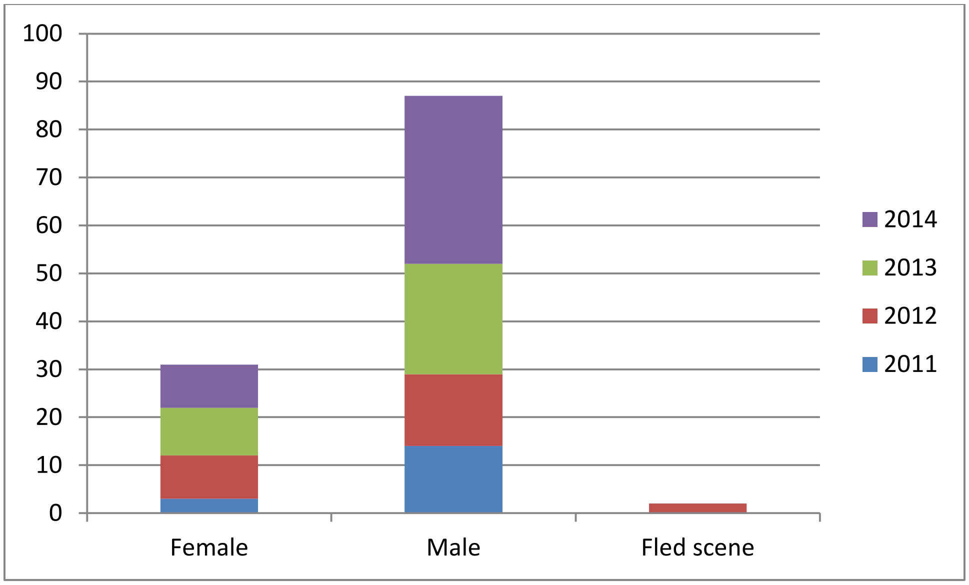


Figure 16. TMA Crashes by Gender of Driver Hitting TMA by Year

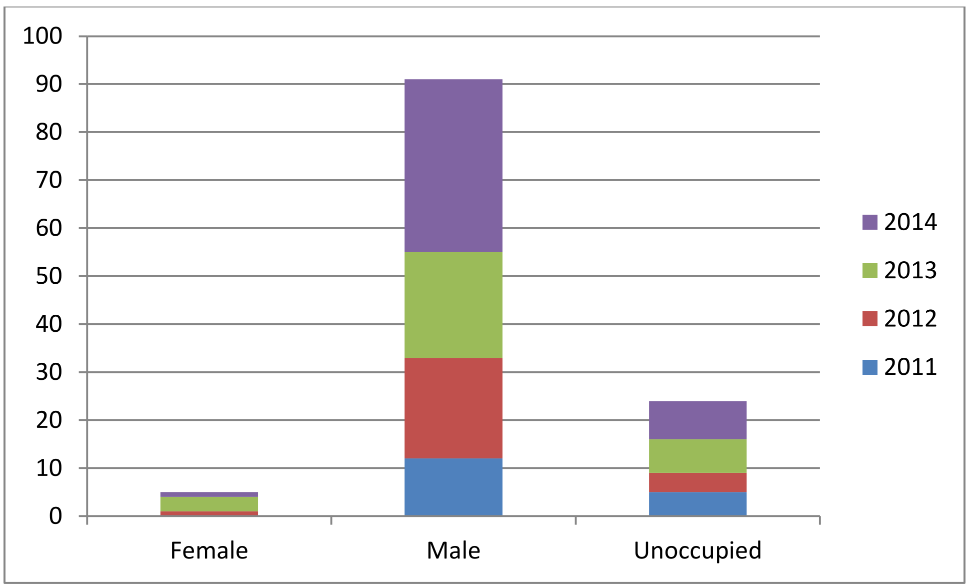


Figure 17. TMA Crashes by Gender of TMA Operator by Year

The speeds of the vehicle before hitting the TMA have a somewhat parabolic shape, peaking at 60 mph (Figure 18).

The driver distraction factors chosen for most crashes were none and blank (no selection) (64%) (Figure 19), indicating that distraction was not considered a contributing factor in 64% of the TMA crashes. Eyes not on road (11.6%) and fatigue (6.6%) were the next two most cited factors.

Figure 20 shows the responses to TMA crashes by driver actions. Generally, driver error was reflected in the responses, with failure to maintain proper control (35.5%) as the most frequent response.

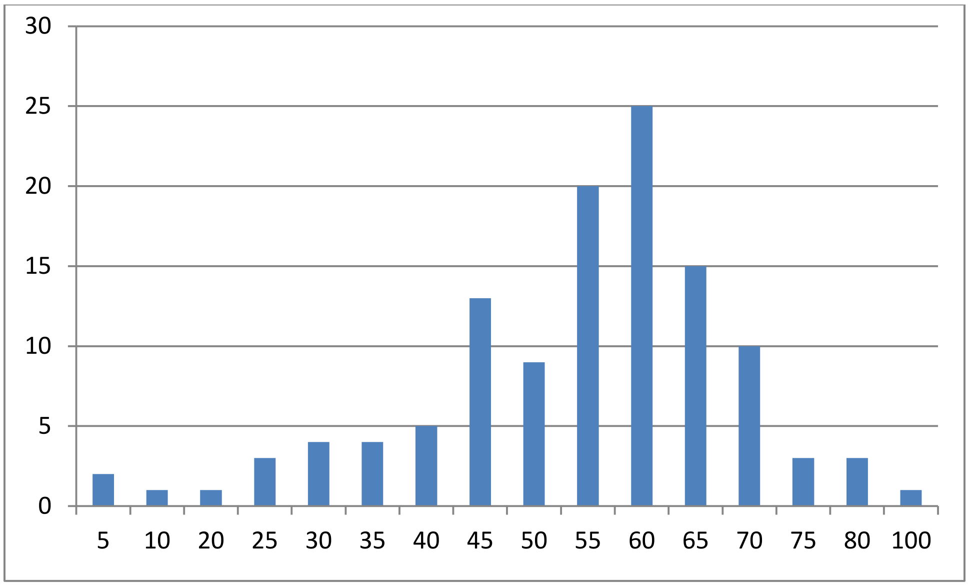


Figure 18. Speed of Vehicle Hitting TMA Before Crash. The speed data were rounded to multiples of 5.

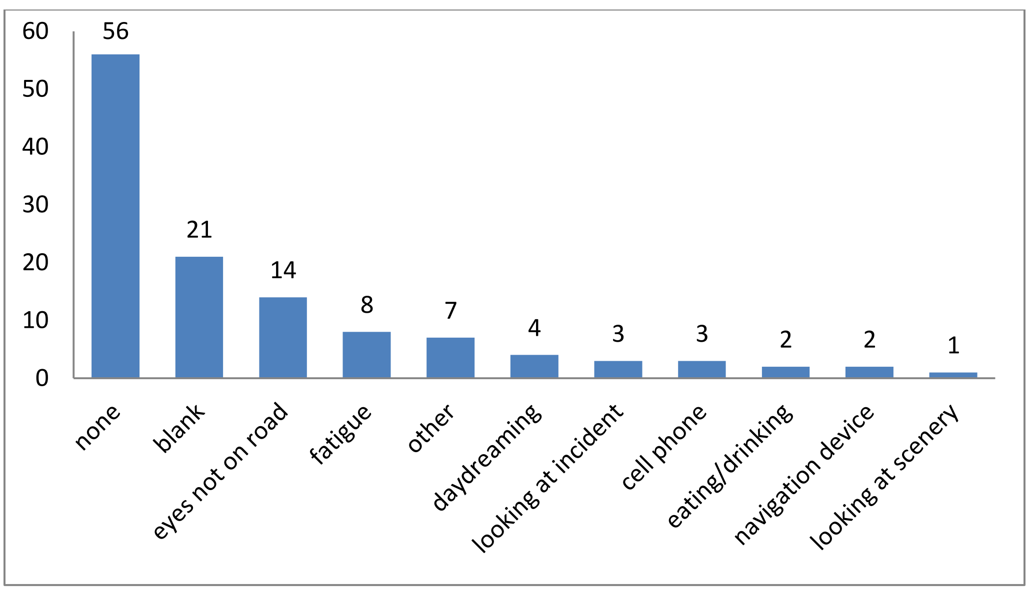


Figure 19. TMA Crashes by Driver Distraction

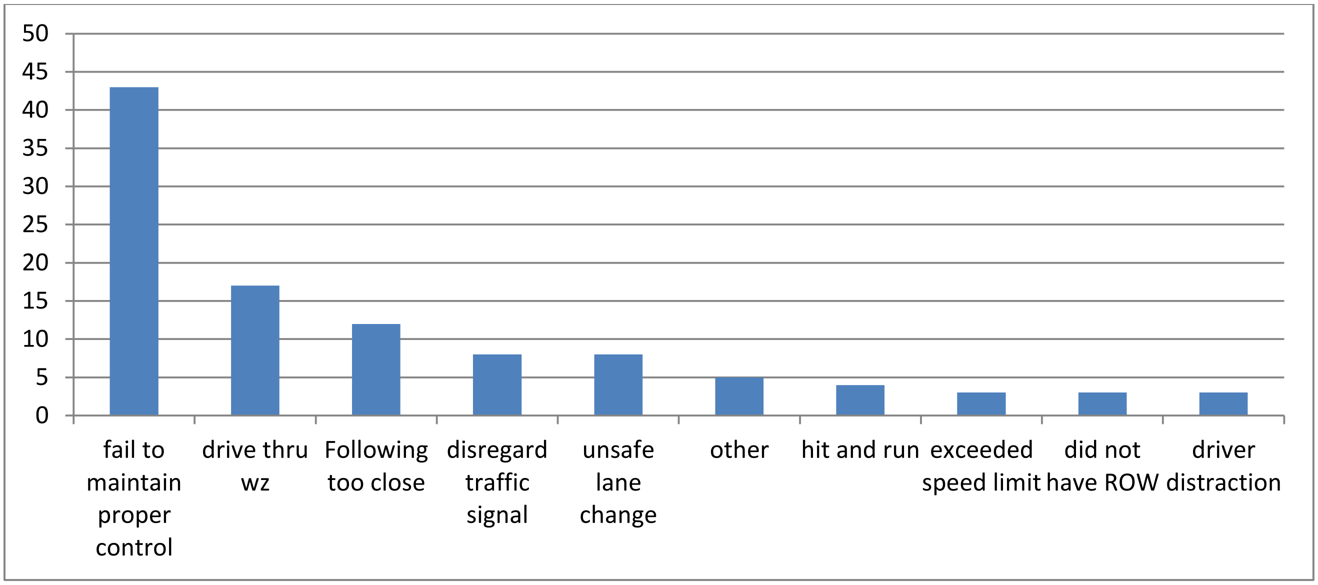


Figure 20. TMA Crashes by Driver Actions (primary categories: 3 or more crashes)

As shown in Figure 21, the vast majority of drivers (81%) had not been drinking; 16 (13%) had been drinking, with 10 (8%) obviously drunk.

In Figure 22, the pattern of crashes in which alcohol played a role is presented. Fifteen of these 16 crashes involving alcohol occurred at night. Nine of the 16 were in the NOVA District and 5 were in the Hampton Roads District (87.5% of alcohol-involved crashes were in these two districts, with 54.5% of all TMA crashes).

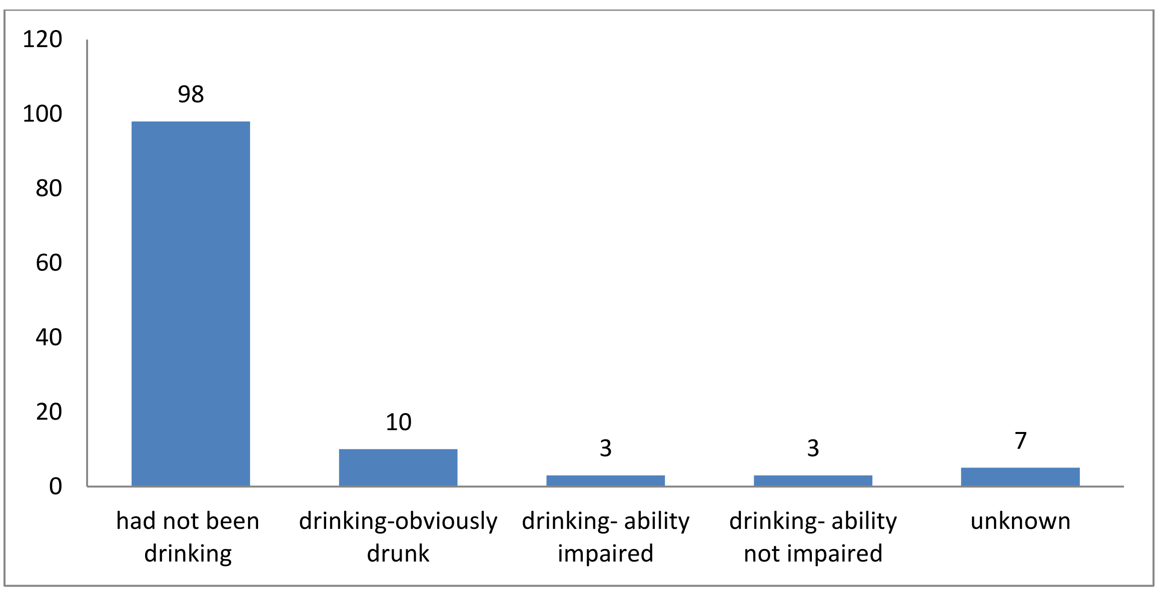


Figure 21. TMA Crashes by Drinking Condition of Driver Hitting TMA

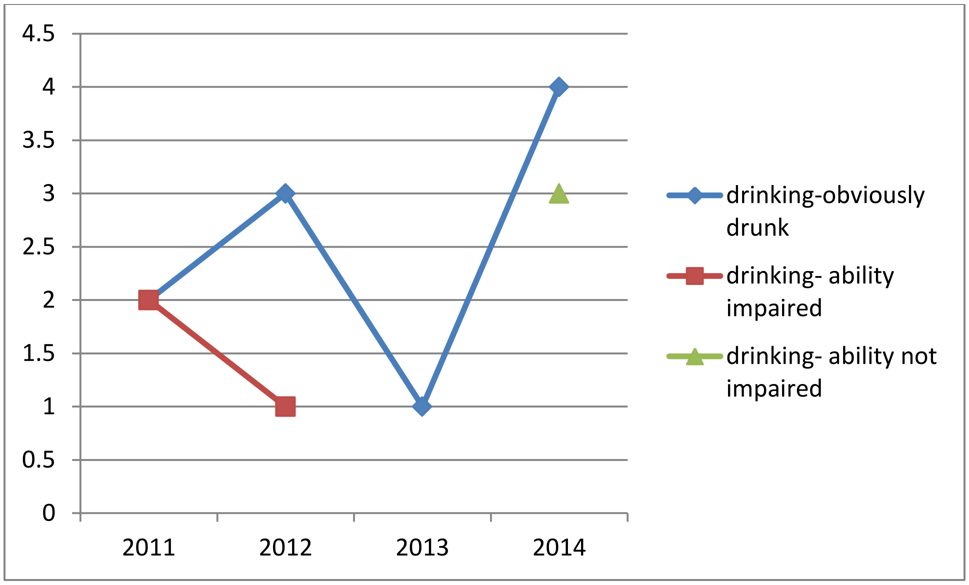


Figure 22. TMA Crashes by Drinking Confirmed by Year

From the crash reports, no contributing condition was listed for 99 (82%) drivers; fatigue and apparently asleep combined for 8% (Figure 23).

Most TMA crashes, 87.6%, did not involve a potential obstruction of the driver's vision as a factor (Figure 24); 12% had a possible influence from obscured vision, such as glare, moving vehicle, or blind spot.

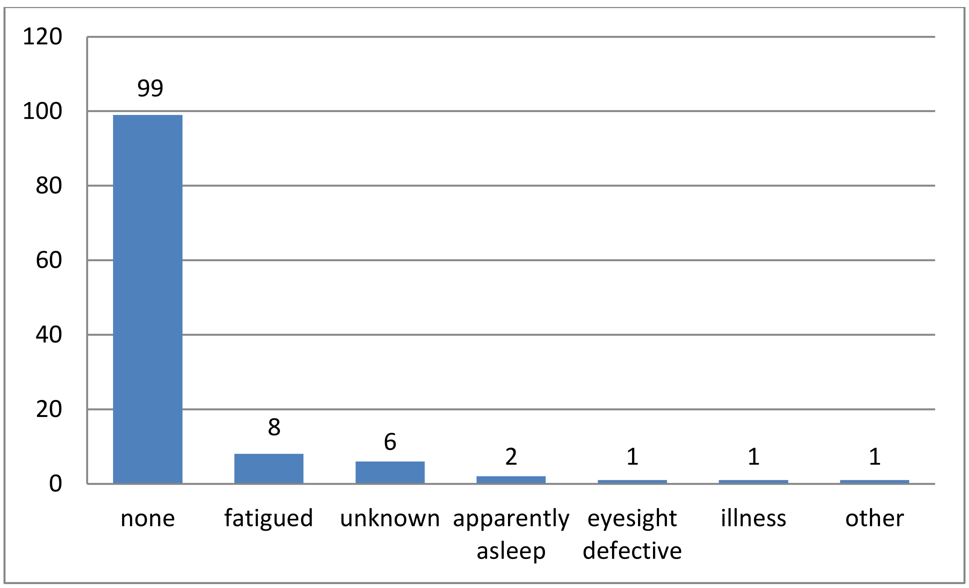


Figure 23. TMA Crashes by Condition of Driver Contributing to Crash

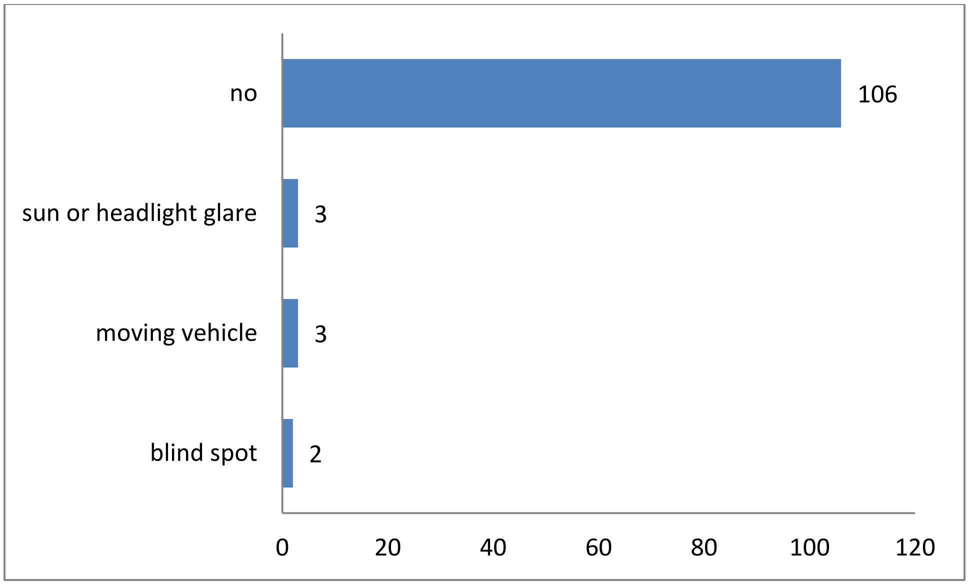


Figure 24. TMA Crashes by Driver Vision Obscured (2 or more crashes)

The two predominant driver maneuvers were going straight (71%) and changing lanes (15%) (Figure 25).

The majority of crashes involved passenger vehicles; this type of vehicle is primarily responsible for the crash increase over time. A single-unit truck with 3 or more axles is the next most frequent vehicle in TMA crashes. There was one crash each involving a recreational vehicle and a school bus; these are not shown in Figure 26. The high involvement of passenger vehicles likely corresponds to their predominance in the traffic stream, being the most common vehicle type.

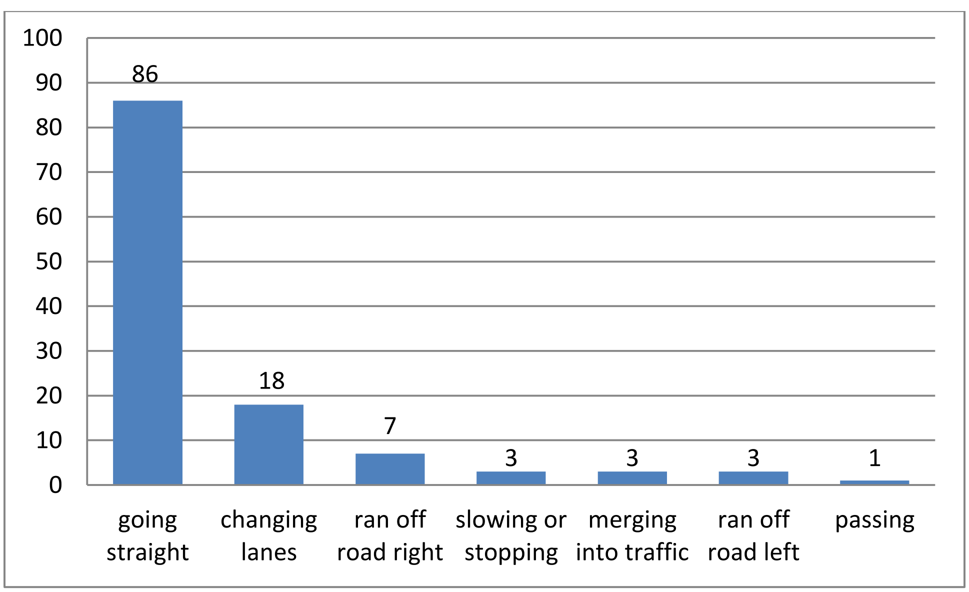


Figure 25. TMA Crashes by Driver Maneuver

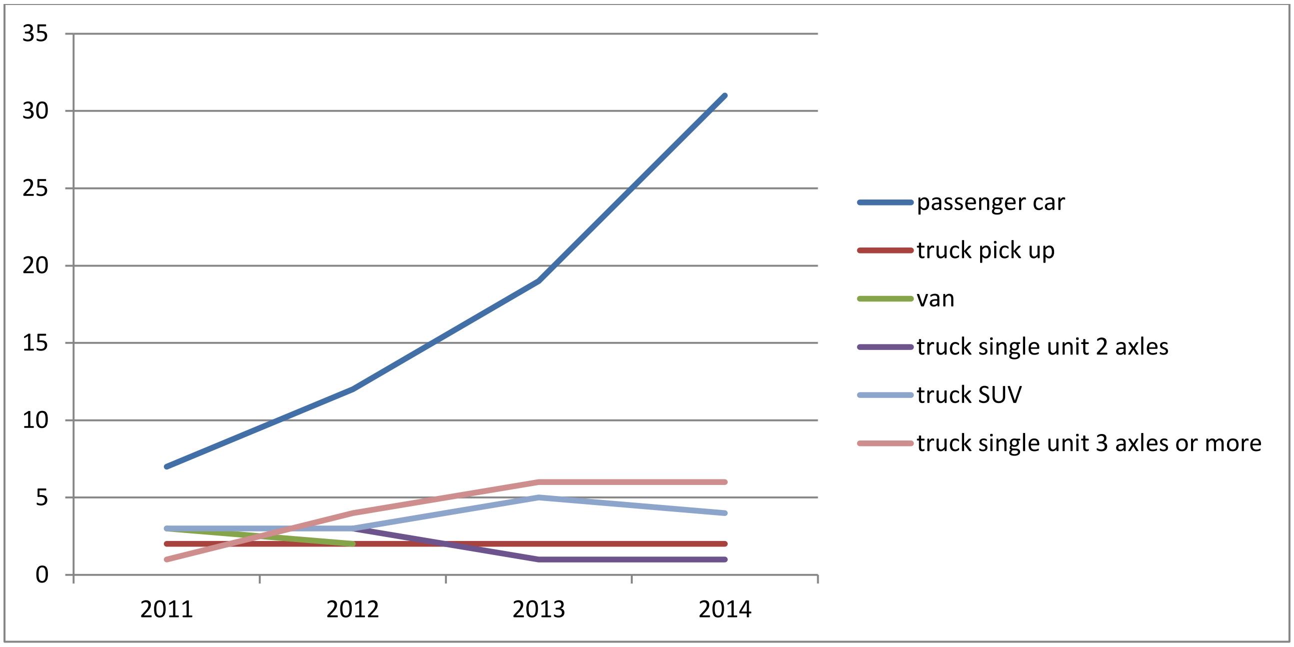


Figure 26. TMA Crashes by Vehicle Type Hitting TMA by Year

Roadway Environment

The roadway was the location of the first harmful event for 93% of the TMA crashes and increased over time (Figure 27). The shoulder location showed a slight increase over time.

With regard to the lane or lateral location in which the TMA crashes occurred (Figure 28), most TMA crashes occurred in the left or right lanes (78%).

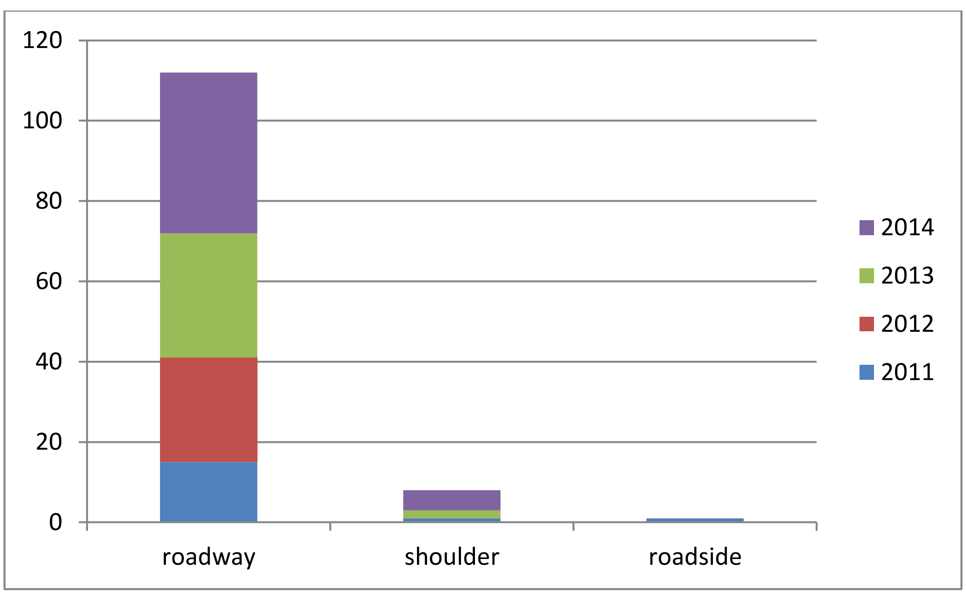


Figure 27. TMA Crashes by Location of First Harmful Event by Year

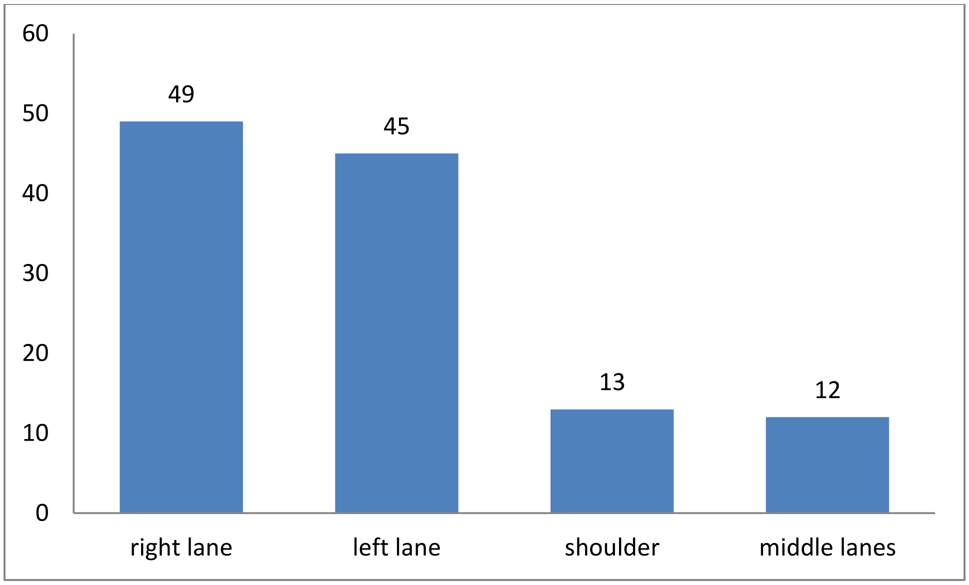


Figure 28. TMA Crashes by Lateral Position in Road

To examine lateral position in more detail, a scheme (xy) was set up that included the lane or position of the crash (x) and the number of lanes on the road section in the same direction (y). Each lane (x) was labeled in increasing order across the road section from right to left beginning with 1 for the right lane; the right shoulder is R; 0.5 indicates that the TMA was straddling the lane/position where the crashes occurred. Figure 29 shows that in decreasing order TMA crashes occurred in the right lane of a two-lane section (12), the left lane of a two-lane section (22), the left lane of a four-lane section (44),and the right lane of a four-lane section (14). The “11” notation in the figure is TMA crashes on a two-lane road (2) or ramp (1).

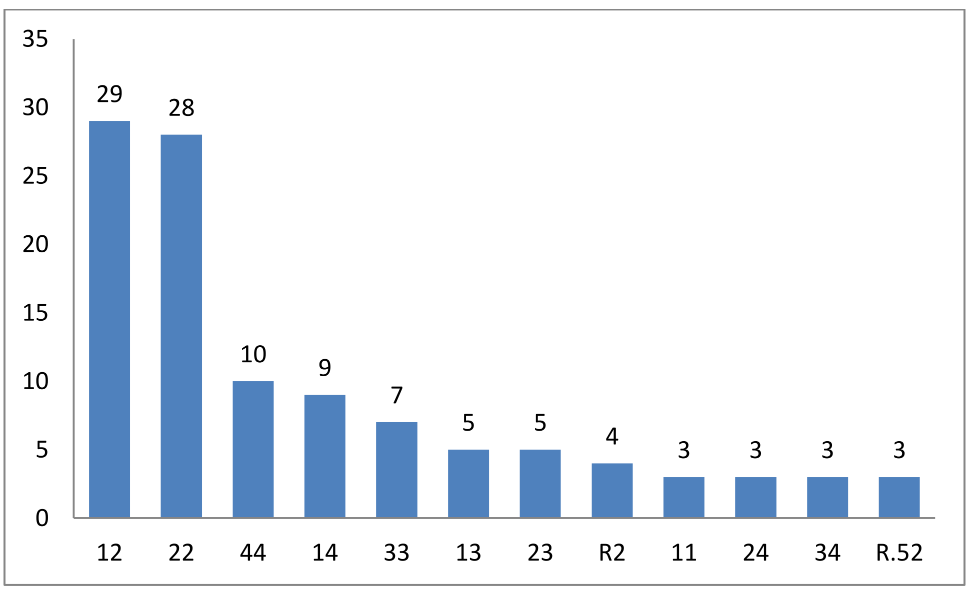


Figure 29. TMA Crashes by Detail Lateral Position in Road (3 or more crashes). xy: x = lane of crash, y = number of lanes in same direction; R= right shoulder, .5- straddling lane/shoulder.

There were a total of six crashes where TMAs were straddling the lane or shoulder. Most crash reports did not provide information on the total number of TMAs in the work zone or which TMA of multiple TMAs was struck (e.g., second of three TMAs).

The majority of crashes (65%) were on straight-level roadway sections (Figure 30). The larger percentage increase in TMA crashes from 2013-2014 was for grade-curve sections and grade-straight sections, 100% and 80%, respectively (3 crashes for each).

The number of crashes by work zone location was equal for the three areas of the work zone (Figure 31). There was no one area within the work zone that was more prone to crashes.

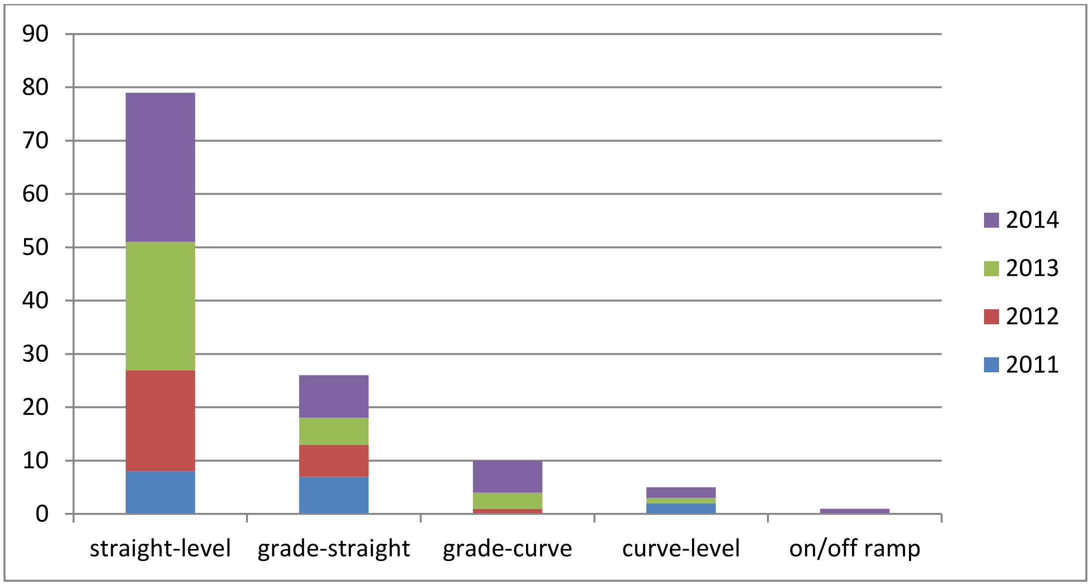


Figure 30. TMA Crashes by Roadway Alignment by Year

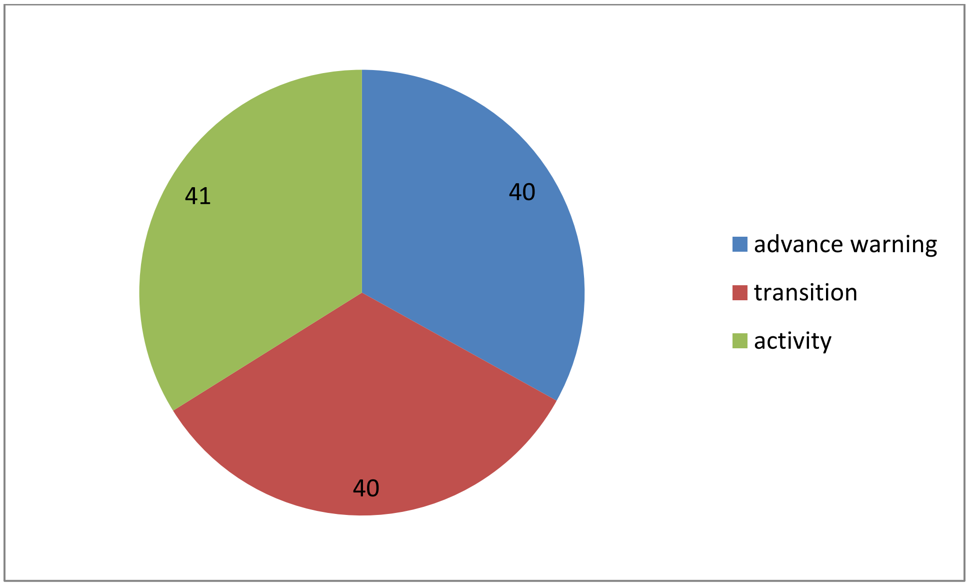


Figure 31. TMA Crashes by Work Zone Location

From Figure 32, law enforcement officers were present during 12 crashes (10%), indicating that their presence does not guarantee that there will be no TMA crashes. There was a trend of increasing crashes where no workers were present. Each of these 5 crashes was in a different district and on a different route.

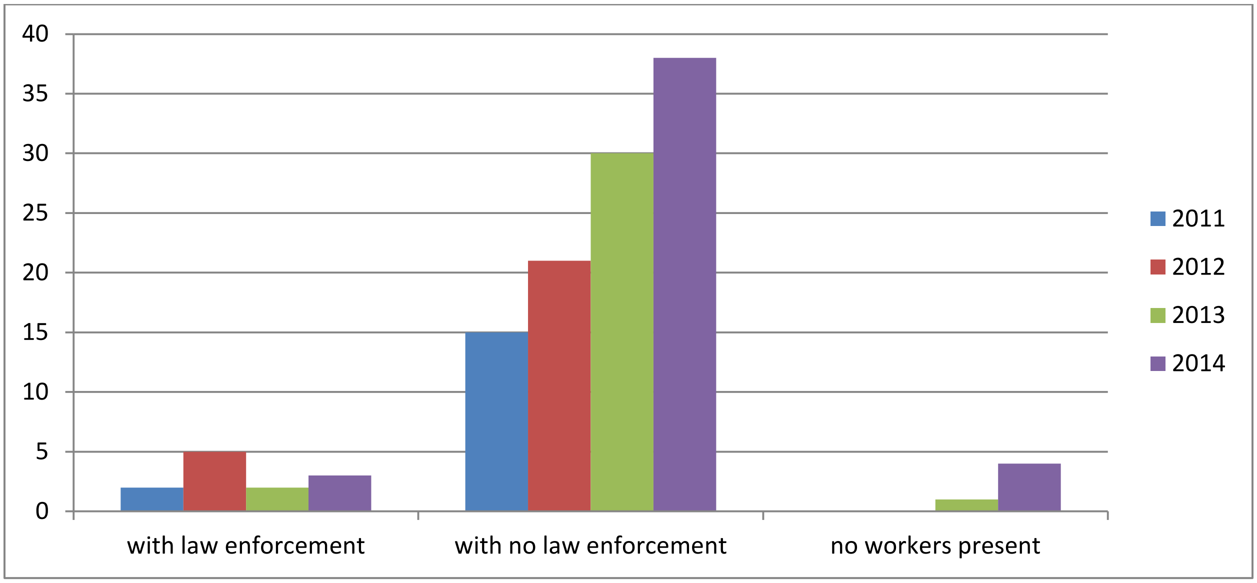


Figure 32. TMA Crashes by Law Enforcement and Workers Present in Work Zone by Year

Review of Work Zones

About 15 work zones were observed in VDOT's Culpeper, Lynchburg, NOVA, Richmond, and Staunton districts. The reviewer observed the use of TMAs in mobile and stationary operations for visibility, placement within VAWAPM guidance, and driver response. There was no police presence at these work zones. A number of observations were made:

- In a median mowing operation on Route 33 in Greene County, the VDOT crew adjusted the spacing of the TMA vehicles to provide adequate visibility around a curve.
- In an I-66 nighttime mobile operation closing the left lane in Fairfax County, the visibility distance of the three flashing arrows of the TMA vehicles was greater than ½ mile.
- On I-495 Southbound in Fairfax County just north of the terminus of the Express lanes, there appeared to be a TMA on both the left and right shoulder protecting the end of a concrete barrier. This application was noted as a concern in the survey results.
- No major issues, concerns, or conflicts were observed where workers were present.

- Figure 32 shows a shadow vehicle with a TMA closing a right turn lane for signal maintenance on Route 33 in Greene County. The sign should state RIGHT LANE CLOSED not LEFT LANE CLOSED.

Figure 32. Shadow Vehicle With Signing Error

Summary of Possible Causal or Contributing Factors and Crash Characteristics for TMA Crashes

Possible Causal/Contributing Factors From Survey

There are a number of possible causal or contributing factors for TMA crashes that were identified from the survey:

- driver inattention/behavior
- road geometrics / sight distance
- mobile operations (particularly near ramps)
- TMA placement in work zone / lack of proper VAWAPM setup
- higher volumes
- time of operations
- inexperienced TMA operators / TMA operator training needed.

Summary of Common TMA Crash Characteristics

The factors noted in italics may be viewed as more relevant based on the TMA crash trend analysis and/or based on the researcher’s opinion.

General:

1. *VDOT district: NOVA, Hampton Roads, Richmond, Bristol*
2. *Work zone type: mobile operations*
3. *Collision type by severity: rear end*
4. *Contractor or VDOT by year: contractor*
5. Day of week: Wednesday, Tuesday, Friday; Sunday increasing
6. *Light conditions: most in daylight*
7. *Light conditions by district: most darkness crashes in the NOVA and Hampton Roads districts*
8. *Route number: most on interstates,* 64, 95, 81, 495, 66, 264, and 77.

Driver/Vehicle:

1. Birth year of driver hitting TMA: minor cluster 1971-1996
2. *Gender of driver hitting TMA: Male*
3. TMA operator gender: male
4. Speed of vehicle hitting TMA before crash: 60 mph
5. Driver distraction: not much: majority none and blank/ next: eyes not on road
6. *Driver actions: general error*
7. *Drinking condition: 13% drinking; most at night in NOVA and Hampton Roads districts*
8. *Condition of driver contributing to crash: most none, fatigue/sleep 8%*
9. Driver vision obscured: minor
10. Driver maneuver: going straight (71%) and changing lanes (15%)
11. *Vehicle type hitting TMA: car.*

Roadway:

1. Location of 1st harmful event: roadway
2. Lateral position in road: left or right lanes (78%)
3. Detail lateral position in road: right lane of a two-lane section, left lane of a two-lane section, left lane of a four-lane section, and right lane of a four-lane section
4. Roadway alignment: straight level
5. Work zone location: no factor
6. *Law enforcement and workers present: police present 10%.*

Potential Alternative Actions to Improve Safety of TMA Use

To transition from the common characteristics of TMA crashes to alternative actions to improve safety, a middle step is the challenge of moving from possible correlation between characteristics of TMA crashes to causation. This study was not able to confirm causation. The practicality of addressing possible factors was considered in developing alternatives. The study recommendations were derived from the list of potential alternative actions.

Motorist

Outreach efforts to drivers to be alert in work zones should continue. Work zone safety should also be considered as an element of distracted driver campaigns. The increased safety concerns of impaired and fatigued driving within work zones should also be highlighted. The media campaign may be focused on select districts; however, statewide efforts would also be useful.

TMA Operator Training

As VDOT outsources more maintenance activities, the exposure of contractors increases and is reflected in the data that show that more contractor-operated TMAs are involved in work zone crashes. To address this challenge, both contractor and VDOT personnel should receive formal training in TMA operations with periodic refresher training. The American Traffic Safety Services Association (ATSSA) has been piloting a training course titled "Operation and Application of Truck-Mounted Attenuators (TMAs)" that could be a valuable resource for contractor staff. The VDOT Learning Center Training Academy offers a 1-day course titled "Truck & Trailer Mounted Attenuator Operator Training" for VDOT staff.

Periodic reminders of TMA-related safety procedures should be shared at safety meetings. In addition, periodic field inspections should confirm that the VAWAPM is being followed and that adjustments in the spacings of shadow vehicles are made when sight distance restrictions occur or when road geometrics necessitate (e.g., near ramps). Although vehicle spacing was not noted as a factor in the crash analysis with Virginia data, it was noted in the literature review. The VAWAPM does note the need to adjust spacing based on sight distance but not for ramps.

In the survey, a contractor noted as a safety concern the importance of communication between TMA operators for maintaining proper spacing and ensuring operators are paying attention and not distracted.

Standard procedures should include requirements that TMA operators keep alert at all times, looking into mirrors and looking around the work area. The TMA operator should use the horn as an alert for a dangerous situation / potential TMA crash by an approaching vehicle and to warn personnel in the work zone.[12] Blowing the horn would alert the approaching driver as well.

VAWAPM and Shadow Vehicle Safety

A review of the VAWAPM for specific improvements related to mobile and short duration operations may be undertaken. A revision to the VAWAPM was made in April 2015. One issue to consider is assessing whether the first shadow vehicle with a TMA in a travel lane should straddle the lane or be fully in the lane. Currently both positions are options. Straddling the lanes gives the appearance of a taper and offers a gradual transition for late mergers. Being fully in the lane may result in a rear end collision with the TMA (the type of collision for which the TMA is designed) versus an angle collision if the TMA is straddling the lane. Another potential issue is the spacing of TMA vehicles near ramps. Another idea is an investigation to determine if there is a safer means to protect the TMA operator through a different seat belt, headrest, or seat.

CONCLUSIONS

- *Driver inattention/behavior, road geometrics / sight distance, mobile operations, and not following the VAWAPM are possible contributing factors for TMA crashes based on a survey of VDOT and contractor staff.*

- *TMA crashes are increasing (2011-2014), and most of the crashes occur on the interstate. A majority of TMA crashes occur in the NOVA, Hampton Roads, and Richmond districts. A typical TMA crash involves a contractor TMA vehicle that is struck from the rear by a male driving a passenger car.*

- *TMA crashes account for less than 1% of all work zone crashes (2011-2014). There is no clear cut solution to decreasing TMA crashes. Although they comprise a small number of crashes compared to the overall number of work zones crashes, most of them affect at least two people, the motorist striking the TMA vehicle and the TMA operator.*

RECOMMENDATIONS

1. *VDOT should require TMA operator training for appropriate VDOT employees and contractors.* VDOT's TED in cooperation with VDOT's Construction Division and VDOT's Maintenance Division is to implement this recommendation. The ATSSA course "Operation and Application of Truck-Mounted Attenuators (TMAs)" that is under development should be considered for contractor TMA operators. The VDOT Learning Center Training Academy course "Truck & Trailer Mounted Attenuator Operator Training" should be considered for VDOT TMA operators. The training should also include specific instructions on how the TMA operator should monitor traffic and alert others by sounding the horn to warn of a potential conflict/collision.

2. *VDOT's TED should inform the VDOT regions of their TMA crash experiences as noted in this report, especially noting the regions with the highest number of crashes.*

3. *VDOT's TED should consider reviewing the benefits of having the first TMA vehicle in the travel lane straddle the lane as opposed to being fully in the lane during mobile operations.* Currently, in the VAWAPM, there is an option to have the TMA vehicle straddle or be fully in the lane. VDOT's TED should also consider the need for guidance on the spacing of TMA vehicles near ramps during mobile operations.

4. *VDOT should consider working with the Virginia DMV and/or others on media and outreach campaigns for distracted driving and include mobile work zones for safer work zones.* VDOT's TED and Communications Division should work together on this effort and establish a preliminary plan of action. A VDOT-only production is also an option.

BENEFITS AND IMPLEMENTATION

Benefits

The safety of motorists in work zones and operators of TMA vehicles will be improved by reducing crashes with TMAs. TMA operator training will result in work zones that are set up in accordance with the VAWAPM. Potential changes to the VAWAPM and/or other documents and practices by VDOT's TED regarding work zones involving mobile operations could also lead to improvements in work zone safety. Finally, media and outreach campaigns targeted at reducing distracted driving in work zones would yield potential safety and operations improvements.

Implementation Plan

By January 2017, VDOT will begin requiring TMA operator training for contractors based on the ATSSA course and for VDOT staff through the existing in-house training course. To support regional efforts to address work zone safety, VDOT's TED will transmit this report to regional staff to inform them of their TMA crash experience from 2011-2014 within 30 days of the distribution of the report by VTRC. With respect to statewide policy, VDOT's TED, with support from VTRC, will review existing guidance on the recommended position of the first TMA vehicle in a travel lane and the spacing of TMA vehicles near ramps during mobile operations. If changes to guidance are appropriate, TED will begin implementation by August 2016. Finally, TED will work with VDOT Communications Staff to develop an action plan for a media and outreach campaign to improve motorist awareness of work zone safety issues. The implementation date for this campaign will be established as part of the action plan.

ACKNOWLEDGMENTS

The author expresses appreciation to In-Kyu Lim, VDOT TED, for providing crash data screening, and Ramkumar Venkatanarayana, VTRC, for entering data in Tableau for analysis. Appreciation is also expressed to the technical review panel members: David Rush, VDOT TED; Larry Weaver, Northwest Region Operations; Brian Frye, Northern Region Operations; Ginger Quinn, VDOT TED; Bryan Maul, VDOT's Richmond District; and Brian Diefenderfer, VTRC. The contributions of VTRC staff Catherine McGhee, Mary Bennett, and Linda Evans are also appreciated.

REFERENCES

1. Virginia Department of Transportation. *Virginia Work Area Protection Manual*. Richmond, 2015.

2. Virginia Center for Transportation Innovation and Research. Minutes: Traffic and Safety Research Advisory Committee. Charlottesville, November 13, 2013.

3. Virginia Department of Transportation. *VaTraffic Guide and Procedure Manual.* Richmond, 2013.

4. Ullman, B.R., Finley, M.D., and Trout, N.D. *Identification of Hazards Associated With Mobile and Short Duration Work Zones.* Texas Transportation Institute, College Station, 2003. http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-4174-1.pdf. Accessed June 30, 2015.

5. Ullman, B.R., Finley, M.D., and Trout, N.D. *Traffic Control Devices and Practices to Improve the Safety of Mobile and Short Duration Maintenance Operations.* Texas Transportation Institute, College Station, 2004. http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-4174-2.pdf. Accessed June 30, 2015.

6. Hadayeghi, A., and Malone, B. Improving the Safety of Mobile Lane Closures. In *NCHRP Research Results Digest 339.* Transportation Research Board, Washington, D.C., 2009.

7. Steele, D.A., and Vavrik, W.R. *Improving the Safety of Moving Lane Closures.* Illinois Center for Transportation, Rantoul, 2009.

8. Steele, D.A., and Vavrik, W.R. *Improving the Safety of Moving Lane Closures: Phase II.* Illinois Center for Transportation, Rantoul, 2010.

9. Bryden, J. Work Zone Crashes Involving Traffic Control Devices, Safety Features, and Work Vehicles and Equipment. In *Transportation Research Record: Journal of the Transportation Research Board,* No. 2015. Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 64-70.

10. National Highway Traffic Safety Administration. *Traffic Safety Facts Research Note: Distracted Driving 2013.* DOT HS 812 132. Washington, D.C., 2015.

11. Theiss, L., and Bligh, R. *Worker Safety during Operations With Mobile Attenuators*. Texas Transportation Institute, College Station, 2013.

12. Vic Roads. *Guidelines for the Use of Truck Mounted Attenuators (TMAs).* Victoria, Australia, 2012. http://www1.worksafe.vic.gov.au/vwa/vwa095-001.nsf/c14309b6789367cdca256fe300068044/e0a3a6b379952d79ca2579c9007d29c0/$FILE/VicRoads%20Guidelines%20for%20TMAs_GDS_08568.pdf. Accessed June 30, 2015.

APPENDIX A

SURVEY OF TMA CRASHES IN WORK ZONES

Email:
VDOT's Research Center is investigating the causes of crashes involving Truck (or Trailer) Mounted Attenuators (TMAs) in work zones. Our goal is to improve work zone guidance for VDOT and Contractors.

Two specific study objectives are to: 1) review trends over the last 3-5 years in crashes involving TMAs; and 2) identify the causal factors of crashes in work zones where TMAs are involved.

By determining the causal factors behind the crashes, improved guidance can be developed. Recommendations from this study are expected to result in changes in work zone operation through revisions in the Virginia Work Area Protection Manual and/or other documents and practices by the Traffic Engineering Division.

We are requesting your assistance in providing information on TMA crashes since 2009.

Please email your response to the following questions and any attachments to Ben Cottrell ben.cottrell@vdot.virginia.gov by Friday, October 3, 2014.

Thank you.

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Survey of TMA Crashes in Work Zones

Name:

Company:

Email Address:

Phone Number:

1. Based on your experience, what are causal factors for most crashes with TMAs? Such factors may include driver behavior, types of roadways, work zone operations, time of day, select regions or roadways, and design of work zones. Please be specific.

2. What are some of your safety concerns with TMA use?

3. What changes do you think are needed to address your safety-related concerns about the use of TMAs in
   a. moving or mobile work zones
   b. stationary work zones?

4. Based on your experience, are there differences in performance between different TMA brands when they are struck? If yes, please explain. If available, please provide supporting information.

5. Crash reports for crashes involving TMAs in WZ from 2009-2013 are being obtained for review by the researcher. If you have investigated such crashes from 2009-present in Virginia, please include your findings from these investigations (attachments are encouraged). If you have copies of FR-300 forms that involved TMA crashes, please include them or the crash report document numbers.

Please email your response to the following questions and any attachments to Ben Cottrell ben.cottrell@vdot.virginia.gov by Friday, October 3, 2014.