HIGHWAY FACTORS
Group Chairman's Factual Report

Fatal Multi-Vehicle Rear-End Accident in a Work Zone
Cranbury, New Jersey

HWY14MH012
(40 Pages)

NATIONAL TRANSPORTATION SAFETY BOARD
OFFICE OF HIGHWAY SAFETY
WASHINGTON, D.C. 20594

Highway Group Chairman's Factual Report

A. CRASH INFORMATION

Location:	New Jersey Turnpike (I-95) northbound near milepost 71.4; Cranbury, Middlesex County, New Jersey
Vehicle #1:	2011 Peterbilt truck-tractor in combination with a 2003 Great Dane semitrailer
Operator #1:	Walmart Transportation, LLC
Vehicle #2:	2012 Mercedes-Benz Sprinter limo van
Operator #2:	Atlantic Transportation Services, LLC
Vehicle #3:	2011 Buick Enclave
Vehicle #4:	2011 Ford F-150
Vehicle #5:	2005 Nissan Altima
Vehicle #6:	2006 Freightliner truck-tractor in combination with a 2001 Utility semitrailer
Operator #6:	4 Way Transport, LLC
Date:	June 7, 2014
Time:	Approximately 1:00 a.m. eastern daylight time
NTSB #:	**HWY14MH012**

B. HIGHWAY FACTORS INVESTIGATIVE GROUP

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C. CRASH SUMMARY

For a summary of the crash, refer to the Crash Summary Report in the docket for this investigation.

D. DETAILS OF INVESTIGATION

The highway group obtained factual information related to the design, maintenance, and operation of the highway environment to establish a foundation for evaluating whether the condition, operation, or design of the traffic facility contributed to or caused the accident. Prefatory data was obtained giving a general description of the highway location; highway information including traffic counts and accident history were obtained from the New Jersey Turnpike Authority (NJTA), and particular focus was placed on reviewing the information that the NJTA uses to make policy decisions regarding Traffic Management Plans, Traffic Control Plans, and other special provisions of the construction contracts used to prevent end of traffic queue hazards.

1.0 Prefatory Data

The accident occurred on I-95 on the northbound outer lanes of the NJ Turnpike about milepost (MP) 71.4 near station no. 3770+00.[1] In this area, I-95 is being widened along a 30-mile-long project[2] that encompasses the area between Interchange 6 and Interchange 9 or approximately MPs 50-83. The accident area was in a 12-mile-long segment designed for MPs 70.6-82.6. The posted speed limit on the variable speed limit signs was reduced from 65 mph to 55 mph beginning at MP 49 in 2012. It was further reduced to 45 mph at MP 71.0 about midnight or 1 hour prior to this accident's occurring. The turnpike facility had three lanes in each direction when this project began in 2009. It was being widened to six lanes in each direction with each direction having a three-lane facility for cars (inner) and an additional three-lane facility (outer) for cars trucks and buses. For detailed information, see Attachment 1, Plans Specifications and Estimates (PSE) for the construction contract.

The three lanes comprising the South to North outer (SNO) lanes were approximately 12-foot-wide lanes delineated by approximately 25-foot-long painted white pavement stripes located at 25-foot intervals. The three main lines were delineated from the 12-foot-wide right-hand shoulder by a solid white pavement stripe. The median

[1] See State Project Plans Project No. T869.120.803 (2012). Station numbers are official numbers describing dimensional project lengths.
[2] Project No. T869.120.803 (2012).

shoulder or the shoulder separating the three South to North inner (SNI) lanes under construction was approximately 10 feet wide, except where it narrowed down to approximately 5 feet wide to provide for guiderail deflection space in the vicinity of support poles for overhead signage. This shoulder was delineated from the main travel lanes by a solid yellow pavement stripe. The shoulders had not yet been milled with rumble strips or alert grooves.

Both the right-hand and left-hand shoulders had blocked w-beam guiderails with standard 6-foot 3-inch post spacings, except in the area of overhead sign supports, which had 3-foot 1 1/2-inch spacings to prevent deflection into rigid fixed concrete pillars. On the left-hand shoulder in the area of bridge pillars, the w-beam guiderail transitioned into a three-beam guardrail, which was connected to a test-level 5, 42-inch-high concrete barrier.

2.0 Accident History

The NTSB requested the NJTA provide an approximate 5-year rear-end accident history for the Interchange 6 to Interchange 9 widening project. See table 1 below for details of rear-end accidents between June 2009 and June 2014, including this accident, on the I-95 Turnpike between MPs 50-83. Also, the table includes 2 years (2007-2008) of accident data when there was no major work zone in place. See Attachment 2, Accident History, for an Excel spreadsheet listing of accidents.

NTSB Table 1.

	2007	2008	2009-2012	2013-2014	Totals
Total Killed	1	2	7	1	11
Total Injured	272	216	1,202	458	2,148
Fatal Crashes	1	2	7	1	11
Injury Only Crashes	156	128	591	273	1,148
Injury & Fatal Crashes	157	130	598	274	1,159
Property Damage Only Crashes	135	384	1,722	599	2,840
Total Crashes	292	514	2,320	873	3,999
Trucks at Fault	79	69	225	Unk	373
Busses at Fault	1	2	10	Unk	13
Motorcycles at Fault	3	1	9	Unk	13
Fatal Crashes Caused by Trucks	0	0	3	Unk	3
Fatal Crashes Caused by Busses	0	0	1	Unk	1

The police crash reports for the seven fatal accidents above during the period 2009-2014 were examined to determine similarities with this crash. For specific details of these crashes, see Attachment 3, Police Reports of Prior Fatal Rear-end Accidents in 6 to 9 Widening Project.

Of these seven fatal accidents, six occurred when traffic was moving slow or had stopped due to congestion related to heavy traffic or an active work zone. One accident resulted when a passenger car drove off the travel lanes onto the shoulder and struck a disabled truck. Of the six fatal crashes related to slow or stopped traffic, three were determined to have occurred when traffic was heavy from routine congestion and three occurred when an active work zone was nearby. Of the three that occurred in a nearby active work zone, one occurred when a work zone 3 miles ahead resulted in congestion, one occurred when a lane closure had just been terminated and traffic had not yet resumed normal operating speed, and one occurred when the two right-hand lanes were closed for construction.

Six of these seven accidents involved a heavy truck, as follows:

1. The one not related to congestion occurred when a car ran off the road, striking a disabled truck.
2. One involved a van striking the rear of a truck-tractor semitrailer (TTST).
3. One involved a TTST struck in the rear by a Single Unit Truck (SUT).
4. One involved a passenger car striking the rear of another passenger car.
5. One involved a motorcoach striking the rear of a SUT and a TTST.
6. One involved a SUT striking the rear of a TTST.
7. The last involved a SUT striking the rear of a passenger car and a TTST when the right two lanes were closed.

3.0 Traffic Metrics

3.1 Volume – The NJTA indicated the traffic volume on Saturday, June 7, 2014, in the vicinity of Interchange 8A was approximately 69,401 vehicles for northbound traffic in the three outer lanes during this 24-hour period. The classification counts indicated that there were 2,553 class 3-class 6 trucks and 557 class B3 buses[3] using the turnpike that day; that is, approximately 4.5 percent of the total volume consisted of trucks and buses. Additional volumes were extracted from the NJTA data for the Saturdays between May 31 and June 28, 2014. For detailed information, see Attachment 4, New Jersey Turnpike Traffic Volumes.

- May 31, 2014: The total volume was 68,144 vehicles, of which 2,824 were class 3-6 trucks and 505 were class 3 buses, so approximately 4.9 percent of the traffic consisted of heavy vehicles.
- June 14, 2014: The total volume was 72,613 vehicles of which 2,547 were trucks and 572 were buses, so about 4.3 percent of the traffic consisted of heavy vehicles.
- June 21, 2014: The total volume was 73,320 vehicles, of which 2,644 were trucks and 562 were buses, so about 4.4 percent of the traffic consisted of heavy vehicles.
- June 28, 2014: The total volume between Interchanges 8A and 8 was 75,504 vehicles, of which approximately 2,816 were trucks and 597 were buses, so about 4.5 percent of the traffic consisted of heavy vehicles.

[3] See http://www.state.nj.us/turnpike/toll-rates.html for class vehicle definitions.

Hourly volumes for these days were extracted for the period from midnight until 1 a.m., along with speed data for each lane of the turnpike at the sensor locations at MP 46.86 South to North (SN) and at MP 87.84 SNO lanes. The average hourly volume for these five Saturdays was 488 vehicles at these two sensor locations, and the average of the mean operating speeds of vehicles were as follows:

- MP 46.86: SN Lane 1 - 66 mph, SN 2 – 70 mph, SN Lane 3 – 76 mph.
- MP 84.87: SNO Lane 1 – 64 mph, SNO2- 67 mph, SNO3 – 73 mph.

3.2 Capacity – The NJTA estimates the Base Free-Flow Speed (BFFS) for the turnpike in a 65-mph speed zone is 70-75 mph and is rounded to 72 mph for capacity calculations. Mainline lanes of the turnpike have capacities estimated using the 2000 version of the *Highway Capacity Manual* (HCM). Capacities applied to different segments of the turnpike are sourced from exhibit 23-2, page 23-4, of the HCM 2000. Capacities can range from 2,280-2,400 Passenger Car Equivalents Per-Hour-Per-Lane (PEPHPL)[4] for BFFS of 55-70 mph. Other quantitative deductions can be made in capacity based on reductions in lane width, shoulder clearance, reduced number of lanes less than five in an urban environment, and for increases in interchange density. For detailed policy information, see Attachment 5, *NJTA Road User Cost Manual*.

3.3 Work Zone Capacity

Effective work zone speed is calculated to be 5 mph above the posted work zone speed limit. Based on the relation of free-flow speed and capacity noted in exhibit 23-2 of the HCM 2000, every 1 mph in free-flow speed equates to 10 PCEPHPL in capacity between 55 mph and 70 mph. The per-lane work zone capacity is then multiplied by the number of lanes open when the work zone is operating to obtain the overall work zone roadway capacity.[5] Base capacity is affected by several variables that can occur in a work zone. Adjustment factors have been incorporated into the road user cost analysis to account for the following factors:

1. Winter weekends – 10% reduction from weekday capacity.
2. Summer weekends – 10% reduction from weekday capacity.
3. Nighttime reduction – 4% capacity reduction for normal and work zone operations.
4. Ramp junction factor – 4%-8% reduction, depending on normal roadway capacity.
5. Lane width factor – 9% reduction for lane widths less than 11 feet.
6. Length of work zone factor – 1.8% reduction per mile of work zone with maximum reduction of 5.5%.

[4] On level highway segments or downgrades, each truck is considered to be the equivalent of 2.0 passenger cars when converting demand volumes from vehicles per hour, where each truck or car is counted once to passenger car equivalents per hour (where each truck is counted twice and each car is counted once). On upgrades with 3% or more grade, trucks are counted 2.5 times. Al-Kaisy, Ahmed, and Fred Hall, "Guidelines for Estimating Capacity at Freeway Reconstruction Zones." *ASCE Journal of Transportation Engineering*, September/October 2003.

[5] New Jersey Turnpike Authority Garden State Parkway and New Jersey Turnpike. "Road User Cost Manual."

7. Work intensity factor – 5.7% reduction for high-intensity work or police presence with flashing lights.

8. Short term work zone with a lane closure – Work zone capacity= 1,710, 1,760, and 1800 PCEPHPL with non-work zone free flow speeds ranging from 58, 65, and 70-75 mph. See figure 1.

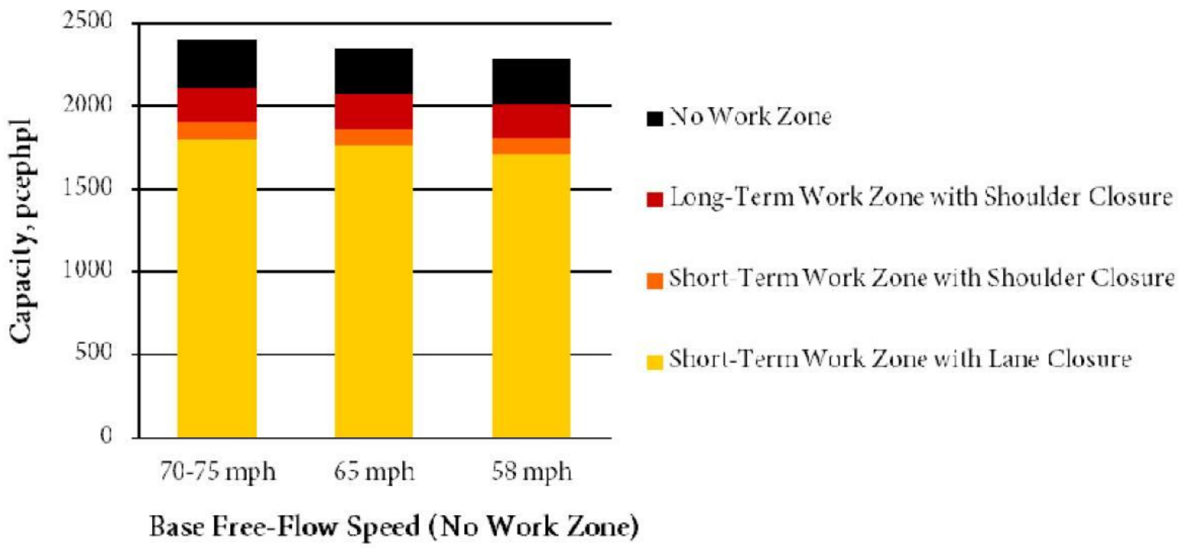

Figure 1.

Adding all of the work zone reduction factors resulted in a 29.2-percent reduction from the estimated 1,800 PCEPHPL capacity, or 1,260 PCEPHPL. The average hourly volume of 488 vehicles indicated the demand or hourly volumes did not exceed the roadway capacity. Consequently, according to the capacity manuals, a queue from congestion should not have developed at this location. Later analysis will provide explanations of why the queue may have developed.

3.4 Queue Discharge Capacity

Exhibit 13-4 of the HCM 2000 shows that traffic exiting a queue flows at the queue discharge capacity, which is less than the non-work-zone freeway capacity when there is no queue. Queues cannot dissipate until the demand volumes drop below the queue discharge capacity. The Federal Highway Administration (FHWA) estimates the dissipation rate for a stop-and-go queue to be approximately 20% less than the freeway capacity when there is no queue.[6] In applying the procedures found in the *Road User Cost Manual*,

> "Note that no two highways or segments of the same highway have the exact same characteristics. Roadway capacity, free-flow speed, potential queue lengths and queue travel times for a given roadway segment may vary from the estimated

[6] "Life Cycle Costs in Pavement Design," Federal Highway Administration, Publication No. FHWA-SA-98-079, Pavement Division Interim Technical Bulletin, September 1998.

or theoretical values from day to day or between different hours of the same day. Factors affecting actual traffic characteristics include but are not limited to, weather, police activity, vehicles on the shoulder, and driver mix (recreational or commuter). These different factors cannot be predicted in advance and sometimes their actual effect on traffic is unknown even after the fact, so it should be understood that the methodology and results from using this Manual will approach, but not perfectly replicate, real-world conditions. However, this Manual uses industry standards and guidelines developed by recognized standard sources, providing an important basis for comparative evaluations of traffic conditions."

"The procedures described in NJTA's Road User Cost Manual are implemented in the Authority's Road User Cost Worksheet. The Worksheets calculate the road user costs based on the volumes and capacities that are inputted and calculated, automatically determining if there will be queuing and associated costs during each hour or fraction thereof."

If queuing is predicted at more than ¼ mile, then a lane closure is not allowed on the New Jersey Turnpike. The NJTA relies on its allowable shoulder closure tables to prevent congestion and queuing when lanes are closed. If lane closures are requested by a contractor during times not allowed by the tables, the request must be approved by the NJTA Director of Operations and the Chief Engineer. The request must include but not be limited to queue detection systems and other measures to ensure congestion does not develop.

4.0 Work Zone Oversight

The FHWA exercises oversight of federal-aid project work zones through guidance found in 23 CFR Part 630 Subpart J, "Traffic Safety in Highway and Street Work Zones." Subpart J was retitled "Work Zone Safety and Mobility" in October 2007 in response to federal rulemaking in 2004. (See 69 FR54562, published September 9, 2004, for more information.)

The key components of the update rule included the following:

1. Development and implementation of an overall, agency-level work zone safety and mobility policy to institutionalize work zone processes and procedures.
2. Development of agency-level processes and procedures to support policy implementation, including procedures for work zone impact assessments, analyzing work zone data, training, and process reviews.
3. Development of procedures to assess and manage work zone impacts of individual projects.

5.0 Oversight by New Jersey Turnpike Authority

The NJTA did not use federal-aid funding for this construction contract. The *NJTA Design Manual*, *Traffic Control in Work Zone Manual*, and the *Road Users Cost Manual*, as well as its contract specifications comply with the federal *Manual for Uniform Traffic Control Devices for Streets and Highways* (MUTCD) and the provisions of 23 CFR Part 630 Subpart J. These documents provide for the advanced planning, work zone impact analyses, training, and inspection of work zones. See Attachment 6, *NJTA Design Manual* and *Traffic Control in Work*

Zone Manual for detailed guidelines. In the contract specifications, contractors acknowledge that they will be assessed a $2,500 penalty for every 15 minutes that a lane closure is conducted outside the allowable times permitted in the lane closure tables, up to a maximum $20,000 penalty fee per day. Additionally, the New Jersey State Police (NJSP) Construction Zone unit provides inspection and oversight authority over all turnpike work zones. See Attachment 7, NJSP Policy on Work Zone Oversight, for policy details.

5.1 New Jersey State Police Construction Unit Traffic Control Oversight

The troopers assigned to the Troop D Construction Incident Management Unit (CIMU) receive work zone traffic control training in the NJSP academy, online annual refresher training, extensive field training, and Work Zone Traffic Control Coordinator training through Rutgers University.

Their duties and responsibilities include the following:

1. Responsibility for all construction activity on the turnpike.
2. Installing and picking up all lane closings.
3. Conducting escorts and traffic slow downs.
4. Enforcing all turnpike policies and procedures.
5. Closing roadways.
6. Investigating industrial or construction accidents.

CIMU troopers specialize in temporary traffic control throughout all work zones on the turnpike. Traffic control is done in cooperation with the NJTP operations department. Supplemental patrols are assigned to work zone areas in addition to the primary CIMU trooper assigned to the work zone. Supplemental patrols patrol work zones every 20 minutes when traffic conditions warrant, utilizing marked vehicles with overhead lights activated. The overall goal is to ensure worker safety and allow for the smooth flow of traffic in and around the work zone. On the night of the accident, one NJSP CIMU Sergeant was supervising and setting up the lane closure and two supplemental units were patrolling work zones on the turnpike. Also, the NJTP Authority Operations Department has Traffic Control Supervisors on duty patrolling the work zones. The CIMU unit is responsible for terminating lane closures. When lane closures are terminated due to traffic conditions, weather, or incidents, the CIMU does not keep records.

6.0 Work Zone and Lane Closure in Operation at the Time of the Accident

The NJTA Manager of Operations indicated that on the day before the accident, contractors submitted a request for the center and right lanes to be closed for work to be performed taking down a large overhead sign about MP 74.1 northbound in the outer lanes. This submission was for a revision to an existing request for a lane closure. Initially, the taper was to begin about MP 72.9, but that was extended back to MP 72.5 to allow enough distance for the complete 2 miles of advance warning and the double taper arrangement.[7] Page LC-T-9 of the

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[7] In a multiple right lane closing, Traffic Protection Standard Drawings require the right lane to have a 1200-foot-long taper, followed by a 1,000-foot-long area for the traffic to stabilize, and then the second 1,200-foot-long taper is put in to close the center lane. For a drawing of the schematic, see Figure 3

Lane Closures Document indicated that on Saturday nights at midnight it was permissible to close two lanes at MP 72.5 in the northbound lanes of the I-95 Turnpike.[8]

The work zone had the following warning signs and devices:

1. Warning began with 2 standard warning signs, one on each side of the roadway, indicating that "Right 2 lanes Closed 2 MI."
2. At 600 feet past the first warning sign, a set of black and white regulatory signs was posted, indicating traffic fines were doubled in the work area.
3. 2,100 feet after sign 2, or at MP 71.0, the 45 mph black and white speed limit sign was posted on both sides of the road.
4. At MP 71.5, or ½ mile up from the first speed limit sign, was a second set of warning signs indicating, "Right 2 Lanes closed 1 MI."
5. 1,500 feet later, or at MP 71.8, a second 45 mph black and white speed limit sign was posted on both sides of the road.
6. About 1,200 feet after that sign, or at MP 72, another set of warning signs was posted on both sides of the road, indicating, "Right 2 Lanes Closed ½ MI."
7. This was followed by another set of warning signs at MP 72.2, indicating, "Right 2 Lanes Closed 1500 FT."
8. This was followed by a set of lane ending warning signs at MP 72.4, and a "Merge Left" warning sign was posted on the right roadside at MP 72.5.
9. At MP 72.5, the 1,200-foot-long taper began with 50-foot spacings.
10. At 900 feet into the taper, a 4-foot by 8-foot flashing arrow board was erected, warning drivers to move left out of the right-hand lane.
11. At the end of the first taper, cones were placed over a 1,000-foot-long area before the next taper closing off the center lane began. The cone spacing was at 75 feet in the tangent area.
12. This taper was also preceded by the lane ending sign and merge left sign, as well as a flashing arrow board.
13. The second taper also had 50-foot cone spacings over a 1,200-foot length.
14. At the end of the second taper, there was a warning sign advising motorists to park disabled vehicles behind cones. This warning sign was followed by another 45 mph speed limit sign.
15. Between the end of the taper and the actual work area, the cones were spaced at 75-foot intervals.
16. The work area at MP 74.1 was preceded by two truck-mounted crash attenuator trucks positioned in each lane, approximately 200 feet prior to the work crew.
17. Additionally, the overhead Dynamic Message Sign (DMS) at MP 72.1 had a Variable Speed Limit (VSL) posted at 45 mph. It displayed "Roadwork Reduced Speed Ahead 45 MPH."
18. The NJTA was unable to determine what message was displayed on the Overhead DMS at MP 62.7.

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[8] See Lane Closure Tables in Appendix B of the *NJTA Manual for Traffic Control in Work Zones*.

Interviews with the consulting engineering company's Traffic Control Coordinator (TCC) and the NJTA Manager of Operations, as well as a review of the NJSP dash cam video indicated the following:

1. At 11:34 p.m., the Variable Message Sign (VMS) at MP 72.1 was turned on to show that the right two lanes were being closed.
2. Prior to the closure, a marked NJSP car began slow down operations in the vicinity of MP 68 by travelling with the traffic with his emergency lights on. This car occupied all of the traffic lanes by veering to the left and right as it progressed northbound to slow down the traffic stream.
3. The contractor, Tetra Tech Inc., and a subcontractor, Griffin Sign Inc., with a seven-person crew, began to place all of the cones in accordance with the TCP.
4. The advance warning signs were placed prior to the state police slow-down.
5. The initial signs posted on both sides of the road were posted at MP 70.5.
6. The speed limit signs reducing the speed limit to 45 mph were posted at MP 71.0 and MP 71.8.
7. The accident occurred about 1 a.m. at MP 71.4.
8. The taper to close the lanes began at MP 72.5.
9. There was advance warning of the lane closure .9 miles in advance of where the collision occurred.
10. The speed limit was reduced to 45 mph at a location .4 mile from the impact location.
11. The double taper arrangement was about 3,400 feet long.
12. The actual work was being performed at MP 74.1, about 2.7 miles ahead of the accident location.
13. The traffic queued back approximately 1.1 miles from the taper and, according to consultants assigned to oversee the lane closures, the traffic rarely queued back to the limits of the warning signs. If it did, procedures were in place to terminate the lane closure and allow traffic to move freely again.
14. Approximately 500 lane closures per week occur on the 136-mile-long turnpike system in New Jersey.

7.0 Work Zone Traffic Control Devices

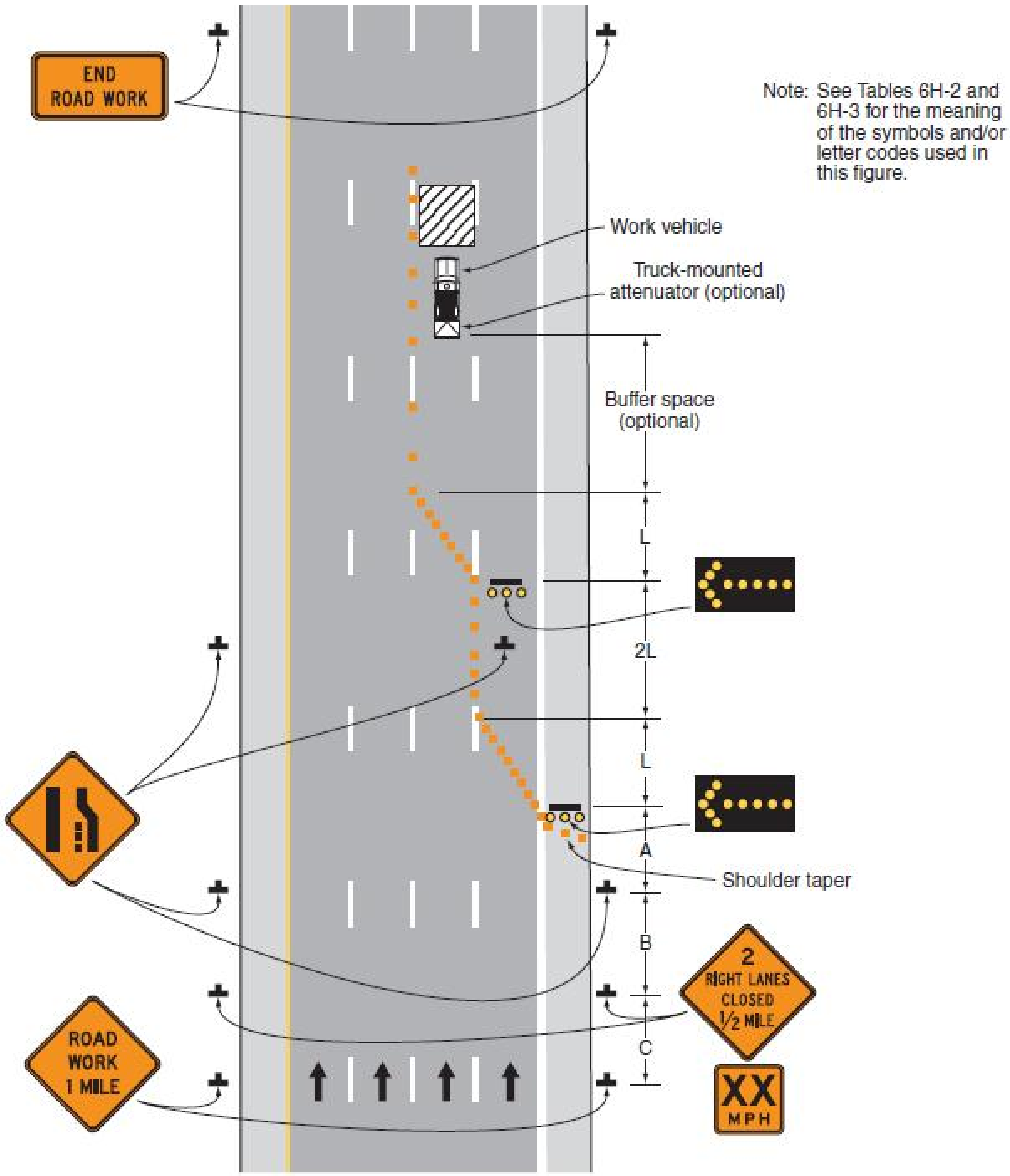
Section 6C.04, Advance Warning Area, in the MUTCD, provides guidance on sign placement for advance warning before a Temporary Traffic Control Zone. The guidance indicates that typical distances for placement of advance warning signs on freeways and expressways should be longer because drivers are conditioned to uninterrupted flow. “Therefore, the advance warning sign placement should extend on these facilities as far as ½ mile or more.” In this work zone accident, the NJTA required advance warning to be extended 2 miles in advance of the beginning of the taper.

The transition area of a temporary traffic control zone is that section of highway where road users are redirected out of their normal path. Transition areas normally involve the use of tapers. Tapers are created by using a series of channelization devices or pavement markings to move traffic out of the normal path. The appropriate taper length should be determined using the criteria shown in MUTCD table 6C-3 and 6C-4. Table 6C-4 provides formulas for determining taper length. In a speed zone of 45 mph or greater, the length of the taper is expressed by L=WS where L is the taper length, W is the width of the offset, and S is the posted speed limit or the anticipated operation speed. This expression indicates that the minimum taper length should have been 540 feet for channeling traffic out of a 12-foot-wide lane in the 45-mph work zone. However, in this accident, the taper length exceeded this minimum requirement. The taper length was 1, 200 feet to close the right-hand lane, followed by a 1,000-foot-long area and then another 1,200-foot-long taper to close the center lane.

The FHWA and the American Traffic Safety Services Association (ATSSA) recommend using longer tapers to help smooth traffic flow at merge locations.[9]

Section 6G.14 of the 2009 MUTCD, “Work Within the Traveled Way of a Freeway or Expressway,” addresses lane closures and multiple lane closures on high-speed freeways and expressways. The standard requires that an arrow board shall be used when a freeway lane is closed. Also when more than one lane is closed, a separate arrow board shall be used for each closed lane. Examples of proper placement of traffic control devices are given in Typical Application (TA 37). Comparison of TA 37 in the MUTCD and the Standard Drawing for a multiple right lane closure for the NJTA (Traffic Protection (TP3) showed that the NJTA complied with and exceeded the MUTCD standards and guidance for color, sign wording, retro-reflectivity, dimensions, advance warning, and placement. See figure 2 for MUTCD TA-37.

[9] “Treating Potential Back-of-Queue Safety Hazards,” American Traffic Safety Services Association, FHWA Grant No. DTFH61-06-G00004.



Typical Application 37

Figure 2.

See figure 3 for NJTA standard drawing for multiple right lane closures TP-3.

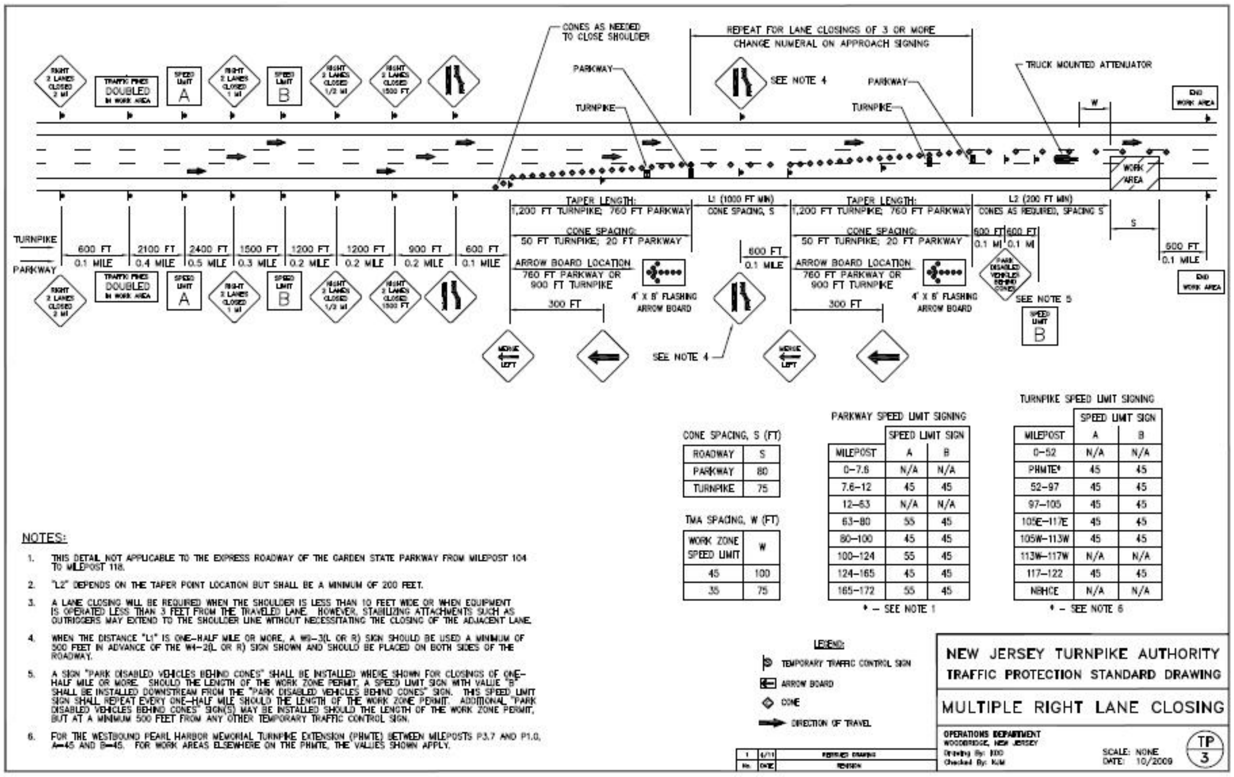


Figure 3.

The only devices not found in this work zone that are sometimes used in other states were temporary transverse rumble strips across the lanes to give motorists a tactile warning to alert them and a portable changeable message (PCM) sign in the advance warning area. These items are permitted by the MUTCD but not required. Specifications for horizontal or transverse rumble strips are found in Section 6F.87 of the MUTCD. Also, a dynamic queue warning system or advanced speed warning system was not used.

Section 6G.19 of the MUTCD provides for special consideration of temporary traffic control during nighttime hours. The following guidance is provided:

> "Considering the safety issues inherent to night work, consideration should be given to enhancing traffic controls (see Section 6G.04) to provide added visibility and driver guidance, and increased protection for workers."

Section 6G04, "Modifications to Fulfill Special Needs," provides guidance on devices that may be added to supplement the devices provided in typical applications. "When conditions are more complex, typical applications should be modified by giving particular attention to the provisions set forth in Chapter 6B[10] and by incorporating appropriate devices and practices from the following list:

[10] Section 6B.01provides detailed information about the seven fundamental principles of temporary traffic control, pages 549-550, 2009 edition MUTCD.

A. Additional Devices

1. Signs.
2. Arrow boards.
3. More channelizing devices at closer spacing.
4. Temporary raised pavement markers.
5. High-level warning devices.
6. PCM signs.
7. Temporary traffic control signals.
8. Temporary traffic barriers.
9. Crash cushions.
10. Screens.
11. Rumble strips.
12. More delineation.

B. Upgrading of devices

1. A full complement of standard pavement markings.
2. Brighter and/or wider pavement markings.
3. Larger and/or brighter signs.
4. Channelizing devices with greater conspicuity.
5. Temporary traffic control barriers instead of channelizing devices.

C. Improved geometrics at detours or crossovers

D. Increased distances

1. Longer advance warning area.
2. Longer tapers.

E. Lighting

1. Temporary roadway lighting.
2. steady-burn lights used with channelizing devices.
3. Flashing lights for isolated hazards.

4. Illuminated signs.

5. Flood lights.

F. Pedestrian routes and temporary facilities

G. Bicycle diversions and temporary facilities

Additional guidance found in section 6G.19 indicates that consideration should be given to stationing uniformed law enforcement officers and lighted patrol cars at night work locations where there is a concern that high speeds or impaired drivers might result in undue risks for workers or other drivers.

The NJSP had the construction unit assigned to this work zone.

Additionally, two supplemental patrols were assigned to the double-lane closure work zone. The NJSP Sergeant assigned to the zone indicated that he supervised the installation of the work zone and traffic control devices and then conducted drive-throughs to inspect the zone about every 20 minutes, when it was feasible. He could not remember the exact time of his last inspection, but he indicated that the traffic was generally light and he noted nothing out of the ordinary. For interview details, see interview summaries in the Survival Group Chairman's Report.

The only existing standard for nighttime temporary traffic control is a requirement for temporary lighting at all flagger stations during nighttime.

8.0 Research Related to the Scope of Work Zone Accidents

The FHWA amended 23 CFR Part 630 Subpart J in 2004 with a requirement for the states to institute the changes by 2007. Therefore, this report will provide the accident statistics for the 6-year period 2007-2012 to assess the general scope of the problem, highlight the problem of truck accidents in work zones by showing a list of fatal truck crashes in work zones, and provide a list of fatal accidents in work zones for the 50 states.

First, however, the report will list the data for work zone fatalities that occurred in the 6-year-period (2001-2006) before the amendments were to be instituted. [11]

- 2001- 1,026 work zone fatalities.
- 2002 – 1,186 work zone fatalities.
- 2003 – 1,095 work zone fatalities.
- 2004 – 1,063 work zone fatalities.
- 2005 – 1,058 work zone fatalities.
- 2006 – 1,004 work zone fatalities.

[11] All data sourced from www.workzonesafety.org/crash_data/workzone-fatalities, accessed on December 16, 2014.

The following list provides the number of fatalities from motor vehicle crashes (including all types of vehicles) in work zones for the years 2007-2012:

- 2007 – 831 work zone fatalities.
- 2008 – 716 work zone fatalities.
- 2009 – 680 work zone fatalities.
- 2010 – 586 work zone fatalities.
- 2011 – 590 work zone fatalities.
- 2012 – 609 work zone fatalities.

The next list shows the number of large trucks involved in fatal and injury work zone crashes for the period 2003-2007.[12]

- 2003 – 196 fatal work zone crashes, 2003 – 3,000 injury work zone crashes.
- 2004 – 225 fatal work zone crashes, 2004 – 4,000 injury work zone crashes.
- 2005 – 235 fatal work zone crashes, 2005 – 4,000 injury work zone crashes.
- 2006 – 216 fatal work zone crashes, 2006 – 2,000 injury work zone crashes.
- 2007 – 174 fatal work zone crashes, 2007 – 2,000 injury work zone crashes.

Additional research showed that on average there were 213 fatalities per year for the period 1996-2000 that involved heavy trucks in work zones. Twenty-four percent of the work zone fatalities that occurred in 2000 involved large trucks in the crash (264 out of 1,093). In 1999, 868 fatalities resulted from motor vehicle crashes in work zones. Twenty-six percent of these fatalities resulted from crashes involving large trucks. In November 2014, the Federal Motor Carrier Safety Administration (FMCSA) published more recent data regarding heavy trucks in fatal work zone crashes.[13] The analysis of Fatality Analysis Report System (FARS) data indicated that 23.6 percent of fatal work zone crashes for the 5-year period 2008-2012 involved at least one heavy truck. Other highlights of the study showed that large truck fatal crashes in work zones are more likely to involve three or more vehicles. In 2012, 32.6 percent of large truck fatal crashes in work zones involved three or more vehicles, while 16.0 percent of fatal large truck crashes in general involved three or more vehicles. Another highlighted fact in the report showed that the majority of large truck fatal crashes in work zones involved large trucks in transport, and most are rear-ended. In 2012, approximately 19 percent of fatal crashes in work zones involved at least one truck that was parked on the shoulder or working in the work zone. The majority (81 percent) of work zone fatal crashes that involved a large truck were in transport or traveling through the work zone. In 2012, 56.2 percent of large trucks in work zone fatal crashes were rear-ended. Table 2 below provides a summary of this information.

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[12] *Large Truck and Bus Crash Facts 2007*, Federal Motor Carrier Safety Administration.
[13] Analysis Brief, "Work Zone Fatal Crashes Involving Large Trucks, 2012," Federal Motor Carrier Safety Administration, Washington, DC. November 2014.

NTSB Table 2.

Table 2. Summary of Results from 2012 Analysis of Work Zone Fatal Crashes Involving Large Trucks		
Crash Type	**All Fatal Crashes**	**Work Zone Fatal Crashes**
Involved at Least One Large Truck	11.2%	23.6%
Involved a Large Truck and Two or More Vehicles	16.9%	32.6%
Involved a Large Truck That Was Parked/Working	4.1%	18.9%

Note: Parked/Working large truck data comes from the Parkwork datafile in FARS.
Source: USDOT, NHTSA, FARS, available at: http://www.nhtsa.gov/FARS.

Table 3. below summarizes the highlighted descriptions above:

NTSB Table 3.

Table 1. Fatal Crashes by Work Zone, 2008–12										
	2008		2009		2010		2011		2012	
Crash Location	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Fatal Crashes Involving Large Trucks										
Not a Work Zone	3,584	95.5	2,852	95.6	3,153	96.4	3,214	95.5	3,335	96.3
Work Zone	170	4.5	131	4.4	117	3.6	145	4.3	129	3.7
Unknown	0	0.0	0	0.0	1	0.0	6	0.2	0	0.0
Total	**3,754**	**100.0**	**2,983**	**100.0**	**3,271**	**100.0**	**3,365**	**100.0**	**3,464**	**100.0**
All Fatal Motor Vehicle Crashes										
Not a Work Zone	33,510	98.1	30,273	98.1	29,756	98.2	29,300	98.1	30,253	98.2
Work Zone	662	1.9	589	1.9	521	1.7	533	1.8	547	1.8
Unknown	0	0.0	0	0.0	19	0.1	34	0.1	0	0.0
Total	**34,172**	**100.0**	**30,862**	**100.0**	**30,296**	**100.0**	**29,867**	**100.0**	**30,800**	**100.0**

Source: U.S. Department of Transportation (USDOT), National Highway Traffic Safety Administration (NHTSA), Fatality Analysis Reporting System (FARS), available at: http://www.nhtsa.gov/FARS.

The following table 4 shows the states with the highest number of fatal work zone crashes involving a large truck.

NTSB Table 4.

Table 6. Top 10 States by Number of Work Zone Fatal Crashes Involving Large Trucks, 2008–12					
State	**2008**	**2009**	**2010**	**2011**	**2012**
Texas	27	17	14	23	28
Illinois	13	10	12	7	9
California	7	9	5	11	16
Florida	13	8	8	7	7
Georgia	11	4	10	6	6
Indiana	6	5	2	11	4
Arkansas	4	5	3	5	4
Tennessee	3	3	0	5	5
Wisconsin	2	4	2	1	5
Nebraska	1	2	1	3	4
Total	**170**	**131**	**117**	**145**	**129**

Source: USDOT, NHTSA, FARS, available at: http://www.nhtsa.gov/FARS.

Over the 5-year period 2008-2012, Texas has had the highest average number of fatal work zone crashes involving a large truck, averaging 21.8 per year. Texas is followed by Illinois, with an average of 10.2 per year, and California, with an average of 9.6 per year. In comparison, New Jersey had eight fatal work zone accidents over the 6-year period 2009-2014 involving large trucks on the New Jersey Turnpike.

In 2012, the most critical precrash event was traveling in the same direction with a higher speed, accounting for 27.2 percent of fatal work zone crashes involving a large truck.

The table below summarizes critical precrash event for large trucks in fatal work zone crashes for the period 2010-2012.

NTSB Table 5.

Table 9. Top Five Critical Pre-Crash Events for Large Trucks Involved in Work Zone Fatal Crashes, 2010-2012			
Critical Pre-Crash Event	**2010**	**2011**	**2012**
Traveling in same direction with higher speed	39	46	44
From opposite direction over left lane line	9	18	19
Other vehicle stopped	16	25	18
Pedestrian involved	6	11	10
Traveling in same direction with lower or steady speed	5	5	10
Total	**150**	**175**	**162**

Note: The FARS variable this table is based on was first introduced in 2010. Individual rows do not add up to total as total includes work zone fatal crashes with other critical pre-crash events.
Source: USDOT, NHTSA, FARS, available at: http://www.nhtsa.gov/FARS.

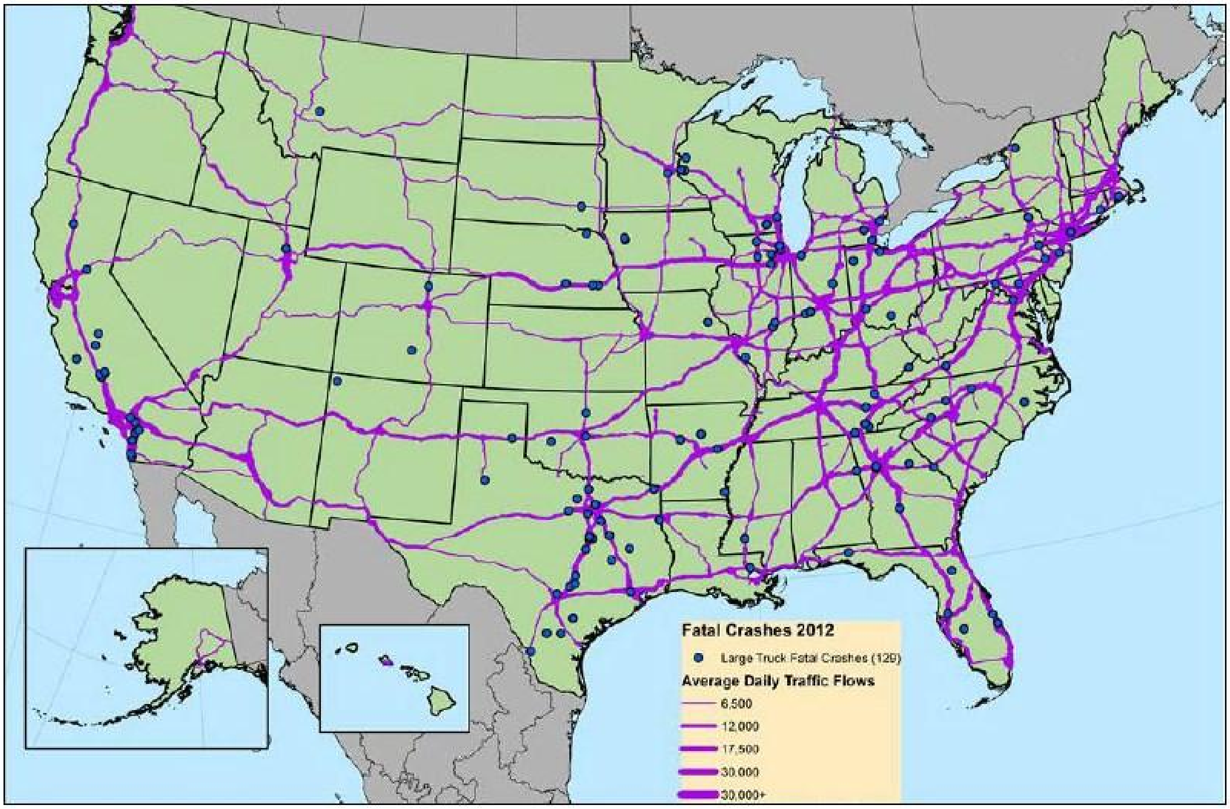
The next table describes the manner of collision, or orientation, for in-transport motor vehicles in fatal work zone crashes involving at least one large truck. Since 2008, the greatest proportion (on average 41.8 percent) of fatal crashes in work zones has been front to rear collisions. In 2012, 56.2 percent of large trucks involved in fatal work zone crashes were impacted at 6 o'clock (i.e. rear-ended) and 39 percent were impacted at 12 o'clock (i.e., front impact).

NTSB Table 6.

Table 10. Manner of Collision for Work Zone Fatal Crashes Involving Large Trucks, 2008–12					
Manner of Collision	**2008**	**2009**	**2010**	**2011**	**2012**
Not a Collision with Motor Vehicle In-transport	41	34	29	46	34
Front-to-rear	70	52	49	59	59
Front-to-front	15	8	11	11	12
Angle	32	21	19	19	17
Sideswipe—Same Direction	8	9	6	7	5
Sideswipe—Opposite Direction	3	4	2	1	1
Rear-to-side	0	1	1	0	1
Other	1	0	0	1	0
Unknown	0	2	0	1	0
Total	**170**	**131**	**117**	**145**	**129**

Source: USDOT, NHTSA, FARS, available at: http://www.nhtsa.gov/FARS.

The map below shows the United States with interstate roadways and their corresponding average daily truck traffic flows, with a colored circle representing each of the 129 fatal work zone crashes in 2012 that involved a large truck.



Note: Average Daily Truck Traffic Flows are based on Freight Analysis Framework (FAF) 3.4.
Sources: **Fatal Crashes** – USDOT, NHTSA, FARS, available at: http://www.nhtsa.gov/FARS. **Traffic Flows** - USDOT FHA, FAF Version 3, available at: http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/.

Figure 4.

The next table shows the number of fatal work zone crashes in each state for 2012.

NTSB Table 7.

Fatalities in Motor Vehicle Traffic Crashes by State and Work Zone (2012)

State	Not in Work Zone Number	In Work Zone Number	Total Number
Alabama	856	9	865
Alaska	59	0	59
Arizona	819	6	825
Arkansas	541	11	552
California	2,790	67	2,857
Colorado	464	8	472
Connecticut	235	1	236
Delaware	112	2	114
District of Columbia	15	0	15
Florida	2,373	51	2,424
Georgia	1,172	20	1,192
Hawaii	124	2	126
Idaho	183	1	184
Illinois	937	19	956
Indiana	765	14	779
Iowa	358	7	365
Kansas	397	8	405
Kentucky	738	8	746
Louisiana	710	12	722
Maine	163	1	164
Maryland	499	6	505
Massachusetts	343	6	349
Michigan	924	14	938
Minnesota	391	4	395
Mississippi	579	3	582
Missouri	819	7	826
Montana	204	1	205
Nebraska	205	7	212
Nevada	243	15	258
New Hampshire	108	0	108
New Jersey	579	10	589
New Mexico	361	4	365
New York	1,152	16	1,168
North Carolina	1,281	11	1,292
North Dakota	169	1	170
Ohio	1,006	17	1,123
Oklahoma	688	20	708
Oregon	331	5	336
Pennsylvania	1,289	21	1,310
Rhode Island	64	0	64
South Carolina	860	3	863
South Dakota	131	2	133
Tennessee	1,002	12	1,014
Texas	3,273	125	3,398
Utah	199	18	217
Vermont	76	1	77

NTSB Table 7 continued.

Fatalities in Motor Vehicle Traffic Crashes by State and Work Zone (2012) | WorkZoneS... Page 2 of 2

Virginia	764	13	777
Washington	443	1	444
West Virginia	333	6	339
Wisconsin	602	13	615
Wyoming	123	0	123
Total	32,952	609	33,561
Puerto Rico	345	2	347

Source: Fatality Analysis Reporting System (FARS) 2012 ARF, NHTSA

Last verified: 11/25/2013

Research at the Texas Transportation Institute (TTI)[14] shows that truck involvement in fatal work zone crashes is over-represented. FARS data show that trucks are involved in 11-12 percent of all fatal crashes, but they were involved in 23.6 percent of fatal work zone crashes for the 8-year period 2005-2012. This percentage is consistent with previous estimates in 1999 and 2000, showing that large truck over-involvement in fatal work zone crashes has remained a consistent problem, spanning several years. Other evaluation work has been the subject of National Cooperative Highway Research Projects (NCHRP).[15] In NCHRP 627, researchers concluded the following:

1. Overall, working at night does not result in significantly greater crash risk for an individual motorist traveling through the work zone than does working during the day.
2. Crashes that occur in nighttime work zones are not necessarily more severe than those that occur in similar daytime work zones.
3. For work activities that require temporary lane closures, the total safety impacts to the motoring public are less if the work is done at night.

Strategies that appear to offer the greatest potential for crash cost reduction include the following:

1. Practices to reduce the number and duration of work zones required;
2. Use of full-directional roadway closures via median crossovers or detours onto adjacent frontage roads;
3. Use of time-related construction contract provisions to reduce construction duration;
4. Moving appropriate work activities (i.e., those require temporary lane closures) to nighttime hours;

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[14] *FHWA Webinar Truck Crash Trends in Work Zones*, October 2014, Ullman, Gerald L, Ph.D., P.E., Texas Transportation Institute.

[15] NCHRP Program Report 500, *Guidance for the Implementation of the AASHTO Strategic Highway Safety Plan*, Volume 17, "Guidance for Reducing Work Zone Collisions," Transportation Research Board, 2006, Washington, DC, and NCHRP 627, *Traffic Safety Evaluation of Nighttime and Daytime Work Zones*, 2008 Transportation Research Board, Washington, DC.

5. Use of demand management programs to reduce volumes through work zones; and
6. Use of enhanced traffic law enforcement.

Other strategies may offer moderate reductions in crash costs due to work zones, depending on conditions. Strategies that have been grouped into this category include the following:

1. Designing adequate future work zone capacity into highways;
2. Use of full roadway closures that require traffic detours onto adjacent surface streets;
3. Use of Intelligent Transportation Systems (ITS) strategies to reduce congestion and improve safety;
4. Improvement of work zone traffic control device visibility;
5. Efforts to reduce flaggers exposure to traffic; and
6. Efforts to reduce workspace intrusions and their consequences- primarily at long-term, high-volume work zones.

One mediation effort that began early in the decade was the development and application of ITS in work zones. ITS in work zones is referred to as Smart Work Zones (SWZ) in the research literature.

8.1 Use of ITS in Work Zones

One of the more promising accident reduction applications is the use of ITS in creating smart work zones. A 2011 research project at the TTI[16] explored the value of and defined an approach to integrating ITS into work zones in Texas. Results of various ITS work zone implementations have been shown to positively impact work zones by reducing queues, reducing speeds, reducing crashes, and providing route guidance information to drivers.[17]

Some of the documented successes from smart work zones include the following:

1. Reductions in queue lengths of about 60 percent are possible;
2. Fifty to 85 percent of drivers surveyed changed their routes based on work zone ITS messages;
3. Speed monitoring displays reduced speeds in the range of 4-6 mph and reduced the number of speeding vehicles from 28 to 78 percent.

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[16] *Use of Intelligent Transportation Systems in Rural Work Zones*, Texas Transportation Institute, Texas A&M University System, Report No. 0-6427-1, Middleton, Dan, Brydia, Robert, Pesti Geza, Songchitruksa, Praprut, Balke, Kevin, and Ullman, Gerald, August 2011.

[17] USDOT, *Intelligent Transportation Systems for Work Zones*, Washington DC. USDOT FHWA, 2007. FHWA-JPO-07-003.

Smart work zones can also improve driver behavior. For example, dynamic lane merge systems help reduce driver confusion at merge points and reduce aggressive driving and turbulence.[18] Typical work zone ITS applications can include the following:

1. DMS – portable or permanent.
2. Highway advisory radios – portable (site specific) or permanent.
3. Over-height detection systems.
4. Intrusion detection systems.
5. Portable signal systems.
6. Speed detection and display.
7. Speed violation and deterrent systems.
8. Speed violation and enforcement.
9. Variable speed limit systems.
10. Automated flagger assistance.
11. Flashing stop/slow paddles.
12. Project information websites.
13. Dynamic lane merge systems.
14. Queue detections systems.
15. Work zone integration into a Transportation Management Center (TMC).

In this investigation, the NJTA used permanent overhead DMSs, a 511 call system, project websites, and variable speed limits. Although not in use at this location, the authority does require queue detection systems at some locations.

8.2 Specific Smart Work Zone Treatments

The TTI research project reviewed relevant recent literature and paid particular attention to studies evaluating the following:

1. The benefits of using ITS in work zones.
2. Various merge control strategies in advance of work zone lane closures.
3. Variable advisory and posted speeds.
4. Dynamic queue warning systems.

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[18] *Intelligent Infrastructure*, *Roadway Operations and Maintenance, ITS Benefits, Costs, Deployment, and Lessons Learned*, FHWA, USDOT, Washington, DC. 2008 update.

8.2.1 Early Merge Control

Early merge strategies encourage drivers to merge into the open lane farther in advance of the lane closure; they can consist of static or dynamic early merge systems. Static early merge systems consist of additional signage posted at 1-mile intervals several miles in advance of the lane closure. These reduce the potential for merge-related crashes and rear-end crashes by alerting drivers farther in advance of the lane closure. Simulation studies indicated that early merge control strategies significantly reduced the frequency of forced merges but increased travel times through the zone.[19] Vehicles are more likely to be delayed over greater distances by slower vehicles ahead of them in the open lane. This may in turn increase the likelihood of drivers' attempting to use the discontinuous lane to pass slower vehicles, which could increase the potential for lane-change accidents.

Dynamic early merge systems can provide warnings over variable distances based on real-time measurements of traffic conditions. Again, heavier congestion and longer queues can develop when these systems are used during heavy peak flows. An example of an early merge dynamic merge control plan used by Indiana is shown below.

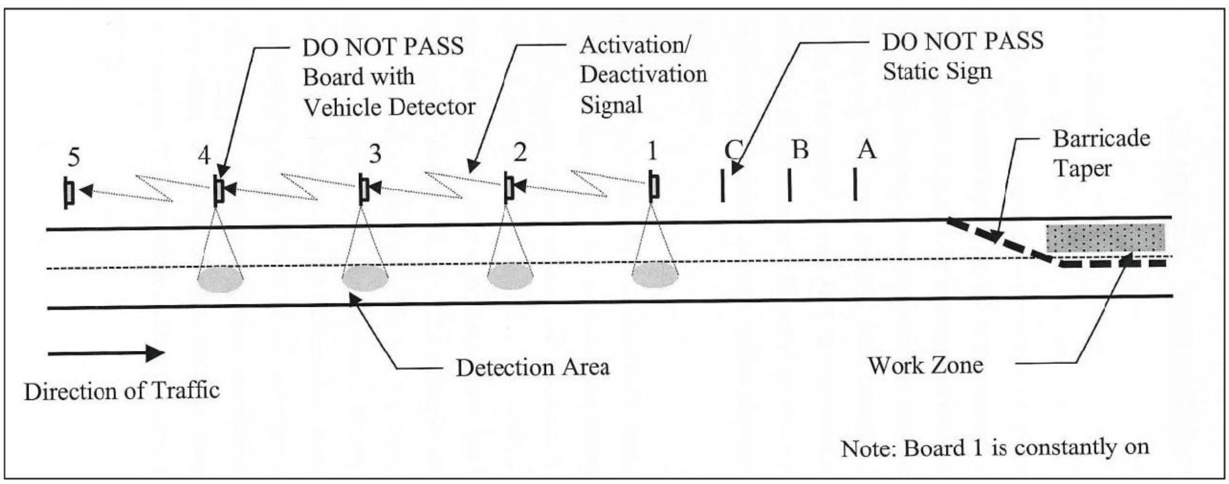

Figure 5.

As the traffic backs up, the vehicle detectors warn traffic not to pass at farther distances back from the merge point.

Another strategy is late merge control, which encourages vehicles to occupy both lanes up to a designated point rather than causing early merging. An example used by the Pennsylvania DOT is shown below.

[19] Nemeth, Z.A., and N.M. Rouphail. "Lane Closures at Freeway Work Zones: Simulation Study." Transportation Research Record No: 869, TRB, National Research Council, Washington, DC.

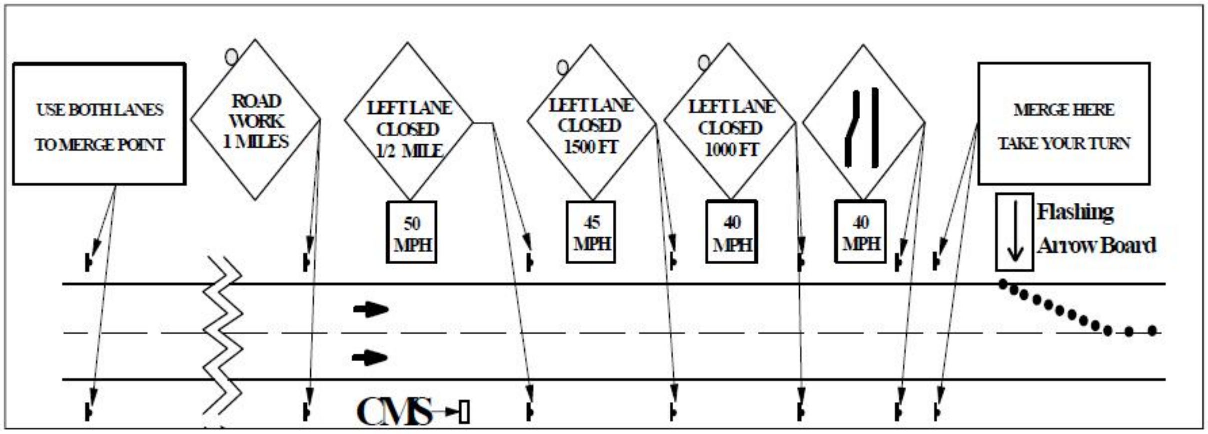

Figure 6.

The advantage of this system is that it allows drivers to use the lane with the shortest queue, up to a designated point. Also, dynamic lane merge systems with vehicle detectors have been used in Maryland, as seen in the figure below.

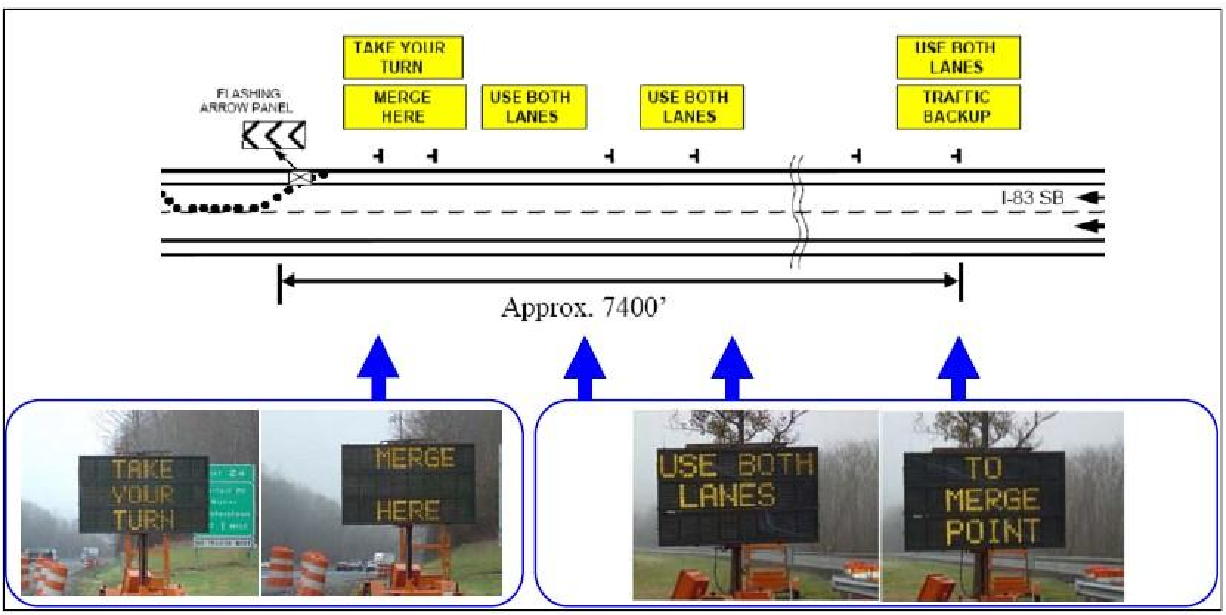

Figure 7.

Numerous studies found that rear-end collisions are the most frequent types of crashes on freeway facilities, especially at work zones.[20,21] Several human factors studies concluded that

[20] National Transportation Safety Board, 2001. *Vehicle-and Infrastructure Based Technology for the Prevention of Rear-end Collisions*. Special Investigation Report NTSB/SIR-01/01. Washington, DC. Available: http://www.ntsb.gov/Publictn/2001/SIR/0101.htm.

[21] Battelle Transportation Systems. "Precursor Systems Analyses of Automated Highway Systems," *AHS Roadway and Analysis*. Report No. FHWA-RD-95-043, October 1994.

drivers approaching the end of queues often have poor perception of the time and distance needed to decelerate safely to a stop. A research project conducted in Texas[22] observed between 1 and 16 hard-braking maneuvers per 1,000 approaching vehicles at two work zone sites. A Canadian study determined that drivers were usually aware of approaching slow vehicle queues, but in cases of large speed differentials (over 25 mph), they often had poor perceptions of how quickly they could slow down before getting too close or colliding with slower vehicles ahead. A TTI report[23] provided a comprehensive list of published research in this area.

Providing effective advance warning to drivers approaching slow or stopped traffic queues requires an understanding of queue dynamics. The appropriate number and spacing of detectors and warning message signs depend on a number of factors, including queue characteristics, (e.g., maximum queue length and shockwave speed or how quickly the queue builds backwards toward approaching traffic) and roadway geometry. Queue characteristics can be measured in the field or estimated using simulation models for operating speed, traffic volume, and lane configurations. When traffic demand or volume exceeds capacity, shock waves may propagate upstream of the warning. An Iowa study[24] of rural interstate work zones with lane closures determined shockwave speeds as high as 30-40 mph.

8.2.2 Active Speed Warning and Queue Detection Systems

Active Speed Warning Signs (ASWS) were evaluated at a construction zone on I-80 near Lincoln, Nebraska.[25] The system consisted of three speed monitoring displays equipped with radar units. They were displayed at ¼-mile increments in advance of the work zone lane closure. The radar units measured the speed of downstream traffic, and the speed messages displayed were intended to warn drivers of stopped or slow-moving traffic ahead. Figure 8 below shows the speed display and its effect on average speed.

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[22] Ullman, G.L., M.D. Fontaine, S.D. Schrock, and P.B. Wiles. *A Review of Traffic Management and Enforcement Problems and Improvement Options at High-Volume, High-Speed Work Zones in Texas*, Research Report 0-2137-1. TTI, College Station, Texas. February 2001.
[23] Wiles, P.B., S.A. Conner, C.H. Walters, and E.J. Pultorak. *Advance Warning of Stopped Traffic on Freeways: Current Practices and Field Studies of Queue Propagation Speeds*, Research Report 0-4413-1. TTI, College Station, Texas. June 2003.
[24] Maze, T., S.D. Schrock, and A. Kamyab. "Capacity of Freeway Work Zone lane Closures, Proceedings, Mid-Continent Transportation Symposium 2000," Center for Transportation Research and Education, Iowa State University, Ames, 2000.
[25] Pesti, G. *Alternative Way of Using Speed Trailers: Evaluation of the D-25 Speed Advisory Sign System.*

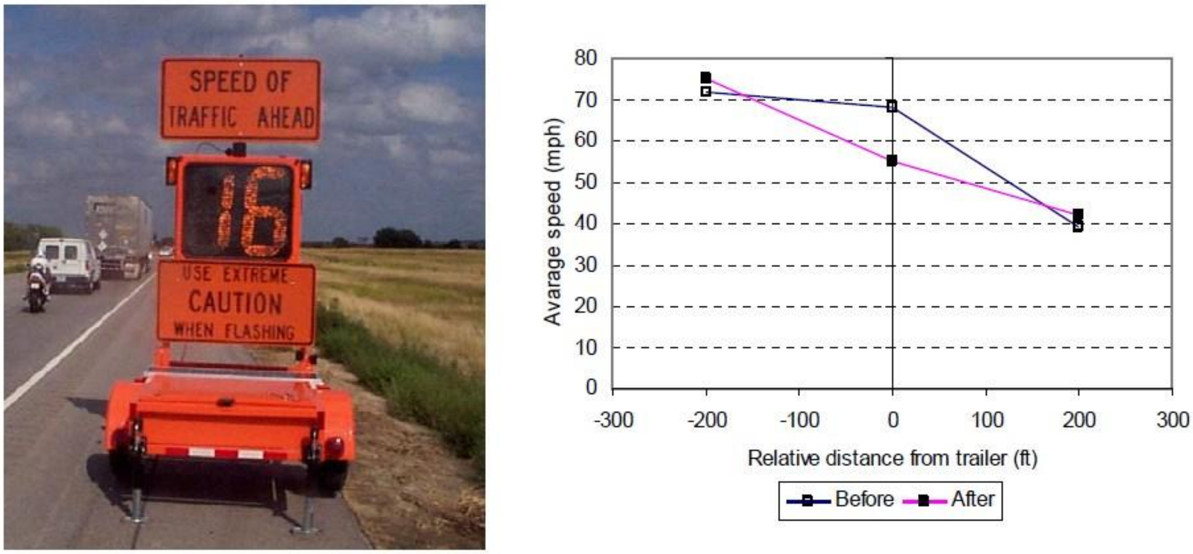

Figure 8.

The results of the analysis showed that the speed messages were effective in reducing the speed of vehicles approaching queued traffic. The change in mean deceleration due to the speed advisory system was statistically significant at the 95-percent confidence level.

The University of Michigan developed and evaluated a Work Zone Safety System for adaptive queue warning.[26] It was a distributed queue-warning system that automatically adapts to the traffic flow situation within and upstream of the work zone. Figure 9 below illustrates the concept of the adaptive queue-warning system.

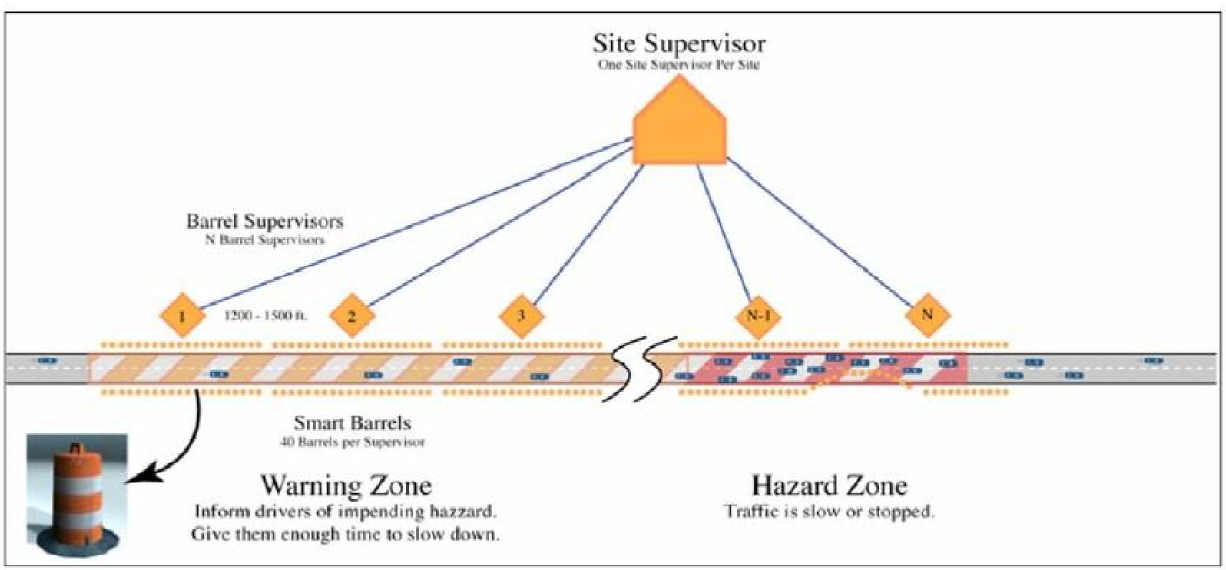

Figure 9.

[26] Sullivan, J.M., C. Winkler, and M.R. Hagan. *Work-Zone Safety Intelligent Transportation Systems: Smart Barrel for an Adaptive Queue-Warning System*. FHWA Report Number: UMTRI-2005-3, Washington, DC, 2005.

A core component of the system is the so-called "smart barrel" (i-cone). The smart barrel is a typical orange traffic-control barrel equipped with an inexpensive speed sensor; a simple, adjustable signaling system; and the necessary equipment for communication to a central controller. The Michigan study prototyped and tested a simple signaling scheme using a series of pole-mounted warning lights in a driving simulator, as illustrated in figure 10.

Driving simulator results indicated that drivers find adaptive systems more helpful than static road signs. Analysts observed systematic positive change in driving performance, which indicates enhanced safety. The technology shows promise in addressing problems of work zone rear-end crashes.

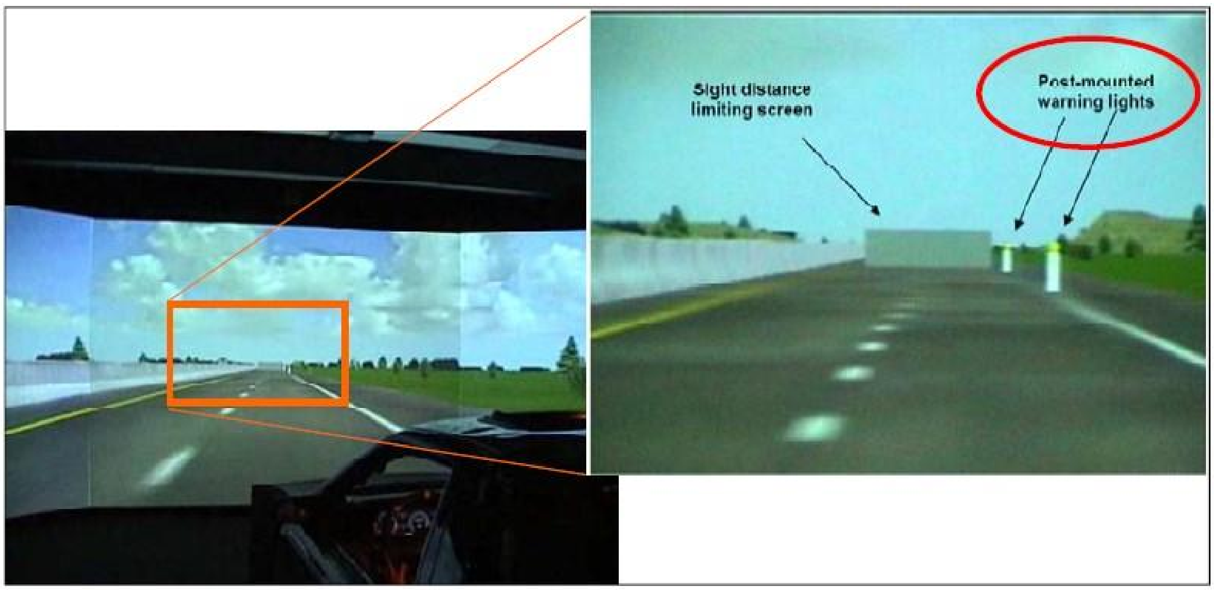

Figure 10

Another speed advisory system found in the Minnesota DOT's Intelligent Work Zone tool box is shown in figure 11.

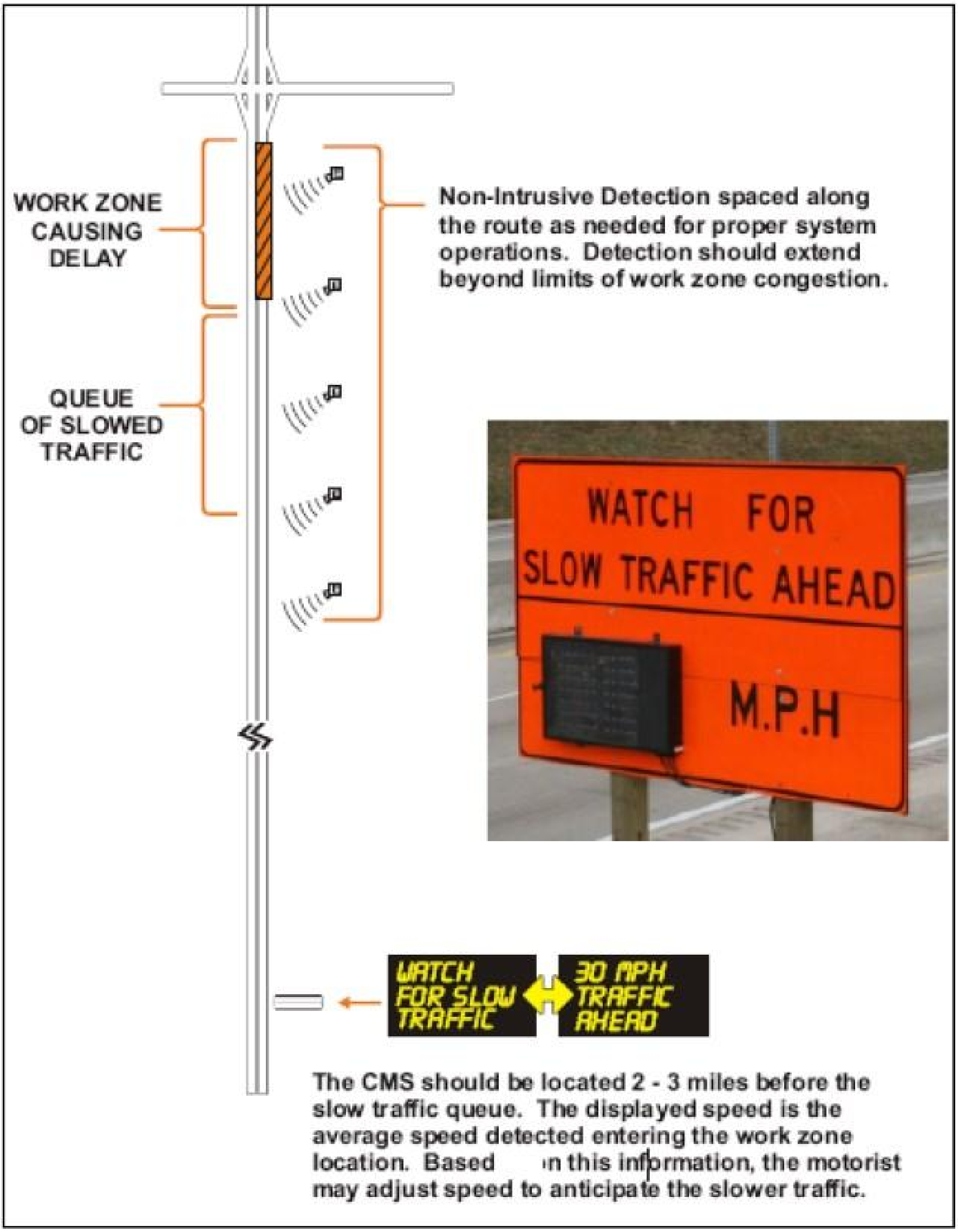
WORK ZONE CAUSING DELAY
QUEUE OF SLOWED TRAFFIC
Non-Intrusive Detection spaced along the route as needed for proper system operations. Detection should extend beyond limits of work zone congestion.
WATCH FOR SLOW TRAFFIC AHEAD
M.P.H
WATCH FOR SLOW TRAFFIC
30 MPH TRAFFIC AHEAD
The CMS should be located 2 - 3 miles before the slow traffic queue. The displayed speed is the average speed detected entering the work zone location. Based on this information, the motorist may adjust speed to anticipate the slower traffic.

Figure 11.

Minnesota uses a similar dynamic sign set-up to warn of stopped traffic ahead. See figure 12.

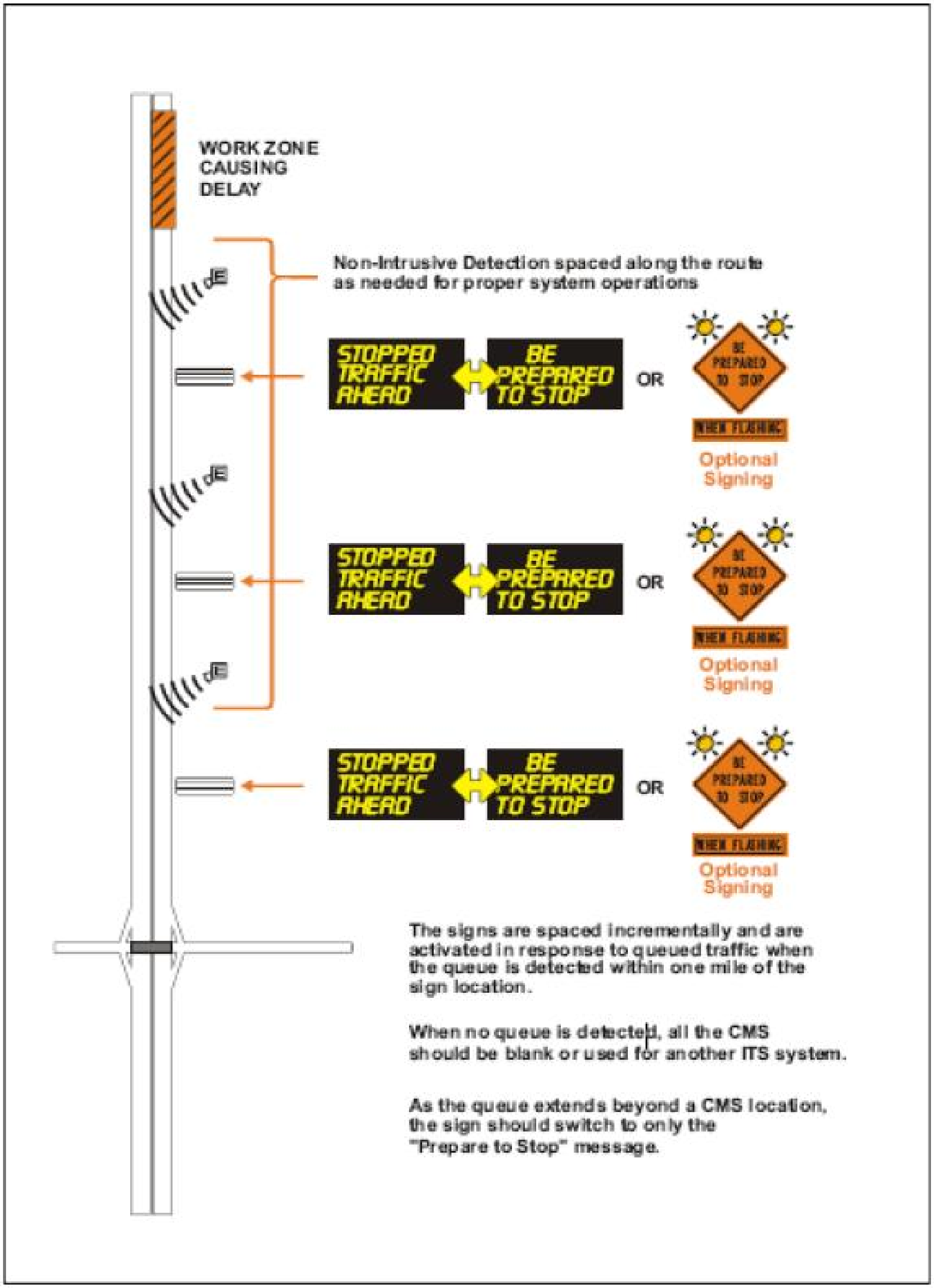

Figure 12.

Researchers examined another ITS project implemented by the Texas Department of Transportation (TXDOT) in October 2006 on I-35 near Hillsboro, Texas. The purpose of the system was to monitor traffic conditions and improve mobility and safety along I-35W, I-35E, and I-35 to the south of the split. Figure 13 shows the Hillsboro area and indicates the work zone.

Figure 13.

I-35 splits north of Waco into I-35E to Dallas and I-35W to Fort Worth. All three roadways are freeways with four lanes, two in each direction, and are otherwise similar. The work zone project was 10 miles in length, began construction in July 2006, and was scheduled for completion in mid-2008. The system provided real-time delay information to motorists based on predetermined speed and occupancy thresholds and recommended alternate routes via DMSs. Three wireless closed circuit cameras provided imagery for monitoring traffic by TXDOT.

The work involved reconstructing the main interchange and rehabilitating the pavement and structures along the route. Lane closures were involved, reducing the capacity of the roadway. TXDOT expected long queues and delays, especially along southbound I-35W upstream of the split. Much of the traffic was commuter traffic.

The system consisted of the following components:

1. Six solar-powered portable microwave detection trailers (sidefire orientation).

2. Six solar-powered PCM signs.

3. Three portable video trailers (with cameras).

4. A system server, web host, and associated software and equipment.

5. A website for use by the general public and TXDOT.

Two sensors monitored traffic on each approach to the work zone and sent messages to two PCM signs, based on predetermined speed and occupancy thresholds. TXDOT had the ability to do the following:

- Dynamically adjust queue thresholds,
- Preempt messages, and
- Alert appropriated personnel if problems occurred.

Objectives of the ITS system included the following:

- Provide delay information and route guidance to motorists,
- Reduce demand and congestion by diverting traffic as needed, and
- Provide trip planning information to commuters and management information to TXDOT.

Objectives of the evaluation included the following:

- Determine traveler response to work zone information,
- Determine the effect of traveler response to traffic conditions, and
- Determine whether the system detected congestion in real time and posted appropriate messages

The study team used diversion rates at freeway exit ramps as the primary measure of effectiveness to evaluate system effectiveness. During times of heavy congestion, motorists were more likely to follow diversion guidance posted on the message boards. The system demonstrated that it could detect congestion and display appropriate messages. Specifically, it posted travel times for free-flow conditions, SLOW TRAFFIC AHEAD and similar messages when speeds dropped, and diversion messages when occupancy met the desired threshold. TXDOT also develop a queue warning system for use on I-35. To evaluate the expected performance of the proposed queue warning system, the research team selected a freeway work zone with a nighttime lane closure from 7 p.m. to 8 a.m. The work zone was located on the southern boundary of an approximately 10-mile-long segment in the southbound direction of I-35 between Hillsboro and West, Texas. The work required closing the left-hand lane of the two-lane southbound freeway. The traffic was modeled using the traffic simulation software VISSIM. The simulation replicated the speed sensors of the queue warning system by placing virtual detectors every ½ mile upstream of the work zone entrance point up to Hillsboro. Every virtual detector could be activated or deactivated during simulation, making it possible to study the impacts of different detector spacings.

The simulation used an average daily traffic of 69,000 vehicles per day with a truck percentage of 37 percent. Figure 14 shows the hourly distribution of traffic volumes, and the estimated capacity was 1,285 vehicles per hour per lane.

Hour	19-20	20-21	21-22	22-23	23-24	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
Volume (vph)	1690	1449	1241	1034	828	620	517	448	448	517	758	1104	1414

Figure 14.

Figure 15 shows a plot of the queue lengths over the entire period of the simulated nighttime work zone lane closure. The unit of measure is feet, and the distance is measured from the lane closure upstream. The maximum queue length was 2.4 miles, and most of the queueing was between 7 p.m. and midnight.

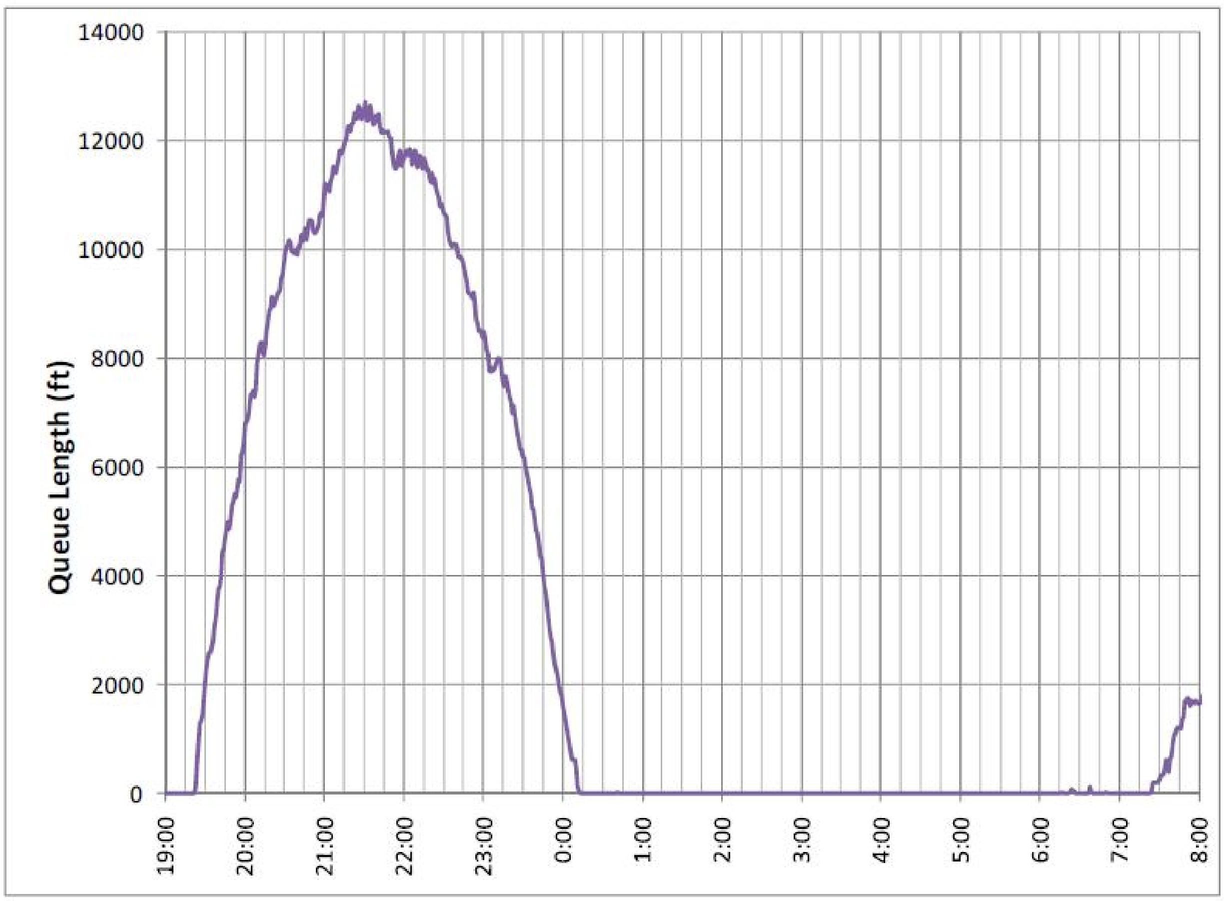

Figure 15.

Based on the findings of the simulation, the research team recommended the queue warning system design parameters summarized in figure 16.

Design Parameter	Recommended Value
Speed threshold for STOPPED TRAFFIC	35 mph
Speed threshold for SLOW TRAFFIC	55 mph
Detector spacing	½ mile
Speed aggregation interval	5 minutes
PCMS message update interval	1 or 5 minutes
PCMS distance upstream of lane closure	1–2 miles upstream of the longest expected queue

Figure 16.

Once the operational characteristics of the work zone queue are understood through simulation, the number and spacing of detectors can be established. Figure 17 shows an example of the system with detector spacings.

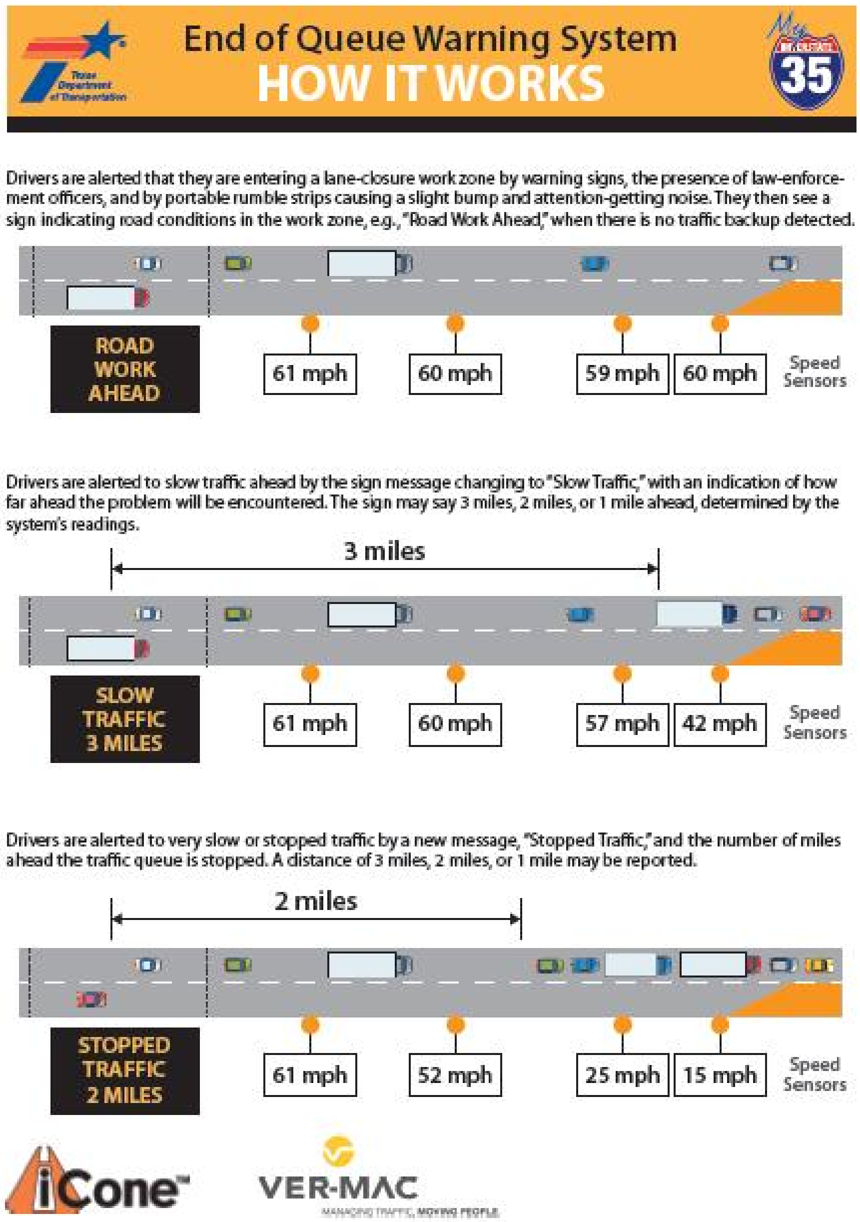

Figure 17.

In summary, smart work zones have been shown to be effective in reducing congestion, travel times, and accidents, but proper investigation of field performance or simulation must be undertaken to ensure that ITS is effective, just as in-field observations of more common static temporary traffic control devices are performed to ensure they are meeting needed objectives. Other common elements of work zone research are the human performance difficulties that drivers have discerning closure rates with slow-moving or stopped traffic ahead, especially at nighttime. These factors and consistent over-involvement of heavy trucks in work zone crashes over the past decades suggest much needed improvement. Presently, the MUTCD provides for the use of ITS in work zones in section 6A.01 support paragraph 09. The MUTCD states,

> "Operational improvements might be realized by using intelligent transportation systems (ITS) in work zones. The use in work zones of ITS technology, such as portable camera systems, highway advisory radio, variable speed limits, ramp metering, traveler information, merge guidance, and queue detection information, is aimed at increasing safety for both workers and road users and helping to ensure a more efficient traffic flow. The use in work zones of ITS technology has been found to be effective in providing traffic monitoring and management, data collection, and traveler information. No other design parameters, guidance or typical applications, or standards exist requiring ITS use."

E. DOCKET MATERIAL

The following attachments and photographs are included in the docket for this investigation:

List of Attachments

Attachment 1 Plans, Specifications and Estimates for Construction Contract

Attachment 2 Accident History Excel Spread Sheets

Attachment 3 Police Reports of Prior Fatal rear-end Accidents 6 to 9 Project

Attachment 4 New Jersey Turnpike Traffic Volumes

Attachment 5 New Jersey Turnpike Authority Road User Cost Manual

Attachment 6 NJTA Design manual and Traffic Control in Work Zones Manual

Attachment 7 NJSP Policy on Work Zone Oversight

Photographs (10)

Photograph 1 (SNO) South to North Outer Lanes at MP 70.2

Photograph 2 SNO MP 70.5 Where Work Zone Advanced Warning Began

Photograph 3 SNO MP 71 View of Outer Lanes

Photograph 4 SNO Approach to Accident Area MP 71.2

Photograph 5 SNO MP 72.1 View of Variable Speed Limit Overhead Sign Which Displayed 45 mph on the night of the accident

Photograph 6 North to South View (Opposite Direction) of Impact Area at MP 71.4 SNO

Photograph 7 View of Tire Marks in Impact Area

Photograph 8 Closer View of Impact Area

Photograph 9 East to West View of Guardrail Impact Damage

Photograph 10 SNO Lanes at MP 71.5 Showing Outer Lanes Open Both Directions With Inner Lanes Closed

//END OF REPORT//

David S. Rayburn

Highway Accident Investigator