Working Paper:

Identify Guidelines to Eliminate Driver Inattentiveness, Design Alternative Strategies and Techniques For Traffic Control

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TECHNICAL MEMORANDUM

Project 2003-27:
Identification of Traffic Control Devices for Mobile and Short Duration Work Operations

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ABSTRACT

This report documents and summarizes: Task 3- Identify guidelines to eliminate driver inattentiveness, and Task 4- Design alternative strategies and techniques for traffic control, for Phase II – Research Approach of the study, "Identification of Traffic Control Devices for Mobile and Short Duration Work Operations", for the New Jersey Department of Transportation. Task 3 was conducted by reviewing the technologies adopted by various DOTs and approved by SHRP for gaining driver's attention. Task 4 was carried out by looking into the practices of various DOTs and research being undertaken by various institutes for new and innovative techniques for traffic control.

Based on the literature search and field inspections of mobile and short duration work zones, interviews with NJDOT personnel and the literature search of the cause of work zone accidents, the following conclusions and recommendations are presented:

- Most NJDOT work zone crashes and careless driving, speeding and motorist inattention cause accidents, which are similar to the causes of crashes in work zones from the literature and other agencies.
- NJDOT mobile and short duration work zones meet the safety standards for design and application specifications for traffic control during highway maintenance by *Manual on Uniform Traffic Control Devices (*MUTCD).
- Safety devices should be selected to reduce traffic speed through work zones, improve motorists' recognition of work zone hazards, and improve motorists' attention to signs and the work zone.
- Any new safety devices for mobile and short duration work zones should be implemented in conjunction with worker safety training, and public safety and education programs.

The devices suggested for catching driver's attention and for traffic control in work zones meet NCHRP 350 testing standards. These devices should be evaluated using the latest technology and standards before procurement in Task 5 of Phase-2.

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INTRODUCTION

This report documents and summarizes: Task 3- Identify guidelines to eliminate driver inattentiveness, and Task 4- Design alternative strategies and techniques for traffic control, for Phase II – Research Approach of the study, “Identification of Traffic Control Devices for Mobile and Short Duration Work Operations”, for the New Jersey Department of Transportation. Task 3 was conducted by reviewing the technologies adopted by various DOTs and approved by SHRP for gaining driver’s attention. Task 4 was carried out by looking into the practices of various DOTs and research being undertaken by various institutes for new and innovative techniques for traffic control.

The objective of this research project is to study mobile and short duration work zone safety with particular attention to the identification of work zone safety devices catching driver’s attention, and recommendation of traffic control techniques to reduce delays and crashes due to work zones. The specific objectives are to:

- Identify state-of-the art work zone safety technologies to improve driver’s attention for worker safety in mobile work zone and short term maintenance operations.
- Identify devices for work zone traffic control to reduce delays and crashes.
- Identify “best practices” for the use of law enforcement to improve work zone safety.
- Identify key issues to be considered from public outreach and information systems.
- The identified work zone safety items will provide improvements for maximum protection of the motoring public; protection of exposed workers in the work zone and of workers in the set up of the work zone, and will meet the current standards established by internal policies of the NJDOT.

IDENTIFY GUIDELINES TO ELIMINATE DRIVER INATTENTIVENESS

General Nature of Work Zone Crashes

Past accident-based analyses have provided some knowledge of the general nature of work zone crashes. However, there is a continuing need for additional analyses of well-defined and more detailed accident data. Through better identification of the specifics of the work zone problem, it is hoped that, ultimately, work zone safety will be enhanced considerably. There is a continuing need for information on the number of vehicles involved, the type of crash and the manner of collision, vehicle maneuvers before the crash, and the first and most harmful events. If these general crash descriptors could be analyzed by zone type, such information would provide a better understanding of the extent to which a crash can be attributed to vehicle flow and the path provided to an individual vehicle. This analysis would be an initial step in setting priorities for treatment development and direction.

Analysis of work zone crashes

Work zone related crashes continue to increase every year across the nation, thus the safety of road users and workers has become a top priority for transportation agencies. Work zones tend to cause hazardous conditions for drivers and construction workers since they generate conflicts between construction activities and traffic. Numerous innovations in temporary traffic control materials and techniques have been developed and deployed in recent years.

Most studies[1-12] seem to indicate that the introduction of work zones lead to an increase in accident rates, although that pattern is dependent on traffic and geometric conditions, traffic control devices, length of work zone, weather, lane closure strategy and other aspects of the work zone environment. The increase in crash rate at work zones may be due to several reasons including disruption of traffic due to closed lanes, improper lane merging maneuvers by drivers, and inappropriate use of traffic control devices

Crash Frequency

Studies related to work zones revealed that crash rates at work zones were higher than at non–work zone locations. They also indicated that crash rates depend on the type of traffic control device used. In a construction zone crash study conducted by Hall and Lorenz[2], crashes during construction increased by 26 percent compared with crashes in the same period in the previous year when no construction. In another study involving short term and long term work zones on freeways, Rouphail[3] and others showed that the crash rates during construction increased by 88 percent compared to the “before” period at long-term work zones and the crash rates for short-term work zones were not affected by the road work. Garber and Woo[4] found that on average the crash rates at work zones on multilane highways in Virginia increased about 57 percent; on two-lane urban highways the increase was about 168 percent when compared with crash rates prior to the installation of the work zones. In a study conducted on all type of roads, Pigman and Agent[5] showed that crash rates during construction exceeded those in the before period at 14 of 19 sites. In another study conducted along rural interstates, Nemeth and Migletz[6] also showed that crash rates during construction increased significantly compared to the before period.

In studies[4,5,7,8,9] involving work zones along two-lane highways, the use of a combination of cones, flashing arrows, and flaggers on multilane highway work zones and a combination of cones, flaggers, or 4 static signs and flaggers resulted in the fewest crashes whereas the use of flaggers at urban work zones resulted in the fewest crashes.

Crash Severity

Studies[4, 7] concluded that work zone crashes were more severe than other crashes, involving a high number of worker fatalities. The average work zone crash was more severe than the average crash in terms of the number of vehicles involved and average property damage.

Crash Location

The location of crashes is an important aspect in analyzing for suitable countermeasures and devices to be adopted for the type of crash. Several studies addressed the locations of crashes in work zones. Two studies found that most crashes occurred in the work area (combining the longitudinal buffer and activity areas). Nemeth and Migletz[6] found that 39.1 and 16.6 percent of accidents occurred in the longitudinal buffer area and in the activity area, respectively at single-lane, crossover, and bi-directional zones (two-lane two-way operation).

From the studies[1-12] conducted related to work zone crashes, it is concluded that the activity area was the predominant crash location, followed by the transition area, the advance warning area, the longitudinal buffer area, and the termination area. The Typical work zone is shown in Figure 1. Figure 2 shows a graphical representation of results obtained based on crash location on work zones.

Figure 3 shows a pie chart that represents the distribution of work zone crashes by road type. Although the highest percentage of work zone crashes occurred on urban interstate highways, it cannot be concluded that these highways are more susceptible to work zone crashes, as these crashes were not normalized for traffic volumes or for the number of work zones on each type of road. The data that would be required for such an analysis was not reported in the literature.

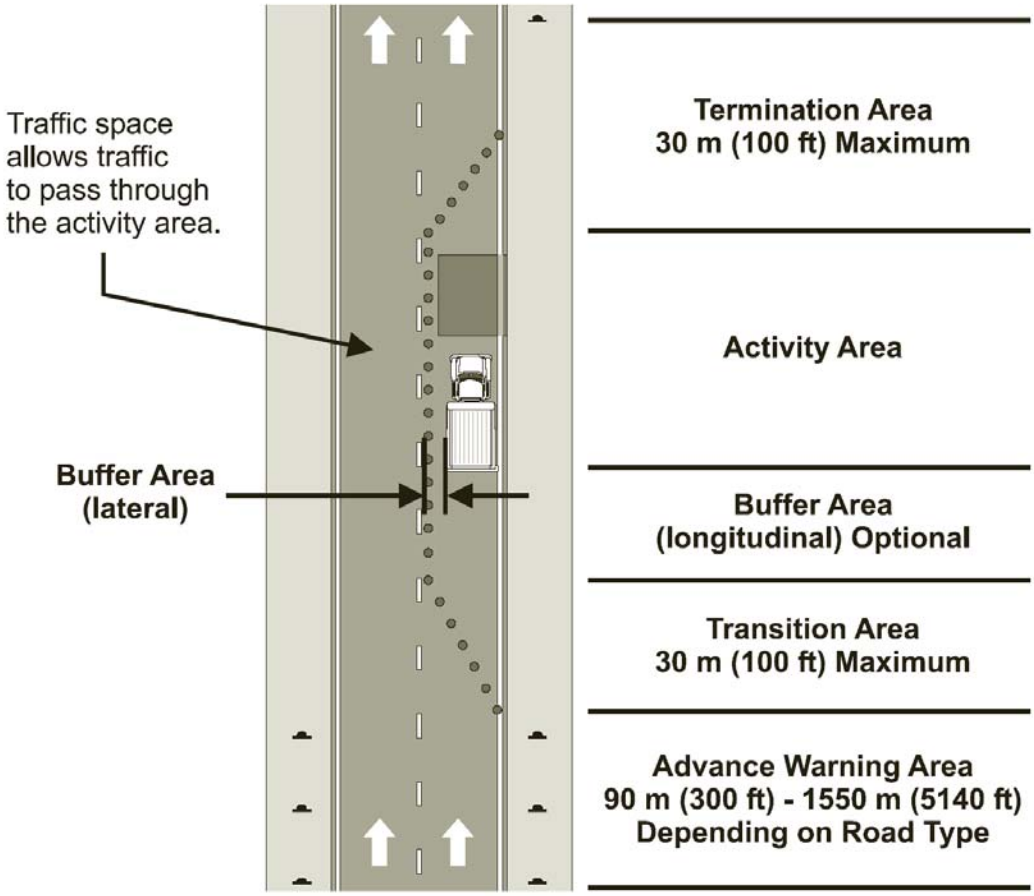

Figure 1: Components of a Work Zone

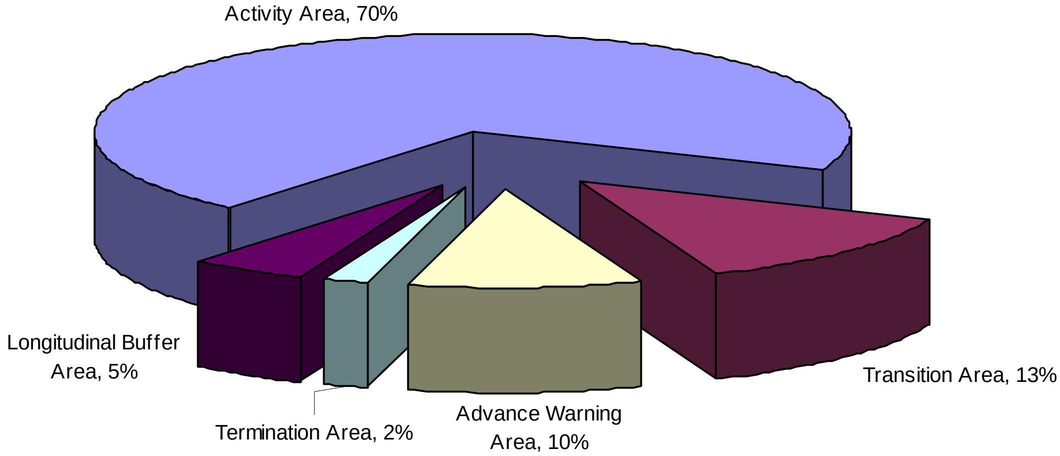

Figure 2: Location distributions of Work Zone Crashes

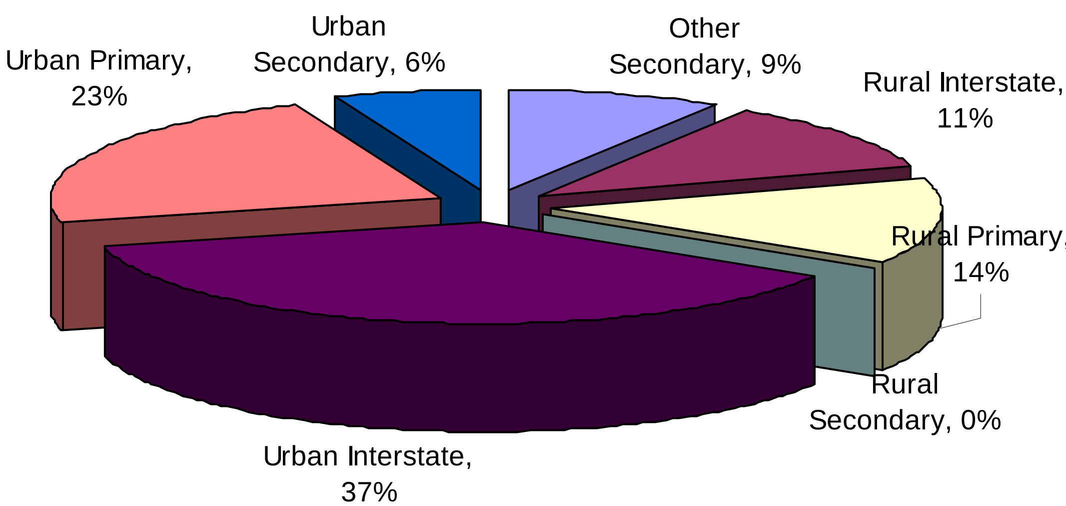

Figure 3: Road type distributions for all work zones

In a recent study conducted by Garber and Ming[1], the results indicate that the activity area was the predominant location for work zone crashes regardless of highway type and that rear-end crashes were the predominant type of crash. The results also indicated that the proportion of sideswipe same direction crashes in the transition area was significantly higher than in the advance warning area and that work zone crashes involved a higher proportion of multi-vehicle crashes and fatal crashes.

Crash Type

The results of several studies indicated that rear end crashes were the predominant collision type in work zones. Richards and Faulkner[12] found that rear-end accidents account for 40 percent of accidents reported in work zones. They attributed this to slowing among preceding vehicles. Single-vehicle, fixed object accidents were the second highest, representing over 15 percent of all accidents reported in work zones. Pigman and Agent[5] found that, as suspected, work zone crashes involving heavy vehicles were more severe than those in which heavy vehicles were not involved. Pigman and Agent also found that crashes during darkness were more severe, whereas Nemeth and Migletz[6] found that crashes during daylight hours were more severe than those at night or at dawn and dusk and that single-vehicle crashes were predominant at night. Two studies concluded that nighttime crashes were especially concentrated in the transition area.

A summary of major studies conducted on crash characteristics and coverage of crash characteristics are tabulated in Table 1 and Table 2 respectively.

Table 1. Major Studies Concerning Crash Characteristics

Ref	Year	Duration	Length or Number of sites	Number of Crashes	State	Road Type
5	1982-85	Average 255 days	168 projects, 172 sections, 1045 mi	631	New Mexico	Rural section of interstate and federal-aid primary
6	1980-85	N/A	4 long-term,25 intermittent or	N/A	Illinois	Chicago area expressway system
7	1982-85	Generally longer than	26 sites	N/A	Virginia	Urban 2-lane, 3-lane highway with 4 or more lanes
8	1983-86	4 yr	N/A	2013	Kentucy	All
9	1973	Mostly within 1 yr	21 sites,384 mi	151	Ohio	Rural Interstates
10	1984-85	2 years	N/A	N/A	Virginia	All
11	1982-86	N/A	All,then 60,then 9 projects	N/A	Ohio	All
12	1977	1yr	N/A	1847 of 2127 selected	Virginia	All

Table 2. Coverage of Crash Characteristics in Various Studies

Subject	Ref. Results	Remarks
Crash Rates	5,6,7,8,9 increase after before period	Crash rates increase in work zones
	7,10 higher at work zones	
Crash Location	5,13,15 most occurred at activity area or combined longitudinal buffer and	Activity area is the predominant location of crashes
Rear End Crashes	4-15 : predominant collision type	Rear end crashes are the frequent type
Multiple Vehicle crashes	4-15: overrepresented at work zones	
Crash Severity	8,11 more severe at work zones	
Crash Severity at night time	8: more severe than daytime	
Severity of crashes involving heavy vehicles	8 more severe	
Collision type distribution	12: fixed object crashes	

Technologies to Reduce Crashes in Work Zones

A1998 report by the Federal Highway Administration[13], noted that the two leading causes of work zone crashes are excessive speed and driver inattention. Further, it noted that there is universal agreement that the most effective way of controlling speed in the work zone is to have a staffed police car with flashing lights at the onset of the work zone. Drivers detect the presence of police either visually or via radar detectors and reduce their speed to comply with the posted work zone speed limit. The reduced speeds and reduced variation in speeds result in fewer accidents or less severe accidents and minimize dangerous interactions between vehicles and workers and equipment.

Traffic control devices used in work zones should strictly follow the MUTCD requirements. Shielding the activity area in a work zones can be done using devices such as Balsi beam, traffic cones, and portable barriers. Additional protection of work zones can be done using intrusion alarms, rumble strips, truck mounted attenuators and effective advance warning signs such as –“Be Prepared to Stop”, - “Shoulder work Ahead”, -“Work Zone Approaching” which would draw driver attention. Warning drivers of queues ahead is another method of preventing crashes caused by vehicles following too closely. Devices such as queue detectors combined with changeable message signs could warn drivers well in advance.

A thorough literature search was conducted using all the available resources for identifying devices and technologies, which are effective in catching driver’s attention. Among various techniques that are being employed by various DOTs, intrusion alarms and portable rumble strips which are the most widely used devices.

Rumble Strips

In an effort to promote safer conditions in work zones, the Kentucky Transportation Center[33], in conjunction with the State of Kentucky and the

Federal Highway Administration (FHWA), sponsored a project to demonstrate the use of the portable rumble strip at maintenance work zones across the State. When drivers feel the vibration and hear the sound caused by the portable rumble strip, they are given a final reminder that they are about to enter a temporary work area.

Developed by the Strategic Highway Research Program (SHRP), the portable rumble strip is placed across the road about 100 m (250 ft) in advance of the work zone. The device causes a vibration in the steering wheel and a rumble as vehicles pass over it, warning drivers that conditions on the road will soon become dangerous. The portable rumble strip is best suited for low-speed roads that carry few heavy trucks. The portable rumble strip is also easy to use. The device weighs about 34 kg (75 lb), and one or two workers can deploy it from the back of a pickup truck.

A number of studies have demonstrated the benefits of shoulder rumble strips in reducing death and serious injury caused by inattentive drivers in Run-off-road (ROR) crashes. The methodologies used in these effectiveness studies and their results vary from state to state, but all show some measure of crash reduction attributed to the presence of shoulder rumble strips.

Intrusion Alarms

Drivers sometimes fail to notice the signs, cones, and other warnings that they are approaching a highway work zone. Intrusion alarm developed under the SHRP[34] provides safety to workers in the work zone either by audio or visual means, when a motorist intrudes into the work zone. State of Vermont is using these alarms to inform the workers well before the danger. Example of audio intrusion alarm is a flashing strobe light, which activates as soon as a driver by mistake enters in the danger part of a work zone. The biggest benefit is that the workers get few seconds to clear out of danger way.

After testing two models of the work zone intrusion alarm, Vermont AOT's research unit purchased a model that uses an infrared beam sent from a transmitter unit to a receiver unit that also houses the siren. When a vehicle breaks this beam, the siren goes off. The research unit picked this model because it was the fastest and easiest to set up.

Criteria for Device Functionality

These evaluation criteria for certain devices will provide assistance in selecting appropriate traffic control devices for worker safety, and the safe and efficient movement of traffic through mobile and short duration work zones. From the devices and equipments identified in the literature report and, depending on the utility and effectiveness, the device functionality can be classified into five categories as follows:

Reduce exposure

Along work zones, the changing driver habits and traffic patterns cause safety concerns. The device should keep the road users and workers safe, while at the same time inhibiting traffic flow as little as possible. The ultimate goal of this criterion is to prevent worker injuries, motor vehicle accidents, and personal injury to motorists and/or pedestrians.

Warn motorists/crew

Maintenance crews in short-term work zones have a frightening job. Short-term/mobile work zones present special challenges in providing safe conditions for work crews. In short duration or mobile work zones, which are only in one place for a short period of time, motorists have very little chance to develop any expectations about the presence or layout of the work zone. Workers must perform their repair work while on constant alert for drivers who disregard or fail to notice the warning signs to slow down. This study is attempting to identify devices that would effectively alert drivers to work zone conditions and motivate them to change the way they drive within the work zone. The traffic control devices should be able to warn as well as minimize the likelihood of crash in order to improve worker and driver safety.

Minimize severity

An effective traffic control device in a short-term work zone must be easy to set up and remove without compromising the safety of the workers. Even though no one device can eliminate all, using devices that could absorb the major impact and reduce exposure to workers can minimize crash severity. Truck mounted attenuators; crash cushions and balsi beam can serve as devices, which satisfy this criterion. The devices should also provide sufficient visibility to gain driver attention.

Provide separation

Separating traffic from work activities by the use of temporary traffic barriers, shadow vehicles with truck-mounted attenuators, or similar devices minimizes risk for both workers and travelers. The need for positive separation should be based on work zone factors including:

- Traffic speed and volume
- Distance between workers and traffic
- Duration and type of work operations
- Physical hazards present

Improve work zone visibility

Visibility issues for motorists approaching and driving through highway work zones is a major concern. Ninety percent of a driver's reaction depends on vision, and vision is severely limited at night or in inclement weather conditions. Depth perception, color recognition, and peripheral vision are all compromised after sundown. Conditions such as fog, rain, snow and dusk also hinders visibility to drivers, therefore decreasing worker safety. Therefore it is important to provide good visible traffic control devices and sufficient lighting to the work zones.

Traffic control devices and delineation treatments need to be effective in meeting the needs of motorists on various types of highway facilities under various traffic and lighting condition. Lighting should be used on traffic control devices such as flashing lights or arrow panels. Drivers and workers must control glare so as not to interfere with the visibility of the work zone.

The work area and its approaches should also be lighted to provide better visibility for drivers to safely travel through the work zone. Illumination should be provided wherever workers are present to make them visible.

DESIGN ALTERNATIVE STRATEGIES AND TECHNIQUES FOR TRAFFIC CONTROL

Technologies

Workers in rural short-term maintenance work zones are placed in a particularly hazardous position. Short-term and mobile maintenance work zones are typically located on high-speed roads; with traffic control installed each day in the morning and removed by dusk. Since these work zones are in place only for a short time, drivers do not expect to encounter them. Regulatory speed limits cannot be lowered at the sites, and it is difficult to get law enforcement agencies to regularly patrol temporary work zone sites in rural areas. Studies conducted at work zones evaluated a large number of innovative traffic control devices that had the potential to improve safety in short-term work zones. Researchers examined countermeasures that would increase driver awareness of the upcoming work zone, make workers more visible, or slow down traffic. Since these work zones were in place only for a short time, it was also essential that each device be easily set up and removed.

Flashing Lights

Research sponsored by the Texas Department of Transportation (TxDOT) and conducted by the Texas Transportation Institute (TTI) [35] has revealed helpful techniques that improve safety for workers and increase visibility of work zones for motorists. In a general scenario, the indication of a work zone ahead is given to the drivers by flashing yellow warning signals or a sign telling to move from one lane to the other. A new method of warning drivers of approaching work zones is proving to be safer and easier to understand from greater distances. The approach was developed as a part of a TTI research project that was sponsored and implemented by TxDOT. It utilizes a series of synchronized flashing lights attached to the drums that form a lane closure taper. The flashing lights illuminate in a sequence from the beginning to the end of the taper. According to closed-course studies at TTI's Riverside Campus in College Station and roadway tests in Houston, drivers responded more positively to the synchronized flashing light system than to the normal traffic control setup used at construction sites in Texas. It was also found that as the synchronized flashing warning light system was activated, there was a one-fourth reduction in the number of passenger vehicles 1,000 feet before the lane closure taper.

Dancing diamonds (lights)

In this context, it is also pertinent to discuss here arrow panels consisting of a matrix of lights. Non-directional arrow panel displays are designated as caution displays. Before 2001, literature lacked significant statistical support for any one type of caution display. A 2001 Oregon Department of Transportation (ODOT) [36] study suggested that the + ACI-dancing diamonds are better than the other caution displays like flashing box. ODOT also found that local citizens preferred the dancing diamonds to other caution displays. However, additional research was needed to confirm these findings.

To evaluate the effectiveness of the dancing diamonds and +ACI- flashing box+ACI- displays, a field experiment was conducted. The results of this experiment showed that the dancing diamond was associated with a statistically significant 3 km/h (2 mph) reduction in mean speeds, whereas the flashing box display was associated with no statistically significant reduction in mean speeds, indicating that the dancing diamonds prompt safety near highway work better than the flashing box.

Rotating lights / Strobe Lights

This comprehensive research report published by TRB was developed due to the growing concern of increasing frequency of hazards during moving and short-term work zone operations. The research was very thorough and effective in a way that it encompassed different possible formations of mobile maintenance operations. Eleven categories of short-term and moving work zones contained corresponding traffic control devices, vehicle warning light systems and driver actions respectively. Though studies supported traffic control devices (TCD) applications and guideline development, it was also found that accident reduction was the ultimate measure of device effectiveness.

This research mainly focused on human response to warning lights varied by the type of light both in closed field and operational tests. It was found during research that no one light is maximally effective in both transmitting information and gaining attention. The reason for this was that rotating and strobe lights, which were effective in getting driver's attention, were not as useful in providing speed and closure rate information especially when the service vehicle was stopped. Conversely flashing lights, which worked really well for giving speed info, were not effective in providing clear clue of working zone to drivers from long distances. Therefore several of the lighting recommendations combine the two types of light in order to ensure optimum information transmission and conspicuity.

Apart from the findings related to different types of lights functioning's, cost benefit analysis was developed to aid in making some of the decisions. Some of the devices like shadow vehicles were found to be very effective in producing desired results but involved substantial costs as well. Therefore separate cost-effectiveness criteria were included as a basis for agency-specific decisions regarding its use.

Advanced Warning Signs

The Virginia Department of Transportation (VDOT) [37] is continuously striving to improve the flow of traffic as well as to protect workers and motorists in work zones. By using an advanced warning sign that is easily understood by motorists, both motorists and workers benefit. VDOT and several other state departments of transportation have expressed interest in modifying the advanced warning signs for work zone operations. The advanced warning sign is intended to alert drivers and to prepare drivers to stop (if necessary) prior to reaching work zone operations.

For example the construction vehicle sign warns drivers that the truck they are following is a construction vehicle and may leave the lane to enter an active work area.

Flashing arrow boards warn drivers that the lane they are traveling in is closing ahead and a lane change is required. The arrow direction will indicate which lane is open for travel.

Similarly, when only the four corners of the board are flashing, drivers must use caution, but do not change lanes. This light pattern is also used when work is on the shoulder of the roadway.

Variable Message Signs

Highway maintenance projects[38] create difficulties for highway workers and motorists alike. Project crews work just steps away from passing traffic, usually separated by only a line of plastic barrels or cones. Motorists must navigate changing traffic patterns, which can cause delays and frustration. They also face an increased risk of rear-end collisions caused by sudden changes in travel speed.

It's not that motorists haven't been warned to slow down as they approach the work zone; rather, many motorists fail to heed the warnings because they find the signs unreliable. They've seen too many "Slow" and "Work Zone Ahead" signs that are still in place after the crews have gone home, or variable message signs whose messages do not reflect current traffic conditions.

Several manufacturers are working to solve this problem by developing systems that use variable message signs to display messages based on real-time measurements of traffic conditions. One such system is *Adaptir (Automated Data Acquisition and Processing of Traffic Information in Real-Time)*, a technology developed by the Scientex Corp. with support from the Federal Highway Administration (FHWA) and the Maryland State Highway Administration.

The Adaptir system measures traffic speeds using Doppler radar, the same technology used by police to detect speeders. Traffic speeds are measured at several points within and upstream of a work zone. The data are then sent to a central control system, which analyzes the data to pinpoint patches of traffic congestion and delay and then selects the appropriate prerecorded message to post on a variable message sign- -or series of signs--just upstream of the site. The messages prepare motorists for actual traffic conditions ahead. For example, if traffic is extremely slow in the work zone, a variable message sign upstream of the work zone might warn of a 10-minute delay ahead; a second sign might then warn drivers to slow to 55 km/h (35 mi/h). If traffic speeds decrease further, indicating worsening congestion, the system would automatically change the signs to indicate an even longer delay and advise of slower speeds ahead. The signs can also be used to suggest alternate routes or tell drivers to tune in to a highway advisory radio station. To emphasize the timeliness of the messages, each sign can also display the time the message was posted. Drivers armed with information on traffic ahead are better prepared for changing traffic conditions and thus more likely to have a safe trip. The economic benefits of reducing delays and improving safety at a work zone can outweigh the cost of the Adaptir system by a factor of six or more, according to an economic analysis conducted by Scientex.

Speed Display Trailer

This evaluation utilized a trailer-mounted speed display provided by TxDOT[39]. The unit features a 24-inch LED display and uses Ka-band radar to detect oncoming vehicles. The display has a strobe lamp that flashes when a vehicle is detected traveling over a preset speed threshold. This feature is intended to simulate the operation of photo radar, possibly decreasing speeds through the threat of automated enforcement. During this evaluation, the speed threshold for the strobe light was set at 75 mph. The display also has a 130 dB siren that can be activated by vehicles traveling over a preset speed. This option is intended to warn workers when an extremely high-speed vehicle is approaching.

This device proved to be effective in short term/mobile operation as the display could be set up in under 10 minutes. The controls were easy to operate, and TxDOT crews that have used the device have reported no maintenance problems.

Figure 4: Rumble Strips

Figure 5: Intrusion Alarms

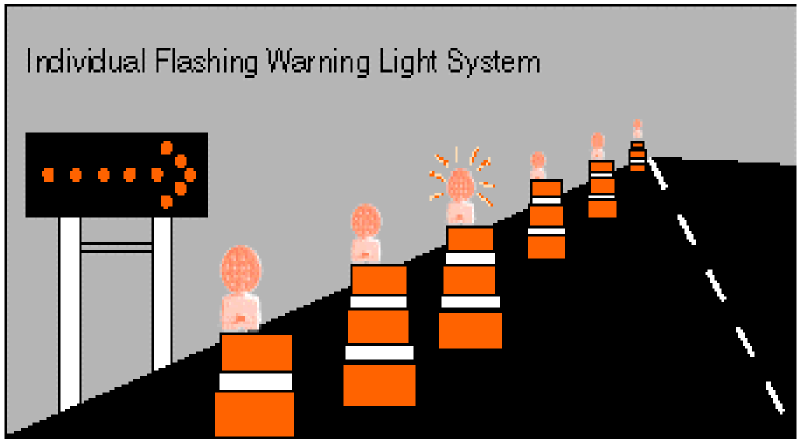

Figure 6: Flashing Lights

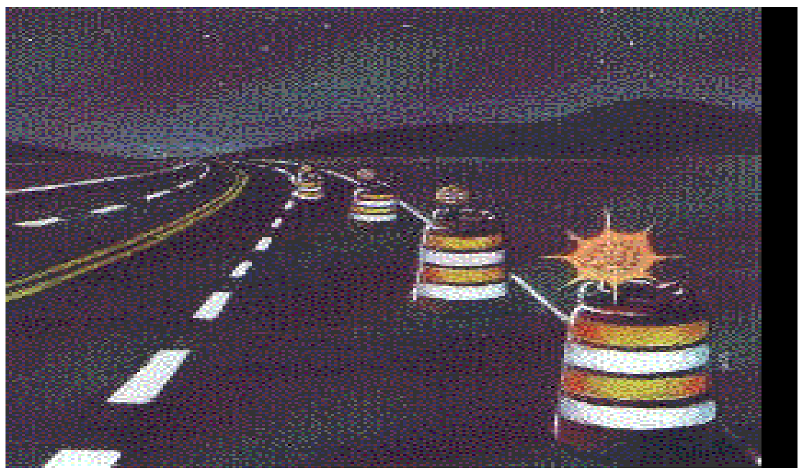

Figure 7: Dancing diamonds (lights)

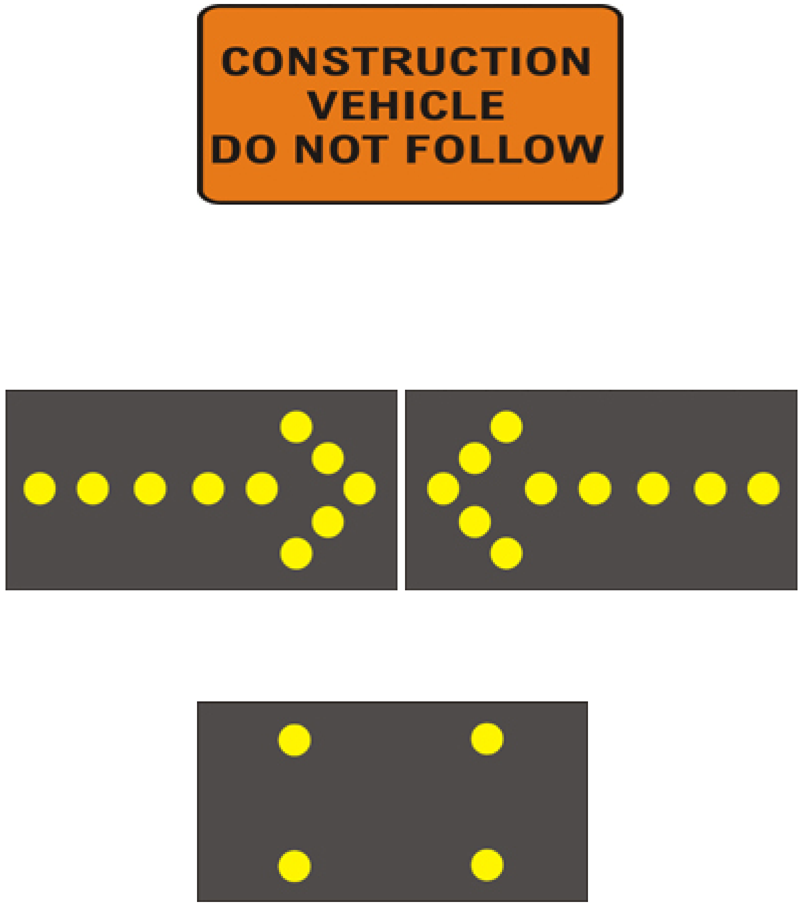

Figure 8: Advanced Warning Signs

Figure 9: Variable Message Signs

Figure 10: Speed Display Trailer

Effectiveness of Police Presence and Enforcement Measures

The use of police enforcement in work zones is a common practice among State DOTs especially during short term/mobile operations. Since inattention and irresponsible behavior by drivers are suspected to contribute to the frequency of work zone crashes, a program featuring presence of and enforcement by law officers has been implemented by many states to alleviate the effect of crashes in work zones. Several studies[16-18] found that the use of extra enforcement in work zones is a common practice in many states and that these practices appear to be increasing. There are several benefits of increased law enforcement police presence and activity in work zones indicated in literature, survey responses and worker interviews. Limited congestion increase has been reported from these efforts. Enforcement activities in work zones has proven beneficial in reducing speeds, ensuring compliance with traffic regulations, and improving safety for workers and motorists.

A study concerning the use of uniformed police officers on federal-aid highway construction projects was prepared pursuant to Section 1213(c) of the Transportation Equity Act for the 21st Century (TEA-21). It concluded that the majority of states use uniformed police officers in at least some work zones where there are particular traffic safety concerns. Officers are commonly deployed both day and night and in a variety of locations within and in advance of actual work activities. The states' survey responses stated an overwhelming opinion that extra enforcement has benefits in both lowering speeds and improving safety in work zones.

The FHWA engineers work closely with state highway engineers and law enforcement officials to identify appropriate engineering safety countermeasures for high-risk locations and for new roads. FHWA also works with the enforcement community, such as the International Association of Chiefs of Police (IACP), regarding the effective use of uniformed police officers on federal-aid highways. FHWA additionally works with emergency medical services, police and fire organizations to ensure that public safety is maintained at high levels and access for emergency vehicles is possible during work zone operations.

Work Zone Enforcement Technology

Police enforcement relies on personal presence supplemented with technology tools such as radars and laser guns. Jones and Lacey[16] (1997) conducted a study in Iowa to determine the effectiveness of laser-based speed enforcement programs compared with radar during 1994–1995. Radar and laser speed measurement devices were used extensively in the cities of Dubuque and Council Bluffs, respectively. Both cities increased speed enforcement activities during the study period and raised public awareness of the risk for being cited for speeding violations. Speed data were collected once each week at 10 locations in each city before and after the enforcement program implementation. The study found that the radar-based speed enforcement program decreased the percentage of vehicles traveling more than 5mph over the posted speed limit by about 20 percent. This observation may be partially explained by the prior existence of a higher level of speed compliance in that community. The researchers concluded that laser-based speed measuring devices should supplement rather than replace existing radar measuring technology.

Remote Speed Enforcement

Another technology and strategy currently considered in work zones is real-time remote speed enforcement. A study conducted in several work zones in Europe[22] conclude that due to high speeds and traffic volumes in many work zones, stopping drivers for traffic violations may be dangerous for both motorists and officers. A remote speed enforcement program uses automated speed enforcement (ASE) system to detect violators and alert an officer located beyond the work zone of the violation. ASE can use a variety of technologies (e.g., radar, LIDAR, elapsed travel measurements, and in-pavement sensors) to detect vehicle speeds. When a violation is detected, a photograph of the vehicle license plate is taken and transmitted to officers stationed outside of the work area. After the violating vehicle has passed through the work area the motorist can be stopped safely. ASE programs can also mail tickets to the owner after a vehicle has been identified. In most states criminal citations cannot be issued using only ASE evidence.

ASE systems have also been employed in the United States. Several communities have used or are currently using ASE. It is common for communities using ASE to experience a decline in both speeding violations and crashes[22]. For example, in Paradise Valley, Arizona, noted a decrease in crashes from 460 in 1986 to 224 in 1992 after implementing an ASE program. Similarly, West Valley, Utah, observed a decline from 2,130 to 1,710 crashes annually after using ASE for two years. A Texas Transportation Institute study[23] examined whether a remote enforcement system was technically feasible and whether vehicles could be correctly identified downstream, and surveyed the attitudes of law enforcement agencies regarding the system. The study found that a downstream observer could correctly match about 84 to 88 percent of the offending vehicles. One problem observed was in the transmission of photographs to an officer downstream. Speed thresholds may need to be established to ensure hardware/software processing capabilities are not overloaded. The law enforcement community expressed concerns with the legal aspects of the system. Some officers and officials believe that modifications would need to be made to the system and/or to state codes to permit enforcement using only photographic evidence.

South Dakota completed a study during 1998 using three deterrents to reduce speeds in work zones: video/LIDAR, a Highway Patrol car, and a decoy car[20]. The study found the most effective option was a decoy car parked on the shoulder. A problem found with the active Highway Patrol car was that when the officer left in pursuit of a violator, he/she was absent from his/her position at the beginning of the work zone for 15 minutes or more. The South Dakota DOT is currently collecting data using an ASE system in work zones. South Dakota DOT is planning to present the findings at a future legislative session in support of legislation to permit direct mailing of citations. All violators cannot be detected with ASE, especially on high speed and high volume roadways, but it is believed that an ASE system can identify many more violators than a single police officer[17].

Work Zone Law Enforcement Functions

Police officers can be utilized in work zones in many different applications, such as:

- keeping travel lanes free of illegally parked or stalled vehicles on detour routes and major traffic arteries by arranging for removal
- controlling illegal turning movements that may restrict capacity at intersections directing traffic in congested situations
- providing advance warning of heavily congested or stopped traffic in advance of a problem area, such as a lane closure
- assisting in traffic control for special construction events, such as bridge beam erection and changes in traffic patterns
- observing and reporting traffic problems on state highways or detour routes to the appropriate engineering staff
- enforcing speed and any other restrictions in or near the work zone area
- aiding in traffic control during the daily signing setup and takedown activities
- preventing intrusions into closed lanes, exits

A study conducted by Virginia DOT[21] surveyed several work zone crews, and that the officer be stationed in the lane closure 500 to 1,000 feet in advance of the first work crew. If traffic backs up, then the officer should be in advance of the backup. Sixty percent of the respondents reported that the officer was most typically located at the beginning or in advance of the lane closure, and 50 percent reported the location as inside the work area, either near the workers or away from the workers. Only 4 percent of the respondents noted the location as at the end of or following the work area. There were also comments suggesting that VDOT or VMS personnel assign the location, that the officer position should depend on the location of the work zone, and that officers be mobile and patrol the entire work zone and thus are not located at any one place.

However, the benefits of enforcement appear to have not been intensively quantified. In addition, procedures for the use of law officers in work zones are quite inconsistent across the nation, and so is the general implementation of specific legislation addressing work zone traffic violations. Variation can also be found in funding levels and sources for enforcement activities in work zones among the states. Training of law officers prior to work zone duty is not mandatory, but it would be better to provide them with adequate training for their work zone duty.

As crashes and deaths continue to rise annually in work zones, it is imperative that beneficial enforcement programs such as the use of law officers in work zone be continued, refined, and expanded. Future studies are needed to supplement the knowledge base and provide guidance to agencies when considering the use of law enforcement to calm traffic, ensure compliance with traffic laws, and thus provide for safer work zones.

Guidelines for Use of Extra Enforcement

Studies have been undertaken to establish guidelines for assigning law enforcement officers to work zones[18]. In 1995, the FHWA developed guidelines for use of uniformed police officers on federal aid projects in Massachusetts. The FHWA conducted interviews with Massachusetts Highway Department personnel from Construction, Traffic, and Design Divisions. Interviews were also conducted with personnel from the Massachusetts Turnpike Authority, the Massachusetts State Police, and the Boston Police Department. Considering information gathered from the interviews (and after consulting the national MUTCD, the state of Massachusetts and local training manuals, and current nationwide practices) the FHWA recommended guidelines to determine when uniformed police officers or civilian flaggers should be used for traffic control on federal-aid projects in Massachusetts. It was recommended that flaggers and uniformed traffic officers should be used only when standard temporary traffic control measures do not adequately guide traffic and provide safety for motorists and workers. The guidelines also state that use of flaggers may be necessary to control traffic on alternating one-way operations or other situations where supplemental information must be provided. Flaggers may be replaced with police officers when high traffic speeds, high traffic volumes, or other extenuating circumstances occur. The guidelines suggest that a uniformed traffic officer with a marked patrol car and flashing, lights should be assigned to nighttime operations. A summary of the guidelines is provided in Table 3.

Table 3. Guidelines for Flaggers and Uniformed police

Work Activity	Low Speed & Low Volume	High Speed & High Volume
Work in the median or roadside area (no infringement on the roadway)	Neither flaggers nor uniformed officers are required	Neither flaggers nor uniformed officers are required
Shoulder closed with concrete barrier	Neither flaggers nor uniformed officers are required	Neither flaggers nor uniformed officers are required
Shoulder closed without concrete barrier (work adjacent to traffic)	Neither flaggers nor uniformed officers are required	1 uniformed officer suggested
Setting up or removing lane closures, lane shift, or other changes in traffic pattern	1 flagger per traffic approach suggested	1 uniformed officer per traffic approach suggested
Lane closed on multi-lane roadway with concrete barrier	Neither flaggers nor uniformed officers are required	Neither flaggers nor uniformed officers are required
Lane closed on multi-lane roadway without concrete barrier (active work adjacent to traffic)	Neither flaggers nor uniformed officers are required	1 uniformed officer per traffic approach suggested
Survey crew—roadway centerline	1 flagger per traffic approach suggested	1 uniformed officer per traffic approach suggested
Temporary Road closure (15–20 minutes)	1 flagger per traffic approach suggested	1 uniformed officer per traffic approach suggested
Ramp work	1 flagger suggested	1 flagger suggested
Moving operation in travel lane	1 flagger suggested	1 uniformed officer suggested
One lane, alternating traffic (no signal)	1 flagger at each end and at each cross street suggested	1 uniformed officer at each end and 1 flagger at each cross street suggested
Work within intersection	Flagger(s) suggested (number dependent upon field conditions)	Flagger(s) suggested (number dependent upon field conditions)

(source: reference no: 26)

In 2002, NCHRP Report 476[22] proposed traffic control guidelines for nighttime maintenance and construction projects. The report states that for all nighttime work activities, the need for and extent of police services should be considered. It was concluded that visible police enforcement is highly desirable in nighttime operations to encourage driver adherence to traffic regulations and to manage incidents such as crashes, breakdowns, and major congestion. Criteria suggested police services might be advisable for nighttime operations as follows:

- construction activities closely adjacent to traffic without positive protection
- restrictions to traffic flow based on work zone features (e.g., no shoulder, reduced shoulder width, reduced lane width, or reduced number of travel lanes)
- locations where incidents are expected to produce substantial congestion and delays
- special operations that require traffic control or shifts of the traffic pattern
- locations where traffic conditions and crash history indicate that substantial problems may be encountered during construction
- projects with heightened public concern regarding the impacts of the traffic control plan

Other factors that should be considered include traffic speed and volume through the construction site. Engineers may also wish to refer to these criteria when deciding whether or not to use extra enforcement during daytime activities.

Work Zone Enforcement Legislation

The Texas Transportation Institute (TTI)[31] conducted a survey regarding work zone legislation in 1997 and provided updated related information on the National Work Zone Safety Information Clearinghouse (NWZSIC) website in 2002[31]. The survey found that 47 states have implemented higher fines for traffic violations in work zones. Enhanced enforcement penalties in most states are applicable to all types of work zones: construction, maintenance, and utility. However, some states limit application to construction areas only.

Of the 47 states with increased fines in work zones, 32 apply the higher penalties only to speed violations, while increased fines can be issued for all traffic violations in 11 of the responding states. Four states describe specific traffic violations where higher fines can be applied, such as reckless driving, driving under the influence, improper passing/overtaking, and following too closely.

Some states actively enforce more than just moving violations in work zones. Michigan, Montana, Oregon, and Washington have enacted legislation allowing a driver to be charged with reckless endangerment of highway workers in a work zone. The state of Oregon also permits drivers to be cited for refusing to obey a flagger. Similarly, Utah allows tickets to be issued for failure to obey a peace officer or other traffic controllers in construction or maintenance zones.

Increased fine amounts vary from state to state; most commonly, standard fine rates are doubled for work zone violations. Midwestern states that apply double fines include Iowa, Kansas, Nebraska, and South Dakota. Fifteen states with increased fines in work zones use fixed amounts for violations. In Missouri, for example, moving violations in work zones are assessed the standard fine amount plus 35 dollars.

The TTI survey found that about one-half of responding states with higher work zone fines require appropriate signing to notify motorists of this fact. Furthermore, approximately half of the states apply increased fines only if workers are present in the work zone. In addition to requiring workers to be present for higher fine application, Illinois has a policy and Tennessee a code provision requiring flashing lights to indicate workers are present.

South Dakota is the only state that authorizes agents or employees of the State department of transportation to issue citations within work zones for speeding and other violations. Despite the commonality of increased penalties for violations among the states, analyses of fatal crashes in work zones between 1984 and 1995 indicated no consistently measurable effect on fatal work zone crash frequency due to higher fines. According to NWZSIC, six states have adopted legislation allowing a speed limit reduction within a work zone without a traffic engineering investigation.

Education And Awareness Programs

Engineers and planners have the responsibility to make sure the work zone is designed and operating properly with safety in mind. Drivers and pedestrians have the responsibility to always be alert and obey the traffic laws. Passengers should always buckle up and act responsibly. The police and the courts have the responsibility to make sure that the traffic and work zone laws are enforced. Public safety agencies have the responsibility of responding to and securing crash locations and enforcing traffic laws. Local communities and county and state governments need to allocate funding for safe roads and increase public awareness about work zone safety. Everyone should take some responsibility for work zone safety.

Several public awareness and technical training is conducted through wide range of activities such as: training courses for federal, state and local highway engineers, worker and drivers; conferences, CDs, brochures for the general public and work zone employees; clearinghouse website; bilingual safety public outreach materials; national work zone awareness week where national, state and local public activities seeks to raise public consciousness about the need for driving safely in work zones.

The National Work Zone Safety Information Clearinghouse started in 1998 by FHWA and the American Road and Transportation Builders Association (ARTBA), provides excellent educational resource reaches the public and the highway community.

Young drivers are prone to create more crashes. In order to educate young drivers, FHWA has produced Moving Safely across America, an interactive CD that is being distributed to 15000 driver education teachers. FHWA is also producing innovative tolls and materials for increasing work zone safety awareness and safe driving to teen drivers.

Good work zone practices of state transportation agencies all over United States, strictly following MUTCD requirements is compiled into a Best Practices Guidebook (available at http://www.ops.fhwa.dot.gov/wz/workzone.htm or on a CD). In the Fall of 2003, FHWA published a Traffic Control Handbook for Mobile Operation at Night that describes detailed guidance for night time construction, maintenance and utility operation.

FHWA maintains good database on recent work zone related research, developments, safety statistics, and technology transfer. These resources are updated regularly and made available to researchers and engineers.

Program Implementation

Many state DOT sponsors work zone-oriented public information programs to reduce the number of crashes in work zones. In Iowa, the current program, "Expect the Unexpected in the Work Zone", is a by-product of the popular television series, "The Twilight Zone". The major components of the program are: an educational curriculum for grades K-12 (this includes a six-minute video tape and a classroom instructor's guide that includes student activities to increase awareness of the need for safe driving in work zones), public service announcements and paid advertising for television, radio, newspapers and magazines to get information about safe driving in work zones directly to the motoring public, brochures, stickers, and posters. Several DOTs' and FHWA propagate tips for driving safely in work zones[24-27].
Samples include:

1. EXPECT THE UNEXPECTED! (Normal speed limits may be reduced, traffic lanes may be changed, and people may be working on or near the road.)
2. SLOW DOWN! (Speeding is one of the major causes of work zone crashes.)
3. DON'T TAILGATE! KEEP A SAFE DISTANCE BETWEEN YOU AND THE CAR AHEAD OF YOU. (The most common crash in a highway work zone is the rear end collision, so it is essential to leave two car lengths between two vehicles. So, do not tailgate.)
4. KEEP A SAFE DISTANCE BETWEEN YOUR VEHICLE AND THE CONSTRUCTION WORKERS AND THEIR EQUIPMENT.
5. PAY ATTENTION TO THE SIGNS! (The warning signs are there to help the drivers to move safely through the work zone. Drivers should observe the posted signs until the vehicle leave the work zone.)
6. OBEY ROAD CREW FLAGGERS! (The flagger knows what is best for moving traffic safely in the work zone. A flagger has the same authority as a regulatory sign, so the driver of a vehicle can be cited for disobeying his or her directions.)
7. STAY ALERT AND MINIMIZE DISTRACTIONS! (It is important to dedicate driver's full attention to the roadway and avoid changing radio stations or using cell phones while driving in a work zone.
8. KEEP UP WITH THE TRAFFIC FLOW. (Motorists can help maintain traffic flow and posted speeds by merging as soon as possible. Do not drive right up to the lane closure and then try barge in.)
9. SCHEDULE ENOUGH TIME TO DRIVE SAFELY AND CHECK RADIO, TV AND WEBSITES FOR TRAFFIC INFORMATION. (One can expect delays and therefore leave early so one can reach the destination on time. All information on work zone delays throughout the country can be found at the National Work Zone Safety Information Clearinghouse - http://wzsafety.tamu.edu)

10. BE PATIENT AND STAY CALM. (Work zones are inevitable. Remember, the work zone crew members are working to improve the road and make driving better).

Like drivers, workers need to be guided by educating them to make sure the existence of a work zone with all its parameters in place. i.e. all the devices should be in right place and working properly. Secondly if it's the night operation then all devices should be reflectorized or illuminated. It should be ensured that all the maintenance vehicles should be within the vicinity of a work zone. In addition, workers with specific traffic control responsibilities should be trained in traffic control techniques, device usage and placement. Don't assign untrained workers the responsibility for setting up and maintaining the system. Workers should be given true information and training and all devices and signs should be removed that are not in use, meaning that there should be minimum hindrance to the free flow of normal traffic. Drivers should not be made to think, respond, brake rapidly by awkward placement of devices and usage of signs. Another important thing to note is that safety features may provide adequate warning for a vigilant driver, but may be inadequate for an inattentive driver. It means that drivers should be guided in a clear and obvious manner throughout the work zone.[40]

CB Wizard Alert System and Program

The device is a portable radio that broadcasts real-time work zone information and safety tips to citizens through radio channels. This device is especially good for truckers by letting them know about the traffic patterns through latest updated news. It is designed to give drivers monitoring the CB radio advanced warning of upcoming delays at construction sites or incidents. The advanced warning will allow drivers the opportunity to moderate their speed and become observant of the need to slow, stop, or maneuver before they reach the work zone or encounter queues of halted vehicles. Since truck operators most commonly monitor CB radios, it was assumed that the CB Wizard would have the most impact on truck drivers. With Certificate of Approval issued in January 1998, Penn DOT is using the device.[41]

Work Zone Evaluation Methods

There has been a dedicated effort over the past five years to minimize impacts to the public as they travel through work zones. While national data on the cost of work zone delays is not readily available, daily road-user delay costs on many urban freeway reconstruction projects have been calculated to be over $50,000 per day. Because of the significant impacts to the public in terms of delay and user costs, the Federal Highway Administration (FHWA) established the Strategic Work-Zone Analysis Tools (SWAT) program [29, 32]. It addresses work-zone factors and stresses the importance of accounting for work-zone influences when making transportation improvement decisions. Three tools are being developed as part of the SWAT program:

a. "Expert System" software program;

b. "Quick Zone" software program

c. A Detailed simulation model.

a. Expert System

With the Expert System, a user would enter data on the characteristics of the work zone, such as the type of highway improvement or repair work being done and the duration of the work. The program would then provide a list of possible mitigation strategies for reducing work zone delays and costs. The software is still being developed by FHWA and its expected release date is 2004. More information can be found on the FHWA Turner-Fairbank Research Center web site at http://www.tfhrc.gov/its/swat.htm.

b. Quick Zone

A prototype version of Quick-Zone, new work zone delay estimation software developed by FHWA in cooperation with Mitretek Systems, is now available on the web for use and assessment. A user need only have Microsoft Excel 97 or higher running on a Windows-based PC to use the Quick-Zone application. The software allows the user to compare the traffic impacts for work zone mitigation strategies and estimate the costs associated with these impacts. The costs can be estimated for both an average day of work and for the entire life cycle of construction. Version 0.99 of Quick-Zone was released in April 2001.

Specifically, the program provides the following functions:

1. Quantification of corridor delay resulting from capacity decreases in work zones.
2. Identification of delay impacts of alternative project phasing plans.
3. Supporting tradeoff analyses between construction costs and delay costs.
4. Examination of impacts of construction staging, by:

- location along mainline;
- time-of-day (peak vs. off-peak); and
- season (summer vs. winter).

5. Assessment of travel demand measures and other delay mitigation strategies.
6. Allowing the establishment of work completion incentives.

The software is available for download at FHWA's Turner-Fairbank Research Center website at: http://www.tfhrc.gov/its/quickzon.htm.

c. Simulation Model

FHWA's simulation model, planned for release in 2004, is designed to be used in conjunction with Quick Zone to more precisely estimate the impacts of specific work zone strategies and the effectiveness of mitigation techniques. More information about the model can be found at the Turner-Fairbank Research Center website: http://www.tfhrc.gov/pubrds/nov00/strategic.htm.

Using a software tool like Quick-Zone, work zone traffic impact analysis could be performed, by selecting appropriate traffic control recommendations for the safe and efficient movement of traffic through construction work zones. The Expert System and Simulation Model, planned for release in 2004, would help in better estimation of work zone impacts, costs, and delays.

CONCLUSIONS AND RECOMMENDATIONS

Several studies and treatments discussed above have improved work zone safety through a multi-faceted approach in the fields of engineering, education, enforcement, and coordination with public safety agencies. The role of FHWA in work zone safety is undeniable. The FHWA partners with several State as well as National organizations in improving roadway safety such the State Departments of Transportation (DOT), the American Association of State Highway and Transportation Officials (AASHTO), the American Traffic Safety Services Association (ATSSA), the American Road and Transportation Builders Association (ARTBA), Texas Transportation Institute (TTI), the Institute of Transportation Engineers (ITE), the National Utility Contractors Association (NUCA), the International Association of Chiefs of Police (IACP), the National Association of County Engineers (NACE), the American Public Works Association (APWA), and the Governors Highway Safety Association (GHSA).

The devices suggested for catching driver's attention and for traffic control in work zones meet NCHRP 350 testing standards and proved very effective when employed by various State DOT's. These devices should be evaluated using the latest technology and standards before procurement in Task 5 of Phase-2. Standardization of work zone traffic control is contained in the *Manual on Uniform Traffic Control Devices* (MUTCD) and all work zone operations should strictly follow MUTCD requirements.

With continuous research, more innovative and effective devices in place and latest technological advancements, future work zone operations can be exercised efficiently and safely.

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