Chapter 2.0 Literature Review

2.1 Introduction

The Interstate highway system in the U.S. is one of the world's biggest engineering feats. Beginning with construction in the late 1950s, most of the interstate system construction has been completed. Now, the aging interstate system requires us to focus on maintenance, reconstruction, and rehabilitation of this facility. Additionally, growth in traffic has necessitated the reconstruction and regular maintenance of these highways and freeways. Increased reconstruction and maintenance activities on freeways and highways have implications on traffic safety and traffic control in terms of accidents, delays, and congestion, especially at highway work zones. Highway work zones pose an impediment to travelers who are accustomed to a clear, unobstructed roadway. Several work zones require partial lane closures to carry out construction and maintenance activities, leading to reduced roadway capacity. This results in unwanted delays and congestion, adding to motorist frustrations. Thus, work zone safety and traffic control will continue to be a major concern. Several Departments of Transportation (DOTs) face work zone-related problems and challenges in their daily efforts to provide better and more efficient transportation facilities. A survey conducted by the Federal Highway Administration (FHWA) on work zone-related problems experienced by DOTs lists the major problems and challenges faced by transportation departments as follows (Ha & Nemeth, 1995):

- Urban freeway reconstruction
- Lack of training of contractor personnel
- Need for specialized equipment, such as changeable message signs
- Motorists speeding within work zones
- Management of both construction or maintenance and traffic control, and
- Increasing number of liability suits

This chapter is an effort to compile as much information as possible on prevailing traffic conditions and characteristics on highways and freeways, with specific emphasis on I-81 in Virginia. It also gives an insight into the nature and magnitude of the problems experienced at highway work zones.

2.2 Overview of I-81 Transportation Issues

I-81 in Virginia is one of the most important transportation links in the state. Serving different types of traffic such as intercity travelers, daily commuters, tourists, long distance drivers, and commercial traffic, I-81 today carries traffic far beyond the capacity for which it was originally designed. In the last 25 years, the traffic on I-81 has nearly tripled, increasing from 2.7 million daily vehicle miles traveled (VMT) in 1975 to more than eight million in 1995 (VDOT, 1996a). Another issue of concern is the increasing percentage of truck traffic in the Corridor. Originally designed to carry about 15% of truck traffic, I-81 now carries anywhere between 19 to 40 percent truck traffic. Figure 4 shows the average annual daily traffic and truck percentage for the nine sections of I-81 in Virginia (VDOT, 1993). VDOT expects a continuing growth in the truck traffic on I-81. This may be attributed to the increased reliance of American businesses on trucks for efficient and economic transportation of goods. According to the state trucking industry, in 1992 trucks carried 80% of all freight in Virginia. By the year 2000, it is expected that the volume of freight will increase by as much as 28 percent (VDOT, 1996a). All these facts show that the nature and magnitude of traffic on I-81 in Virginia is changing, and that there is an urgent need to enhance the capabilities of the existing interstate system to accommodate for the growth and changes in traffic characteristics, and plan for the future.

A study was carried out by the Virginia Tech Center for Transportation Research (CTR) as a step towards identifying the various transportation issues on I-81 in Virginia that need immediate attention. Data on traffic volumes, accident statistics, truck travel, work zone issues, and intercity travel was collected. A preliminary survey of truckers on I-81 was also conducted. Analysis of this data revealed four critical issues of concern regarding the

I-81 Corridor. These include work zone safety and control, traffic safety, trucking issues, and intercity traveler needs.

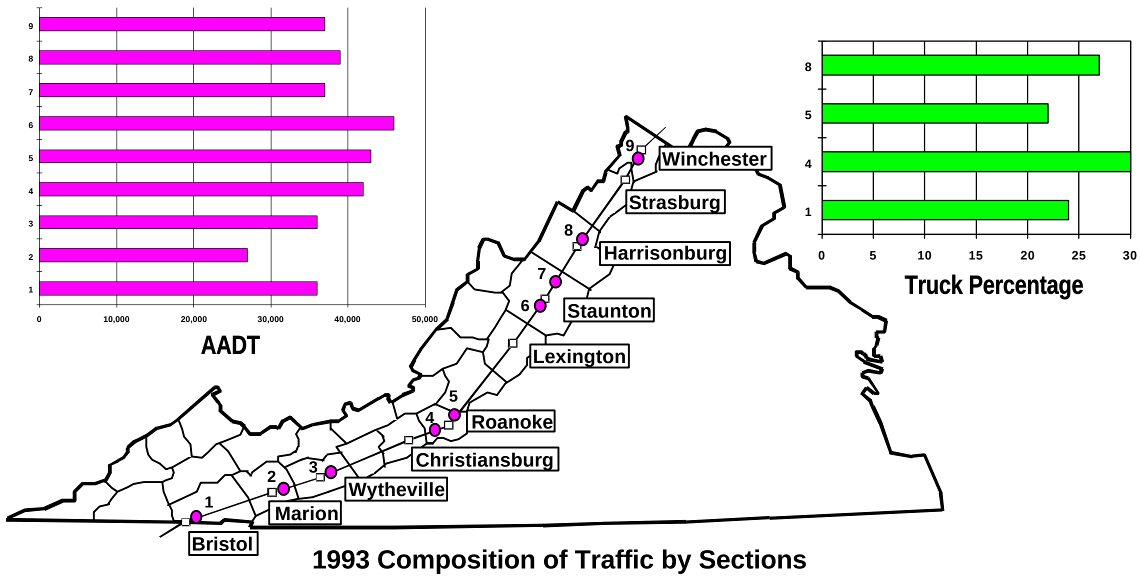

Figure 4. Traffic characteristics on I-81 in Virginia by section

(Source: CTR, 1996)

2.3 Work Zone Safety and Traffic Control

Work zone safety and traffic control have been gaining a lot of attention during the past few years. Increasing maintenance and reconstruction activities have exposed travelers to several types of work zones on a regular basis. Work zones pose a hazard to the regular traveler in terms of safety. An increasing number of fatalities, injuries, and costs due to work zone-related accidents and incidents have indicated that some affirmative action needs to be taken to enhance work zone safety and traffic control. The first step in resolving the growing problem of work zone safety and traffic control would be to study in detail the nature and size of the problem. The following statistics on work zone accidents give a detailed description of the magnitude and types of accidents currently experienced at highway work zones. Analysis of these statistics gives us an insight into the problems experienced, their probable causes, and possible solutions to resolve them. The literature reviewed provided information on national work zone accident statistics and also gave an assessment of the nature and magnitude of work zone accidents on the I-81 Corridor in Virginia.

2.3.1 An Examination of National Work Zone Accident Statistics

The number of fatalities at work zones has been fluctuating over the past decade, but has shown an increasing trend in the last few years. Figure 5 shows the number of fatalities resulting from crashes in highway work zones for the years 1984 through 1994.

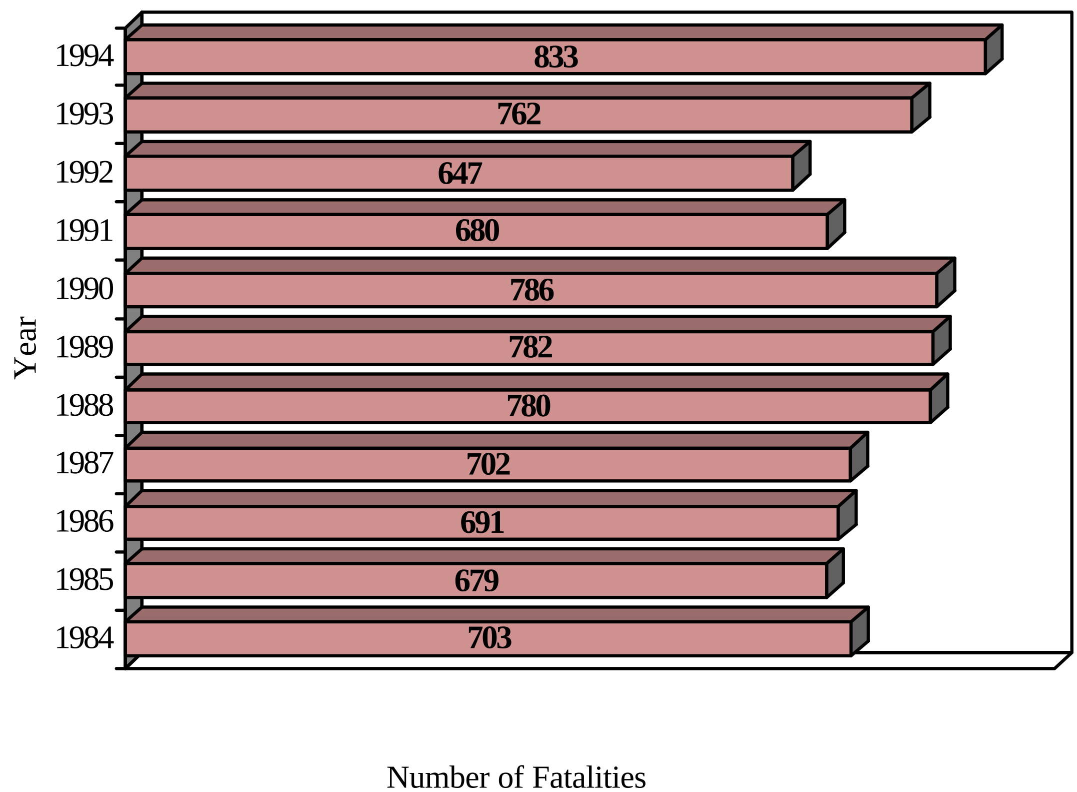

Figure 5. Work Zone Fatalities

(Source: NHTSA, 1994)

A total of 680 fatalities were reported in 1991. The number decreased to 647 in 1992, reaching an all-time low for the past decade. Since then there has been an increasing trend in the number of fatalities. In 1994, a 29% increase was observed in the number of fatalities as compared to those for 1992. While an overall fluctuating trend is observed, the numbers for recent years are disturbing.

A recent investigation carried out by the Federal Highway Administration (FHWA) as part of the Highway Safety Information System (HSIS) support contract pointed out some interesting facts on general accidents and work zone accidents from a national perspective. In the HSIS database, accident information for seven states was collected. Of these, information pertinent to work zone-related accidents was available for three states. Table 2 gives a summary of the accident information for these three states. It can be observed that work zone accidents constitute two to three percent of total accidents. This was found to be consistent with several other states.

Table 2. Magnitude of Work Zone Accidents from HSIS (1991-1992)

(Source: Wang et al., 1996)

State	Work Zone Accidents	Total Accidents	% Work Zone Accidents
State 1	1,541	68,702	2.24
State 2	5,132	171,140	3.00
State 3	5,386	280,714	1.92

2.3.1.1 Change in Accident Rates During Construction

Studies show that there is an increase in accident rates due to construction and maintenance activities. Ha and Nemeth (1995) compared and summarized seven studies to depict a nationwide work zone accident experience. Table 3 shows a summary of the changes in accident experiences during construction activities.

Table 3. Accident Experience during Construction

(Source: Ha & Nemeth, 1995)*

STUDY	STUDY SITE	% CHANGE IN ACCIDENT RATE
California (California Business and Transportation Agency, 1972)	California	+ 21.4 to + 7.0
Virginia (Lisle et al., 1976)	Virginia	+ 119.0
Georgia (Georgia DOT)	Georgia	+ 61.3
Midwest Research Institute (Paulsen et al., 1978)	Colorado Georgia Michigan Minnesota Ohio New York Washington	+ 6.8
Ohio (Nemeth & Migletz, 1978)	Ohio	+ 7.0
Rouphail (Rouphail et al., 1988)	Unknown	+ 88.0
New Mexico (Hall & Lorenz, 1989)	New Mexico	+ 33.0 (Rural Interstate) + 17.0 (Federal-Aid Primary) + 23.0 (Federal-Aid Secondary)

*Data collected is for different studies performed during different years

All of these studies indicate an increase in accident rates during construction and maintenance activities. Ten studies were also compared and contrasted in terms of accident severity. Most of the studies showed an increase in injuries and fatalities; however, the investigators concluded that there was a great deal of inconsistency in the nature of the findings.

2.3.1.2 Work Zone Accident Location

A study of the location of accidents within work zones summarized by Ha and Nemeth (Table 4) shows the distribution of accidents at different areas within the work zones for different states. The buffer zone, advance zone, and taper zone may be clearly identified as potential hazardous locations within the work zone.

Table 4. Distribution of Accidents by Location

(Source: Ha & Nemeth, 1995)*

ACCIDENT LOCATION		STUDY: Virginia (Lisle et al, 1976)	Ohio Rural (Nemeth & Migletz, 1978)	Ohio Turnpike (Pigman & Agent, 1990)	Kentucky (Nemeth & Rathi, 1983)
Advance Zone		12.7%	15.9%	6.5%	5.6%
Taper		13.3%	22.5%	9.2%	7.9%
Work Area	Lane Closure or Buffer area	44.7%	39.1%	23.2%	54.1%
	Construction Area	-	16.6%	-	-
Ramp		0.0%	3.3%	0.0%	0.0%
Crossover		0.0%	0.0%	34.1%	0.0%
TLTWO		0.0%	0.0%	22.2%	0.0%
Others (Intersections)		29.3%	2.6%	4.8%	32.4%

*Data collected is for different studies performed during different years

TLTWO = Two Lane Two Way Operation Zone

Different roadway types and the varied use of traffic control devices involved affected the frequency of accidents at various locations within the work zone for all the studies, signifying a lack of consistency in the findings. The authors also report that the accident data analysis showed that the factors contributing to work zone accidents are numerous and include driver inattention, congestion at work zones, traveling at unsafe speeds, rash driving behavior, liberal use of safe speed limits, failure to heed warning signs, following too close, lack of public information about work zones, and unfavorable environmental or weather conditions. Findings from accident studies show that the current methods employed to reduce speeds at work zones are not very effective, and improper traffic control in the work zone was a major factor contributing to work zone accidents. Analysis of national work zone-related accidents also revealed that most accidents at crossovers had a high involvement of truck traffic, and the predominant type of accident was rear-end collisions.

2.3.1.3 Major Work Zone Accident Types and Causes

Studying accident information with respect to accident type, Wang et al. (1996) found that the number of rear-end collisions were the highest, followed by single vehicle, fixed-object accidents. The predominant factors contributing to these accidents were identified as failure to drive within single lane, failure to reduce speed, failure to yield right of way, and failure to drive within the designated lane (Wang et al., 1996). These accident types and causes were found to be consistent with those found for several other states. The following bulleted list gives a brief summary of the work zone accident studies carried out in the past.

- A study on the I-495 beltway (1975) showed that fixed object type accidents claimed 52% of total accidents during construction, while rear-end collisions accounted for 28.2%, and sideswipe accounted for 15.6% of total accidents. The major contributing factor for these accidents was found to be driver inattention (48.1%) and speeding (10.6%) (Liste et al., 1976).
- A study on work zone accident characteristics on Ohio's rural interstate system (1973) reported that rear-end collisions represented 40.4% of all work zone-related accidents, followed by fixed object off road (37.09%). The most probable accident causes were listed as excessive speeding, driver inattention, following too close, failure to yield, and improper passing (Nemeth & Migletz, 1977).
- A study on construction zone accidents carried out by the Midwest Research Institute in Kansas City showed that for the seven states examined, 38.79% of all work zone-

related accidents were rear-end collisions, followed by fixed object-type collisions (16.24%) and sideswipe, which accounted for 9.68% of all work zone accidents (Graham et al., 1977).

- A study carried out in Texas reported that 40% of the accidents in work zones were rear-end collisions, making it the main type of collision experienced during construction and maintenance activities (Richards et al., 1981).
- Nemeth and Rathi (1983) studied the characteristics of freeway work zone accidents in Ohio and reported that fixed object-type collisions were the main contributing type of accident (52.43%), while rear-end collisions accounted for 22.7%, and sideswipe accounted for 9.73% of all work zone-related accidents. The listed causes for the accidents included driver inattention and driving too fast (Nemeth & Rathi, 1983).
- A study conducted on work zone accidents in Kentucky (1983-1986) showed that the most common accident was rear-end collisions (29.3%), followed by sideswipe (15.1%) and fixed object-type collisions (6%). The contributing factors included driver inattention (31.5%), failure to yield right-of-way (14.9%), following too close (11.6%), and unsafe speed (10.4%) (Pigman & Agent, 1990).
- Wang et al. (1996) studied work zone crashes for the three states of Maine, Illinois, and Minnesota and reported that a large percentage of work zone accidents involved a rear-end collision (Wang et al., 1996).
- A study on Tennessee work zone accidents (1992) showed that rear-end collisions contributed to the majority of injuries in work zones. The rear-end collisions were classified according to driver action; rear-end driver inattentive represented 29% of work zone fatalities, followed by rear-end following too close (22%), and rear-end speeding (6.4%) (Ried et al., 1997).

2.3.2 Work Zone Accident Experience on I-81 in Virginia

In recent years, the importance of I-81 as a major transportation link has increased tremendously. I-81 is being exposed to traffic volumes much higher than its planned capacity, and a significant percentage of this traffic constitute trucks. A recent update on the I-81 Corridor traffic characteristics by VDOT showed that the percentage of truck traffic varied anywhere between 19 to 40 percent depending on the time of day and the section under consideration. The increasing traffic volumes and change in composition of traffic with a higher percentage of trucks renders I-81 more accident prone. Work zones under such traffic conditions make travel on the Corridor unsafe and inefficient.

Work zone accident data for the state of Virginia (provided by VDOT) showed that a total of 1,981 work zone accidents were reported for the period 1991-94. Of these, 962 (49%) were injury accidents and 42 (2%) were fatal (see Figure 6). The yearly variation of work zone accidents indicates an increasing trend. It is noteworthy that the rate of fatal accidents has increased each year. I-81 has also experienced an increasing trend in the number of work zone accidents, as shown in Figure 7.

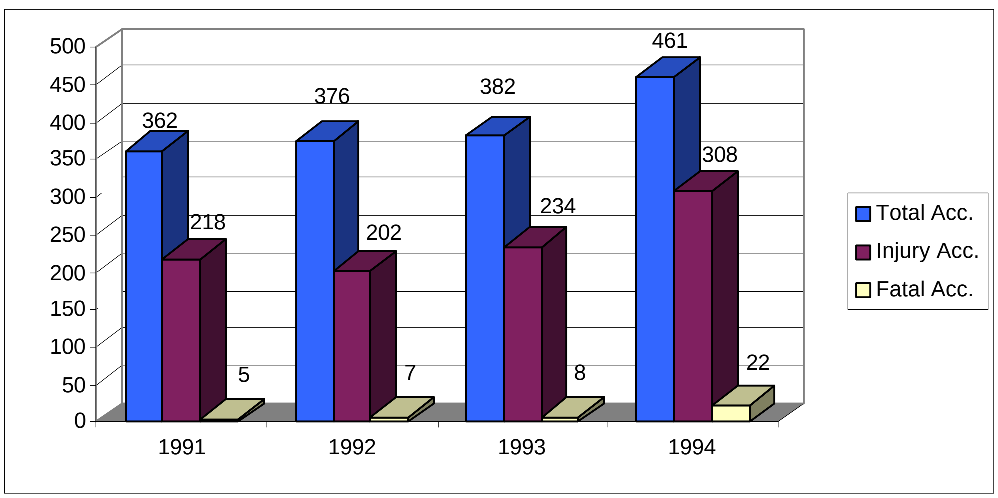

Figure 6. Statewide Work Zone Accident Statistics
(Source: VDOT, 1996)

The VDOT accident database shows that a total of 68 accidents occurred in work zones on I-81 during 1991-1994. These accidents accounted for 1% of the total accidents on I-81 during the same period. Of the 68 accidents, 53 (78%) involved two or more vehicles, 22 (32%) were related to trucks, and 5 (7%) were fatal (CTR, 1996). These statistics clearly highlight the severity of work zone accidents and the importance of addressing this issue.

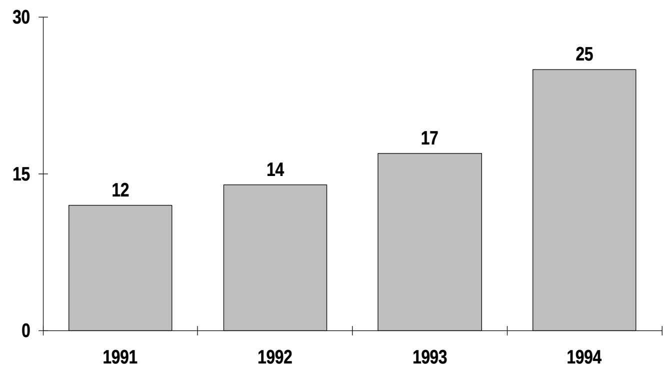

Figure 7. Number of Work Zone Accidents on I-81

(Source: VDOT, 1995)

To better understand the nature and causes of these accidents, the data was sorted by various factors, including driver's action, collision type, highway alignment, weather condition, surface condition, and time of day (Table 5). Examining the table, the following observations can be made (CTR, 1996):

- The top two causes of accidents among the identified driver's actions are "Driver Inattention" constituting 22% of all work zone accidents and "Exceeding Safe Speed" constituting 13% of all work zone accidents. It may also be noted that accidents caused due to "Following Too Close" (7%) exceeded the figure for statewide work zone accidents (3%). These figures indicate the need for enhanced traffic control at work zones.
- Among collision types, "Rear-End Collision" (57%) was the most typical type, followed by "Fixed-Object Off Road" (21%) and "Same Direction Sideswipe" (15%). The "Rear-End Collisions" or "Same Direction Sideswipe" accidents may be caused due to driver actions such as "Driver Inattention," "Exceeding Safe Speed," and

Table 5. Characteristics of Work Zone Accidents on I-81 (1991-1994)

(Source: VDOT, 1995)

ACCIDENT CHARACTERISTICS	NUMBER OF ACCIDENTS	PERCENTAGE OF TOTAL ACCIDENTS
DRIVER'S ACTION		
Driver Inattention	15	22%
Exceeding Safe Speed	9	13%
Following Too Close	5	7%
Others	13	19%
None	26	39%
COLLISION TYPE		
Rear-End	39	57%
Fixed Object off Road	14	21%
Sideswipe	10	15%
Fixed Object in Road	3	4%
Others	2	3%
ALIGNMENT		
Grade Straight	32	47%
Straight Level	30	44%
Hillcrest Straight	3	4%
Grade Curve	2	3%
Curve Level	1	2%
WEATHER		
Clear	42	62%
Cloudy	20	29%
Raining	3	4%
Fog or Mist	2	3%
Snowing	1	2%
SURFACE CONDITION		
Dry	60	88%
Wet	5	7%
Snowy	1	2%
Other	2	3%
TIME OF DAY		
Daylight	55	81%
Darkness, Highway not Lighted	11	16%
Dawn	2	3%

“Following Too Close”. The high percentage of “Fixed-Object Off Road” accidents requires further analysis, but is most probably related to driver inattention as well.

- A significant percentage (16%) of accidents have occurred under the “Darkness, Highway Not Lighted” condition. This fact underscores the need for improved lighting and messaging of work zone areas at night, and more effective driver warning. This issue attains added importance when one considers the increasing trend in scheduling construction or maintenance activities at night.

The literature reviewed shows that work zones are hazardous locations and are more accident prone than non-work zones. The accident experiences summarized depict the nature and magnitude of the current work zone safety problem. The major areas of concern may be identified as increased number of accidents and fatalities, and unsafe driving practices that render sections such as the advance zone, the taper zone, and the buffer area within a work zone as potential accident locations. The majority of accidents that occur are rear-end-type collisions and fixed-object off road-type collisions, with driver inattention and exceeding safe speed being the topmost contributing factors. There is also potential to enhance the existing traffic control devices.

2.3.3 Future Reconstruction Activities on I-81

According to VDOT’s six-year (1997-2002) improvement program (Virginia Department of Transportation and Department of Rail and Public Transportation, 1997), a substantial amount of funds are allocated for the rehabilitation and reconstruction of I-81. A total of 57 different improvement/widening projects are planned, at a total estimated cost of $568 million (Table 6). The information in this table signifies the level of work activities in the years to come, and the importance of work zone safety and control. If the above accident trends continue, construction activities on I-81 will pose major concerns in the future. Thus, there is an urgent and critical need to research work zone issues and devise

Table 6. Six-Year (1997-2002) Improvement Program on I-81
(Source: VDOT and VDRPT, 1997)

District	Projects		Total Cost (million)
	Improvement*	Widening Only	
Bristol	07	12	180
Salem	08	12	320
Staunton	11	05	68
Total	26	29	568

* Includes some widening and improvement projects together

methods/applications to mitigate these problems. VDOT officials were recently interviewed in order to better understand the work zone issues on I-81. These interviews confirm the nature of the specific issues, concerns, and needs. Major concerns were: safety of workers and drivers; overspeeding; liberal use of safe speed limits; driver inattention; congestion near work zones; and lack of public awareness about work zones. These concerns open up opportunities for innovative technological applications to address these issues.

2.4 Technological Innovations for Work Zone Safety and Traffic Control

Work zone safety and traffic control has been an important topic of discussion among several DOTs. DOTs are involved in numerous construction and maintenance programs and projects, and the magnitude of these programs demand that special attention be given to the issues of work zone safety and traffic control. Past experiences show that there is an increase in the number of accidents occurring due to the presence of work zones. Accident statistics and analysis suggest that many of the accidents occur due to driver inattention, exceeding safe speed limits, and most of all, not knowing what to expect ahead at the work zone. To address the safety and traffic control issues at work zones, several technology applications have been developed and implemented in the past. Newer technologies, including innovative applications, are being examined for the future. This part of the chapter reviews these work zone traffic control systems and technologies.

With the increase in the number of highway accidents and growing fatality rates, especially at highway work zones, enhancing existing work zone safety programs and implementing the use of advanced technologies have gained much importance. The Strategic Highway Research Program (SHRP) played a key role in developing several new safety devices for worker safety and for work zone safety and traffic control purposes. Table 1 gives a summary of the technological innovations for work zone safety and traffic control and their operating characteristics (CTR, 1996). Following is a short description of a few of the products developed for work zone safety and traffic control.

- **Work Zone Intrusion Alarm:** The work zone intrusion alarm is a device developed by SHRP to enhance the safety of workers by giving them an audible warning in the event of work area intrusion. Several versions of the intrusion alarm are available. The basic model developed by SHRP was adopted by manufacturers and enhanced to meet specific needs. Common to all the versions are a means of marking the perimeter of the work zone, a signal sender, a signal receiver, and a siren. These devices are portable, easy to install, convenient, and adaptable to temporary work zones. The signal sender varies depending on the type of technology the system employs. For example, it can be a pneumatic tube, infrared rays, or microwave rays. If a pneumatic tube is used, the pneumatic tube is stretched along the perimeter of the work zone and connected to a box containing a rechargeable battery and transmitter located on the roadway shoulder. In the event that a vehicle crosses the work zone perimeter, the pneumatic tube is pressed and a signal is sent to the receiver, which in turn transmits a signal to a box holding a rechargeable battery and a 120-125 decibel siren placed near the

Table 7. Summary of Technological Innovations for Work Zones
(Sources: SHRP, 1993; Flynn et al., 1995; Scientex Corp., 1996; South Dakota DOT, 1993)

Technology / System	Application	Operating Characteristics
Work Zone Intrusion Alarms	Safety	Designed to activate a warning for workers to take evasive action when errant vehicles have penetrated work zone barriers.
Safety Warning System	Safety	Utilizes radio and microwave technology to enhance highway safety. Unmanned radar transmitters send signals to drivers to warn of work zones ahead, and other types of road hazards.
Condition-Responsive Work Zone Traffic Control System	Advisory, Control	Uses UHF, rather than cellular communications technology, so that it can be deployed in rural areas and other locations where cellular service is not yet available. Consists of an on-site central system controller and several roadside remote stations. Based on communication from the central system controller, roadside remote stations update messages via changeable message signs and highway advisory radio (Source: Scientex Corp., 1996)
Speed Monitoring System with Radar	Advisory, Control	A portable self-contained trailer unit equipped with radar to measure the speeds of on-coming vehicles, and a variable speed display panel.
Congestion - Monitoring System with Radar	Advisory, Control	A CMS is equipped with radar to monitor congestion based on speed measurements in work zones. Real-time dynamic messages can increase the reliability of traffic information.
Barrier Lighting Unit	Safety	Low maintenance, electrically-powered lighting unit. Can be installed on concrete barriers and construction barricades.
Radio Emergency Alert Communication Trailer	Advisory, Control	Mobile HAR Radio Station with an erectable flashing highway sign. HAR technology allows direct communications between transportation agencies and drivers as they approach and pass through work zones, using a standard AM automobile radio.
Lightweight CMS	Advisory, Control	Uses new super LED technology to make the CMS light enough for one worker to carry, yet large enough to grab drivers' attention.
Portable Rumble Strip	Control	Designed for low-speed traffic conditions, and to improve driver recognition of the STOP/SLOW sign on the approach to a work zone. Causes a vibration and an audible rumble.
Truck-Mounted Attenuators	Safety	Used as protective vehicles to protect workers from errant vehicles. These crash cushions are mounted on trucks for mobile lane closures.
Flashing Stop/Slow Paddle	Advisory, Control	Consists of strobe or halogen lights on the sign face which are bright enough to get the attention of inattentive drivers. The flagger can activate the light manually by hitting a button if a driver seems to be ignoring an instruction.
Durable Fluorescent Materials	Advisory, Safety	Fluorescent colors provide outstanding visibility under all daylight driving conditions, but have very poor color stability over time. A field study indicated that fluorescent retroreflective sheeting provides better daytime and nighttime visibility than ordinary signing materials.
Solar-Assisted Arrowboards	Advisory, Control	Uses high efficiency solar modules with single crystal solar cells to charge heavy-duty deep-cycle batteries. Provides additional advance warning and directional information to assist in diverting and controlling traffic around work zones.

workers, sounding a loud siren. This gives the workers a few seconds to react and move out of the way of the errant vehicle. In the case of the infrared or microwave system, infrared or microwave rays are aimed between the transmitter and receiver/siren. The transmitter and receiver are mounted on barrels or cones. As the beam is broken by an errant vehicle, the alarm is activated. The intrusion alarm was successfully used in New York and showed positive results in enhancing worker safety and work zone safety.

- **Flashing Stop/Slow Paddle:** Flaggers often have trouble getting the attention of drivers as they approach work zones. The workers within the work zone depend on the flaggers to effectively warn motorists and prevent any disastrous accident. SHRP has developed a new safety device called the Flashing Stop/Slow Paddle to help flaggers attract the attention of inattentive drivers. This device consists of two high-intensity, quartz halogen lamps that are visible from as far away as 1000 feet. If cars do not appear to be slowing as they approach the work zone, the flagger activates the lights by pressing a button on the side of the paddle pole. This causes the lights to flash alternatively 10 times, and then the sign automatically resets. The device uses 10 rechargeable D-cell batteries in the handle of the paddle to provide all the needed power. SHRP-sponsored closed track and open road tests showed that the sign was not only more visible to drivers, but also resulted in immediate recognition and speed reductions. Several users, such as the New Jersey DOT and the Iowa DOT, are pleased with the results produced by the flashing stop/slow paddle (Flynn et al., 1995).

- **Portable Speed Bumps/Rumble Strips:** The portable speed bumps/rumble strips are another safety device developed by SHRP to warn drivers of approaching work zones. This device is portable and lightweight and can be placed on the road at one or more locations ahead of the work zone, ideally just ahead of the warning signs and the flagger. This causes a jolt to the drivers and also lets out an audible rumble, alerting drivers of possible danger ahead. This device is made of durable neoprene rubber, measures about 10 ft long by 18 ft wide, and weighs just 75 lbs. It can be easily unfolded and placed in the proper location by one or two workers. This device is expected to be valuable in rural, flagger-controlled work zones where moderate to high-speed traffic is being channeled from two lanes to one. An evaluation of the portable rumble strips was carried out by the South Dakota DOT (1993), which determined that the portable rumble strips were not very effective in achieving the required results.

- **Radar Speed Monitoring Systems:** This system was developed to reduce vehicle speeds within work zones for added safety and traffic control. The system consists of a portable self-contained trailer unit equipped with a drone radar to measure the speed of on-coming vehicles. It also employs a variable speed display panel which displays the speed of the on-coming vehicle and advises regarding appropriate speeds within the work zone. This system has been reported as effective in reducing the speed of traffic approaching the work zone.

- **Safety Warning Systems:** These systems are basically used for work zone safety, and they utilize radio and microwave technology to enhance safety. Unmanned radar transmitters are used to collect traffic information at work zones, send signals to drivers, and warn them of road hazards and approaching work zones. These systems employ the use of variable message signs as a means of communication with motorists.

- **Lightweight Variable Message Signs:** The lightweight VMS are a means of communicating with motorists. They employ super LED technology to produce bright high-intensity messages to catch the attention of motorists. The lightweight characteristic improves their portability.

- **Radio Emergency Alert Communication Trailers:** This system consists of a mobile HAR radio station and an erectable flashing highway sign. The HAR technology allows direct communication between the transportation agencies and motorists as they approach the work zone. Standard AM automobile radio is used. The flashing sign tells the motorists which station to tune to for detailed information on traffic conditions and advice on what measures should be taken for a safer and easier journey.

- **Radar Congestion Monitoring Systems:** This system uses variable message signs equipped with radar to monitor congestion based on the speed measurements within the work zone. The congestion levels are monitored, and appropriate messages (real-time/dynamic) are displayed using the VMS to increase traffic safety and control.

While the above products and devices help in improving work zone safety and control to a certain extent, they lack certain real-time/dynamic capabilities that could be incorporated using advanced technologies and innovative systems. The advent of Intelligent Transportation Systems (ITS), including Advanced Traffic Management Systems (ATMS) and Advanced Traveler Information Systems (ATIS), have opened up avenues for developing a comprehensive system that integrates several technology components and operates in a dynamic fashion in real-time to address work zone issues. Based on past accident experiences on the I-81 Corridor in Virginia and the planned future construction and maintenance activities, it will be necessary to employ such real-time work zone systems to help reduce the impact of long-term and major construction activities on the flow of traffic. These systems may help reduce work zone-related fatalities, enhance safety and traffic control, and save valuable time, fuel, and money. The next chapter discusses the need for such dynamic/real-time systems and gives a descriptive update on the latest developments in this field.