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16. Abstract

This report summarizes the results of studies conducted in Texas to evaluate traffic control and safety at various types of work zones. Based on the study findings, recommendations for improving work zone traffic management, particularly at rural work zones and at freeway reconstruction sites, were made and are summarized herein. The following topic areas are specifically addressed:

1. Work zone accidents
2. Rural work zones
3. Freeway reconstruction work zones
4. Highway Advisory Radio
5. Work zone safety programs

This report is the final report in a series of seven which document the work conducted in Study 263. The other reports in the series are:

Report No.	Short Title
228-1/263-1	Annotated Bibliography
228-9/263-2	Changeable Message Signs and Highway Advisory Radio
263-3	Work Zone Accidents
263-4	Traffic Control on I-10 in Chambers County
263-5	Work Zone Traffic Safety Programs
263-6*	Rural Work Zone Traffic Handling

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TRAFFIC MANAGEMENT DURING FREEWAY RECONSTRUCTION AND IN RURAL WORK ZONES

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Research Report 263-7F

Traffic Management During Freeway Reconstruction
and in Rural Work Zones
Research Study 2-18-79-263

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The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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INTRODUCTION

Each year more and more maintenance and reconstruction activities are performed on our aging highway system. Unlike new highway construction, these activities are accomplished with vehicle traffic traveling past the work area. As a result, motorist and worker safety, as well as work zone traffic flow, must be considered.

The Manual on Uniform Traffic Control Devices (1) contains standards for handling traffic at work zones. The standards in the MUTCD are somewhat general and do not always provide adequate guidance to insure safe and efficient work zone traffic operations. In recent years, traffic safety and operational problems at work zones have grown in number and severity. In fact, they have become so frequent that in 1976 the Federal Highway Administration declared work zone traffic safety a national priority area (2).

Study Objectives

Study 263 was initiated in response to the national and local concern over work zone traffic safety. One purpose of the study was to determine the nature and extent of the work zone traffic safety problem in Texas. To accomplish this objective, over 8,000 work zone accidents occurring on Texas highways during 1977 were investigated.

Study 263 also evaluated traffic control and management at two particular types of work zones: 1) rural work zones and 2) freeway reconstruction work zones. Rural work zones were selected for study because they are so common in Texas and because they display a wide variety of traffic control practices. The objectives of the rural work zone investigation were to observe current

traffic control practices, identify resulting safety and operational problems, and recommend specific solutions to these problems. As part of the research, 17 rural work zones throughout the State were visited and evaluated.

The study of freeway reconstruction work zones was conducted in response to the growing number of these work zones statewide, and the tremendous impact which they have on area traffic operations. Two reconstruction work zones were evaluated as part of Study 263, one on I-45 in downtown Houston and the other on I-10 in rural Chambers County. Based on the results of field studies and motorist surveys, innovative traffic control approaches were documented and traffic management recommendations were prepared for the Department.

Study 263 also investigated the use of Highway Advisory Radio (HAR) for managing traffic at highway work zones. An HAR installation at a rural freeway work zone provided input for the investigation. This HAR system was evaluated in a series of "before and during" field studies. A questionnaire survey was administered to 53 motorists who were exposed to the HAR system to gain driver input on the performance of the HAR system. General guidelines for HAR use in work zones were developed based on the results of the field studies and motorist survey.

Midway through Study 263, the Federal Highway Administration issued an important directive to states dealing with work zone traffic safety (3). The directive, FHPM 6-4-2-12, required the Department to: 1) submit Traffic Control Plans for all Federal projects, 2) initiate a statewide employee training program, 3) modify traffic control bidding procedures, 4) inspect work zones for traffic control deficiencies, and 5) implement a work zone

accident reporting system. To assist the Department in evaluating their work zone traffic safety program, an objective was added to Study 263 to survey other states' work zone safety programs. Forty-four states responded to the survey. Many innovative and effective procedures and policies for work zone traffic control were identified as a result.

Reports

Study 263 began with a review of pertinent work zone literature. The findings of this literature review are summarized in Report 228-1/263-1 (4).

The remaining work performed as part of Study 263 is documented in the reports listed below. These reports are summarized in the following sections of this Final Report.

Title	Report No.
1. An Evaluation of Work Zone Traffic Accidents Occurring on Texas Highways in 1977	263-3
2. A Limited Review of the Handling of Traffic at Work Zones on Rural Roadways	263-6*
3. Feasibility of Changeable Message Signs and Highway Advisory Radio for Freeway Maintenance	228-9/263-2
4. Traffic Control at the I-10 Reconstruction Work Zone in Chambers County, Texas	263-4
5. A Review of Work Zone Safety Programs in Selected States	263-5

* Unpublished

ACCIDENT STUDY

Background

Several research studies have been conducted in recent years to evaluate the extent and nature of the work zone traffic safety problem (5,6). These studies have concluded that there is a serious accident problem at some work zones, and that work zone traffic control generally needs to be improved. None of the studies, however, addressed work zone accidents in Texas.

As part of Study 263, an evaluation of work zone traffic accidents occurring on state-maintained streets and highways in Texas during 1977 was conducted. The purpose of the evaluation was to determine the magnitude of the work zone traffic safety problem in the State (e.g., the number and severity of work zone accidents). The evaluation, which is documented in Report No. 263-3, also identified several factors which contribute to work zone accidents (7).

Data Collection and Analysis

Accident records in the 1977 Texas Master Accident File were the primary data used in the study. The File is compiled by the Texas Department of Public Safety and it contains collision and roadway information for every reported accident occurring on state-maintained streets and highways in Texas. The 1977 File includes data for over 227,000 accidents. Accidents in the Master Accident File were identified as work zone-related if they occurred at a detour, lane closure, maintenance, or construction site. Accidents which involved a vehicle hitting a work zone traffic control device or construction/maintenance machinery were also identified as work zone-related.

A standardized statistical analysis program (called S.A.S.) was used to select work zone accidents from the Master Accident File. The S.A.S. program package was also used to reduce and analyze the accident data. Work zone accidents were compared to total accidents to identify trends in work zone accidents as a group.

Extent of Accident Problem

In 1977, there were 7,936 reported work zone accidents on state-maintained streets and highways in Texas. This number represents 3.5% of the total accidents. It was concluded that work zone traffic safety is an apparent problem in the State and that work zone traffic control deserves the increased attention that it has received in recent years.

Accident Severity

There were 63 fatal work zone accidents on Texas highways in 1977, resulting in 73 deaths. There were an additional 2,879 injuries. On the average, however, 1977 work zone accidents were less severe than total accidents as indicated by the data in Table 1. From the table, there were approximately 90 deaths and 3,600 injuries per 10,000 work zone accidents. In comparison, there were 120 deaths and 5,300 injuries per 10,000 total accidents. (Total accidents include all reported accidents.)

Problem Location

The accident evaluation found that work zone accidents are a statewide problem. They occur in relatively large numbers in both urban and rural areas and at all types of work zones. They occur most frequently, however, at major reconstruction worksites in urban areas. For example, 10 freeway reconstruction

TABLE 1. INJURY AND FATALITY RATES FOR WORK ZONE AND ALL TYPES OF ACCIDENTS (TEXAS 1977)

Accident Category	Approximate Number Per 10,000 Accidents	
	Injuries	Fatalities
Work Zone	3,600	90
All Types	5,300	120

work zones accounted for one-fourth of the State's work zone accidents (over 2,000 accidents) during 1977. To further illustrate the contribution of major freeway work zones, the I-35 reconstruction work zone in Austin produced almost 70% of all the work zone accidents in the Austin area (Travis County) during 1977. Three major freeway work zones in Houston produced one-half of the work zone accidents in Harris County during the study year.

It should not be surprising that major freeway work zones experience high accident frequencies. Typically, these work zones create major traffic disruption (e.g., detours, lane closures, etc.) over long time periods. They also experience the highest traffic volumes.

Rural Work Zones

In 1977, approximately 20% of the State's work zone accidents occurred in rural areas. These rural accidents had similar characteristics to other work zone accidents with one notable exception. They were more severe. In fact, over one-half of the deaths and injuries resulting from work zone accidents occurred at rural area worksites. The greater severity of the rural work zone accident is attributed to the higher speeds in rural areas.

Accident Type

During 1977, a disproportionately large percentage of the work zone accidents involved two or more vehicles in a rear-end collision. Most of the accidents resulted when a vehicle collided with another vehicle which was slowing or stopped in response to a work activity. This suggests that the speed differentials among vehicles at work zones may be a primary contributor to work zone accidents.

Also in 1977, there were 53 pedestrian accidents reported at work zones. These accidents resulted in 4 deaths and 58 injuries. It was revealed that most of the pedestrians killed or injured at work zones are workmen or flaggers.

Truck Accidents

Trucks and truck-trailer combinations were involved in a disproportionately large percentage of work zone accidents (31%). This finding indicates that large trucks had difficulty traveling safely through some work zones and may suggest that the geometric design features of these work zones were inadequate for accommodating the special operating requirements of trucks.

There is another possible explanation for the high involvement of trucks in work zone accidents, however. A relatively high percentage of the 1977 work zone accidents occurred on Interstate highways. These facilities generally carry more large truck traffic compared to the remainder of the highway system. It is possible that this fact is related to the higher involvement of trucks in work zone accidents.

Nighttime Accidents

The accident data did not indicate that there was a serious nighttime accident problem at work zones in general. Only 27% of the work zone accidents in 1977 occurred at night, while 31% of total accidents occurred at night. It should be noted, however, that during 1977 there was not a great deal of work activity performed at night around the State.

Speed Violations

The study included an evaluation of driver violations contributing to work zone accidents. It found that speed violations contributed to 27% of the work zone accidents compared to only 15% for all accidents. These data suggest that speed control at work zones is critical to work zone traffic safety. There is a need to develop practical guidelines for speed control at work zones.

Geometric Design

Work zone accidents occurred more frequently at curves and on grades compared to total accidents. This finding suggests that these design elements should be considered in developing work zone traffic control plans.

Traffic Control

It was difficult to evaluate the influence of traffic control features on work zone accidents using the computerized data. However, the study results did suggest that two traffic control elements common at work zones (flaggers and no-passing zones) did not contribute significantly to the accident problem. Only 3% of the work zone accidents in 1977 reportedly occurred at work zones where a flagger was controlling traffic, and only 2

work zone accidents in 1,000 involved a vehicle attempting to pass illegally in a no-passing zone.

RURAL WORK ZONES

Background

The work zone accident evaluation revealed that approximately 1,600 accidents occurred at rural work zones in Texas during the one year study period, resulting in 39 deaths. These numbers were significantly high to warrant investigation into traffic control practices at rural work zones. Thus, as part of Study 263, field evaluations were made at various types of rural work zones throughout the State. The purpose of the field evaluations was to identify and recommend solutions to apparent traffic safety and operational problems.

Study Description

In July 1979, a questionnaire survey was conducted statewide to locate rural work zone study sites. Each District was asked to identify at least 5 rural work zones representative of the types of work zones which are most common and result in the greatest traffic safety hazard. Approximately 150 work zones were identified by the Districts. The work zone types most commonly cited were: 1) reconstruction, 2) bridge widening/repair, and 3) pavement overlays and sealcoats.

From the list of candidate work zone sites, 17 sites were selected for field evaluation. The sites represented a wide range of traffic volume conditions and roadway types (e.g., Interstate highways, two-lane FM highways, etc.).

Each of the work zone study sites was visited by a 2-4 man study crew. The crew documented traffic control procedures and devices used at each work

zone and observed traffic operations. The crew also collected traffic data when appropriate, including spot speeds, traffic volumes, lane distribution and accident data.

Areas of Needed Improvement

Based on the field evaluation results, 12 areas of needed traffic control improvement were identified. The areas are listed and briefly discussed below:

1. Speed Control -- It was observed that regulatory and advisory speed zone signing are not very effective in reducing vehicle speeds at rural work zones. Research sponsored by TSDHPT and FHWA is currently underway to develop and field test more effective speed control techniques.
2. Project Limit Barricading -- At the time of the field evaluations, the researchers noted several non-uniform applications of project limit barricading. Updated standards for barricading are presented in the Texas MUTCD (8) and in the Department's "BC" Sheets (9). As field personnel have become familiar with these revised standards, the problem of improper barricade use has decreased significantly.
3. Advance Signing on Intersecting Roadways -- Based on the evaluation results, advanced signs like the one shown in Figure 1 are recommended on roadways intersecting a highway which is under repair or construction. The Texas MUTCD and the Department "BC" Sheets now contain standards for the use of such signing.
4. Use of the Shoulder as a Bypass Lane -- The Texas MUTCD illustrates how traffic may be shifted onto the shoulder at work zones on two-lane, two-way highways (p. 6B-8.1). Based on the results of field

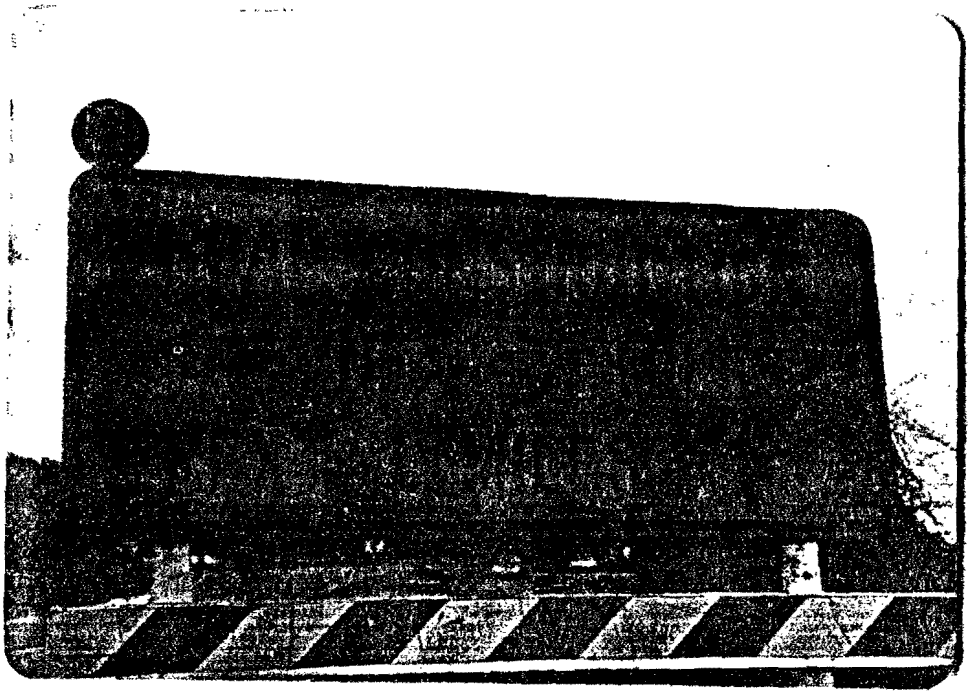
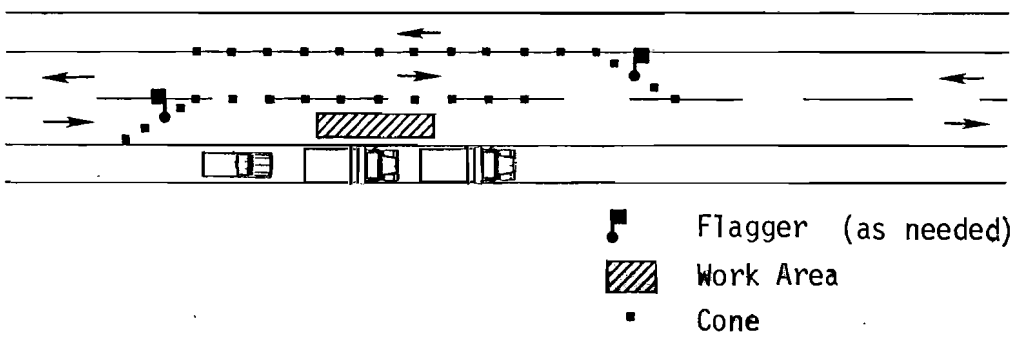


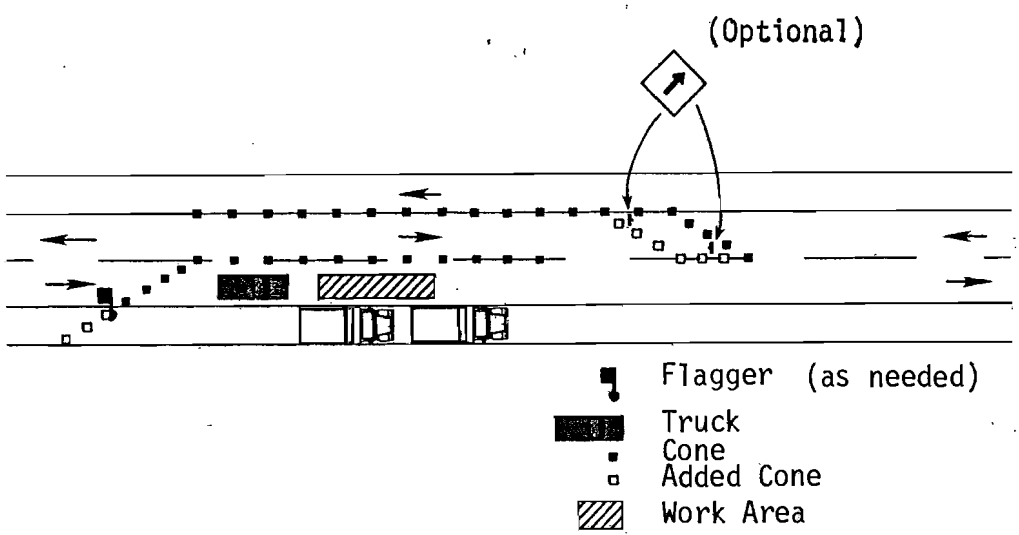
Figure 1. Advance Sign for Intersecting Roadways

studies, an improvement to the Texas MUTCD approach is suggested as shown in Figure 2.

5. Adjacent Projects -- Work projects often have overlapping boundaries. There is a critical need to coordinate traffic management and traffic control device placement in these situations.
6. Signing for Uneven Lanes -- The symbol sign (CW 21-14) currently recommended in the Texas MUTCD may indicate that the left or right lane(s) are higher. At some work zones, the inappropriate version of this sign is being used. Based on the field evaluations, there is also some confusion as to where uneven lane signs should be located (e.g., at the point of first drop-off or in advance of the drop-off). Additional guidelines may be needed in the MUTCD addressing these issues.
7. Flagging -- Additional guidelines are needed for determining when and how to use flaggers at rural work zones. In addition, all flaggers should be properly trained and attired.
8. Temporary Pavement Markings -- There were great inconsistencies observed in the use and types of temporary pavement markings. FHWA is currently sponsoring research to establish guidelines for work zone temporary pavement markings.
9. Road Closure and Detours -- During the studies, a variety of road closure and detour strategies were observed. It is suggested that this type of work zone should involve considerable traffic control planning. Special attention should be given to motorist communication at the closure point and along the detour route.



Observed Practice



Suggested Practice

Figure 2. Improvements to Traffic Control at Shoulder Bypass Work Zones

10. Shoulder Drop-off -- At the sites visited, a variety of approaches were used to protect and warn motorists at shoulder drop-off locations. There is a need to develop guidelines for uniform shoulder drop-off treatments and delineation devices. In addition, the situation illustrated in Figure 3 should be avoided (e.g., the drop-off delineation should generally not be outside of the drop-off).

11. Headwall and Railing End Treatments -- At a few sites, partially completed culvert headwalls or bridge rails were exposed to traffic as fixed objects hazards. There may be a need to protect motorists from such hazards during the construction period.

12. Construction Approach Warning Signs -- Approach warning at some of the work zones were placed at the beginning of the project limits. There were no other warning signs, even though the actual work area was several miles away. Thus, the signing was not very effective. The Department revised its "BC" Sheets in 1981 to discourage this practice.

Study Results

The rural work zone evaluations provided the Department with relevant information about existing traffic control practices and resulting problems for their internal use. The study findings and recommendations are documented in an unpublished report (10).

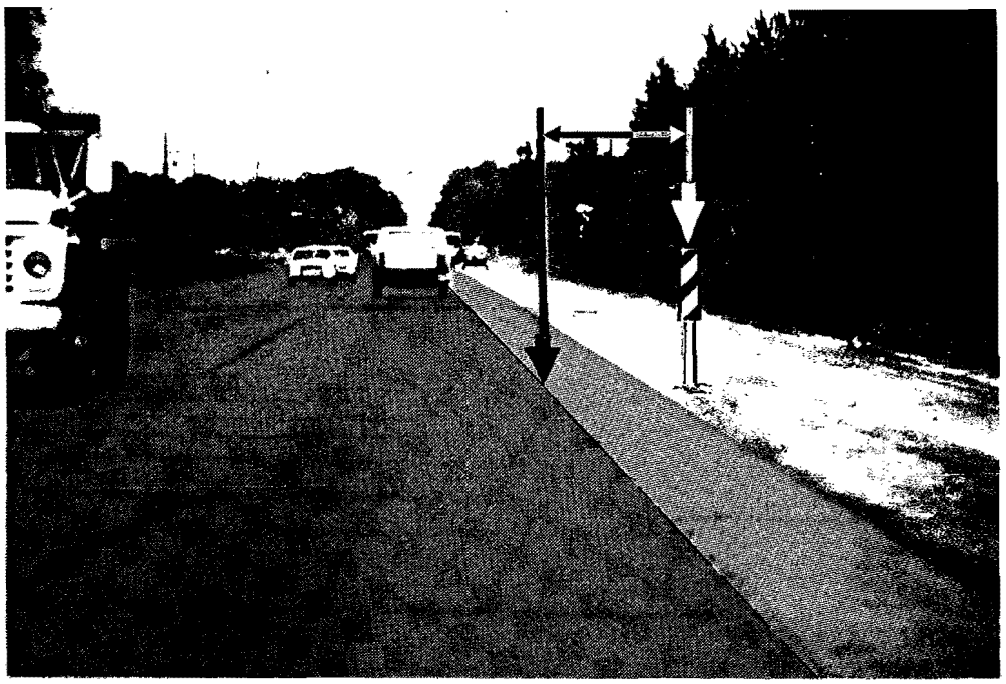


Figure 3. Improper Shoulder Drop-off Delineation

FREEWAY RECONSTRUCTION WORK ZONES

Background

As our freeway system ages, freeway reconstruction work zones are becoming more common. These work zones pose a special challenge in handling traffic due to certain inherent characteristics (i.e., heavy traffic volumes, high speeds, close proximity to CBD or other major traffic generators, etc.). As a result, traffic management approaches which minimize traffic congestion and interference must be used. Special steps must also be implemented to enhance traffic safety, since freeway reconstruction sites account for a large share of the State's work zone accidents (7).

The minimum standards presented in the MUTCD, when used alone, are simply not adequate at many freeway reconstruction work zones to accomplish the high level of safety and traffic service required. Oftentimes, innovative traffic management strategies and control devices must be used. Recognizing this fact, field studies were conducted at two freeway reconstruction work zones in Texas in order to document and evaluate certain innovative strategies and devices.

The first of these studies was at a work zone on I-45 (Pierce Street Elevated Section) in downtown Houston. The results of the study were documented in a series of technical memorandums and are summarized in this chapter. The second study was at a work zone on I-10 in rural Chambers County. The results from this study are discussed in the next chapter which deals specifically with the use of Highway Advisory Radio (HAR) at work zones. (HAR was used at the I-10 work zone, marking its first use at a work zone in Texas.)

I-45 Work Zone

In May 1978, major reconstruction of the Pierce Street Elevated Section on southbound I-45 began. The work involved replacing the deteriorating bridge deck on this 3/4-mile structure. Due to the high traffic volumes and close proximity to downtown Houston, the section could not be completely closed to traffic during the one year work period. Thus, it was necessary to implement one of the most elaborate work zone traffic control plans ever devised. The plan involved over 150 major signing modifications, closure of two freeway-to freeway connector ramps, and 77 miles of freeway diversion routes. It cost an estimated $750,000 to implement.

The primary traffic management approaches utilized in the traffic control effort are identified below:

1. To provide adequate work space, the normal 5-lane section with a shoulder was reduced in width to permit three 10-foot lanes with no shoulder. A concrete barrier was installed to separate the three narrow lanes from the work area.
2. Reducing the number of lanes from 5 to 3 substantially lessened the available work zone capacity. It was therefore necessary to reduce traffic demand at the work zone by closing two freeway connector ramps and diverting the traffic normally using the ramps around the work zone. The result, in the words of FHWA, was "the largest mass detouring system used on any construction project in the nation." The mass diversion of traffic was accomplished through an extensive overhead signing system which encompassed several freeways in the Houston area.

3. The bridge decking on the structure was deteriorating so rapidly that it was unsafe for truck traffic to use the structure. Load zone signing was installed to prohibit trucks over 8,000 pounds from the work zone. The truck traffic was diverted to an alternate freeway route.
4. In an attempt to enhance work zone safety, 35 mph speed zoning was implemented in advance of and through the work area. (The normal posted speed limit was 55 mph.)

Advance Notification Program

In an effort to forewarn the thousands of motorists that would be affected by the reconstruction project, the Department implemented the most comprehensive public information campaign for a single project in its history. The campaign was directed not only to the citizens of Houston, but reached statewide to inform the trucking industry and the general traveling public. The impending project was publicized widely through television, radio, and newspaper public service announcements, and through press releases to public and private journals throughout the State. Pamphlets were distributed to all workers in the downtown area to apprise them of the ramp closures and illustrate diversion routes.

Field Evaluation

While the work was in progress, a series of field studies was conducted to evaluate the performance of the various traffic management approaches. These studies included truck counts, spot speed measurements, and origin-destination (O-D) studies. Work zone accidents were also reviewed.

The findings of the field studies and accident analysis are summarized in the following sections.

Lane Width Reduction

The narrow lanes used at the work zone apparently had a significant effect on mean traffic speeds. From Figure 4, mean speeds decreased 3-8 mph through the narrow lane section. The data plotted in Figure 4 were collected under moderate flow conditions (e.g., 800-1000 vph/lane).

In addition, the use of 10-foot lanes apparently did not increase accidents at the work zone. The accident evaluation revealed that the number of accidents decreased during the work period and the accident rate remained constant. (The constant rate is attributed to the fact that traffic volumes also decreased during the project due to ramp closures and traffic diversion).

Ramp Closures and Traffic Diversion

Two freeway-to-freeway connector ramps were closed for the duration of the work. The ramps were physically closed by W-beam railing mounted on 55-gallon drums. This closure technique proved to be very effective and relatively maintenance free.

Many motorists normally using the closed ramps were encouraged to use alternate freeway routes by means of a diversionary signing system. Figure 5 shows two of the overhead signs in the system. This signing, combined with the advance publicity campaign, encouraged approximately one-half (47%) of the sign audience to voluntarily divert onto the most desirable alternate freeway route. This finding is based on data collected in the O-D studies. The drivers who did not respond to the special signing were mandatorily detoured to another alternate route upon reaching the closed ramps.

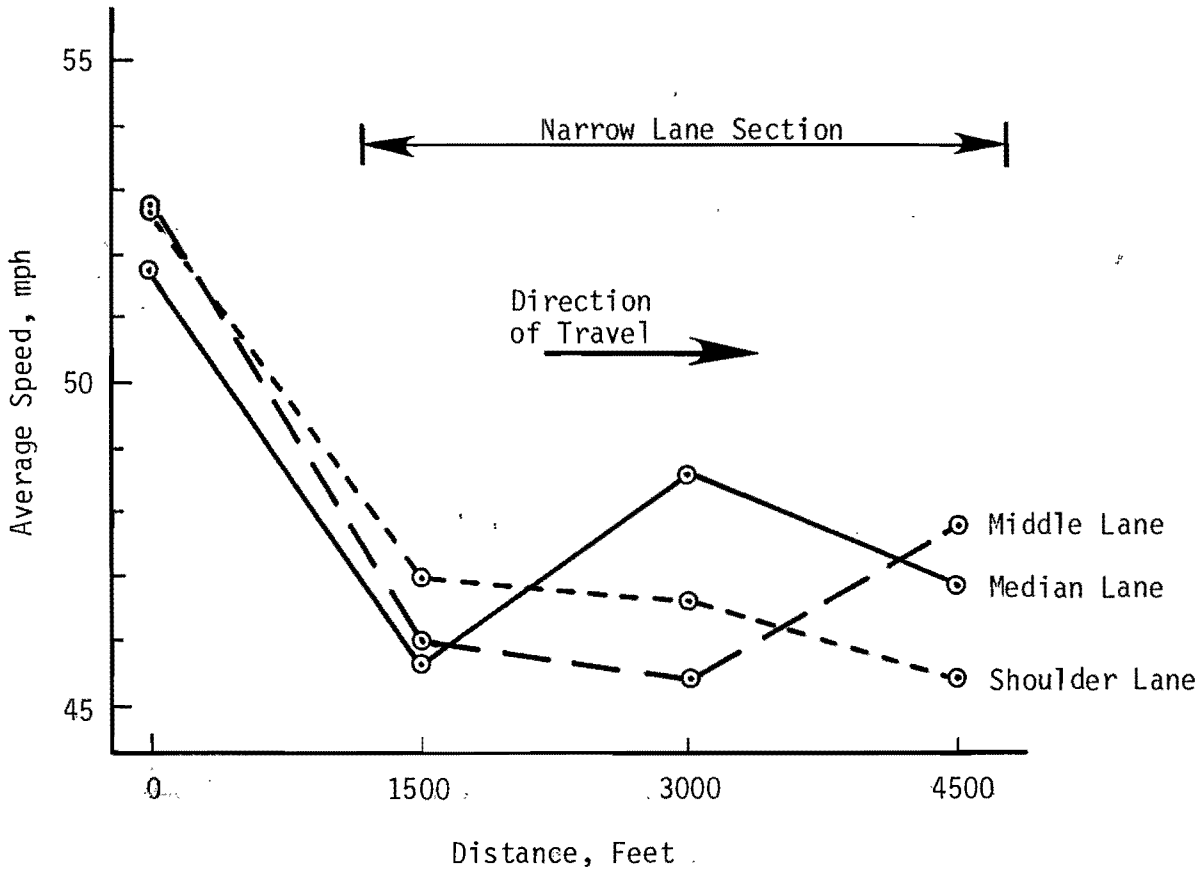


Figure 4. Observed Average Speeds by Lane at the I-45 Work Zone

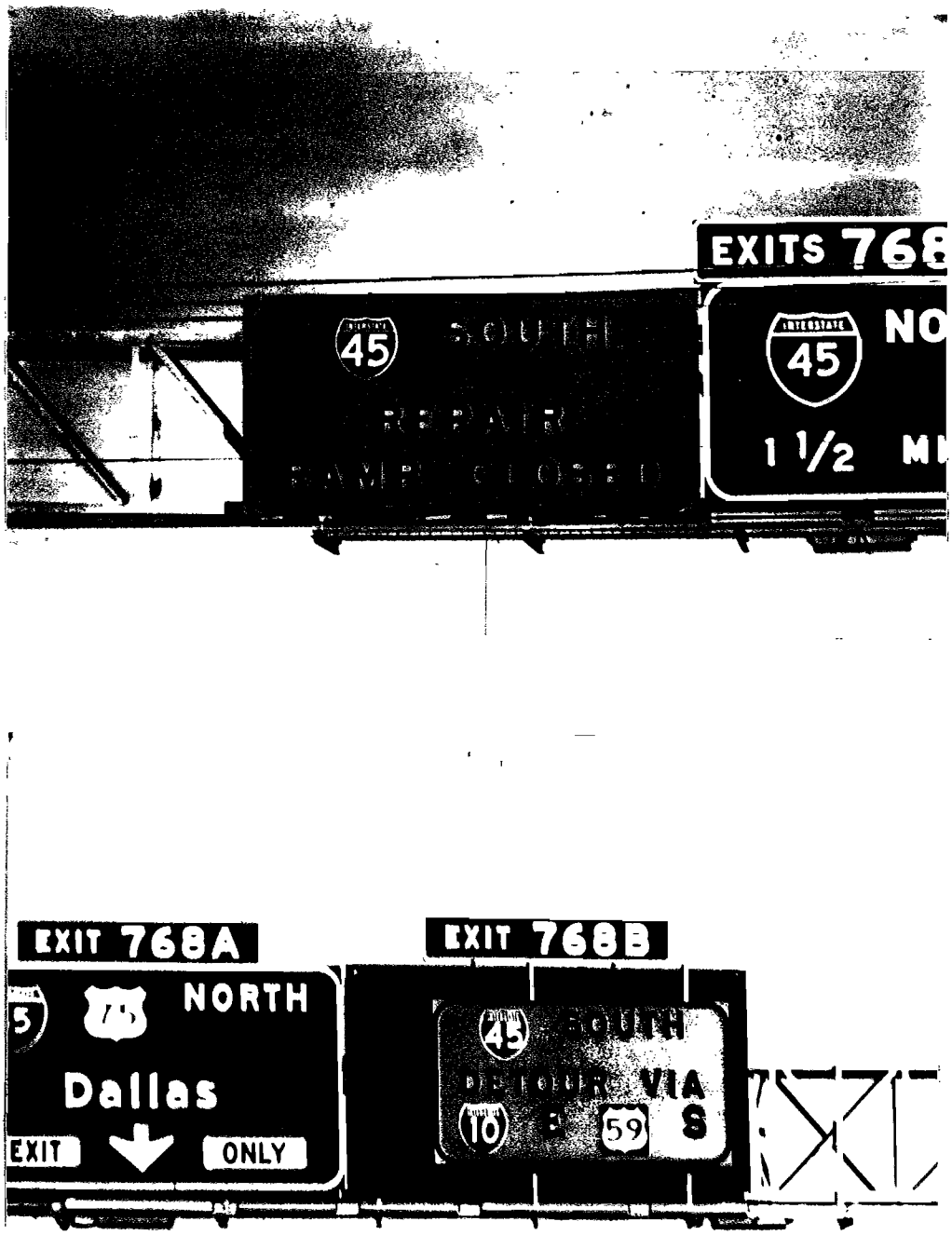


Figure 5. Special Diversion Signing at the I-45 Work Zone

The elaborate signing system was very effective in encouraging voluntary diversion. The system did, however, have one weakness. Motorists, once on the alternate route, were guided along the route by a series of black-on-orange overhead and ground-mounted "trail-blazer" signs. The "trail-blazer" signing was discontinued just before diverted motorists re-entered I-45 (their desired route). It was believed that the existing guide signing for the I-45 interchange would be sufficient to redirect motorists back onto I-45. Such was not the case, however, and up to 20% of the motorists failed to return to I-45 at the appropriate point. This deficiency was later corrected by adding additional "trail-blazer" signs through the interchange area.

Load Zoning

Vehicles weighing over 8,000 pounds were restricted from the work zone by special regulatory load zone signing. This load zone signing was supplemented by an elaborate detour signing system which directed displaced truck traffic to an alternate freeway route.

The load zoning strategy was very effective. Field observations revealed that the load zone violations were less than one per hour. The success of the strategy was enhanced by increased surveillance and enforcement by local police.

O-D studies did reveal an interesting response to the load zoning on the part of truck drivers. Although truck drivers were encouraged by diversionary signing to use a special freeway detour route, only 25% elected to use the route. The other 75% chose various other freeway and arterial routes which they felt were more suitable.

Reduced Speed Zoning

The reduced speed zoning using regulatory speed signs was totally ineffective. Studies showed that all of the drivers in a 400 vehicle sample were violating the 35 mph work zone speed limit. Over 90% were exceeding the reduced speed limit by more than 10 mph. The only apparent factor that effected speeds at the work zone was the narrow lanes.

HIGHWAY ADVISORY RADIO

Background

Highway Advisory Radio (HAR) is a means of providing motorists with pertinent traffic and travel-related information over their standard AM car radios. It is intended to supplement visual signing (e.g. conventional highway signs, changeable message signs, etc.) in those situations where signing alone is inadequate, inappropriate, or inefficient. In 1978, the Federal Communications Commission amended its regulations pertaining to HAR to permit greater areas of use. There have also been advancements in hardware and operational technology in recent years (11,12). These developments prompted the FHWA to encourage the use of HAR on a temporary basis at construction work zones.

HAR appears to have great potential as a traffic management tool at some types of work zones; however, there has been very limited experience with the use of HAR at actual work sites. As part of Study 263, a field evaluation of one of the first HAR work zone installations in the United States was conducted. This HAR system was used to divert traffic around a rural freeway reconstruction worksite. District 20 of the Texas SDHPT installed and operated the HAR system. The results of the HAR field evaluation are presented in Reports 263-4 and 228-9/263-2, and also are summarized in the following sections (13,14).

Special Traffic Management Approaches

The I-10 work zone studies provided the opportunity to observe other innovative traffic management approaches, in addition to HAR, applicable to

freeway reconstruction work zones (e.g., special signing and diversion of selected mainlane traffic to the frontage roads). These innovative approaches are documented in Report 263-4 and are discussed in the following sections along with the use of HAR.

Study Site

In early 1979, the mainlanes of a 14-mile rural section of I-10 in Chambers County midway between Houston and Beaumont, Texas were reconstructed. The work involved milling the existing pavement and placing additional base material and an asphaltic concrete overlay on the travel lanes. The resurfacing work was performed utilizing 4 construction phases. During each phase, the mainlanes in one travel direction (eastbound or westbound) were completely closed to traffic for approximately one-half the total project length.

Figure 6 shows the innovative traffic control strategy used to divert traffic around the portion of the work area closed to traffic. From Figure 6, all trucks and buses were required to use the open mainlane section to travel through the work area. This open side was temporarily converted to a two-lane, two-way roadway. Passenger cars, pick-ups and vans were diverted from the mainlanes and required to use the parallel frontage roads to travel around the work area. For the duration of the work activity, the two-way frontage roads were converted to one-way operation.

To inform motorists of the special traffic conditions and diversion routes at the work zone, an elaborate system of overhead and ground-mounted signs was installed at the worksite. A combination of channelization devices, including barrels, vertical panels, and paint markings, were installed at the diversion points on both ends of the work area.

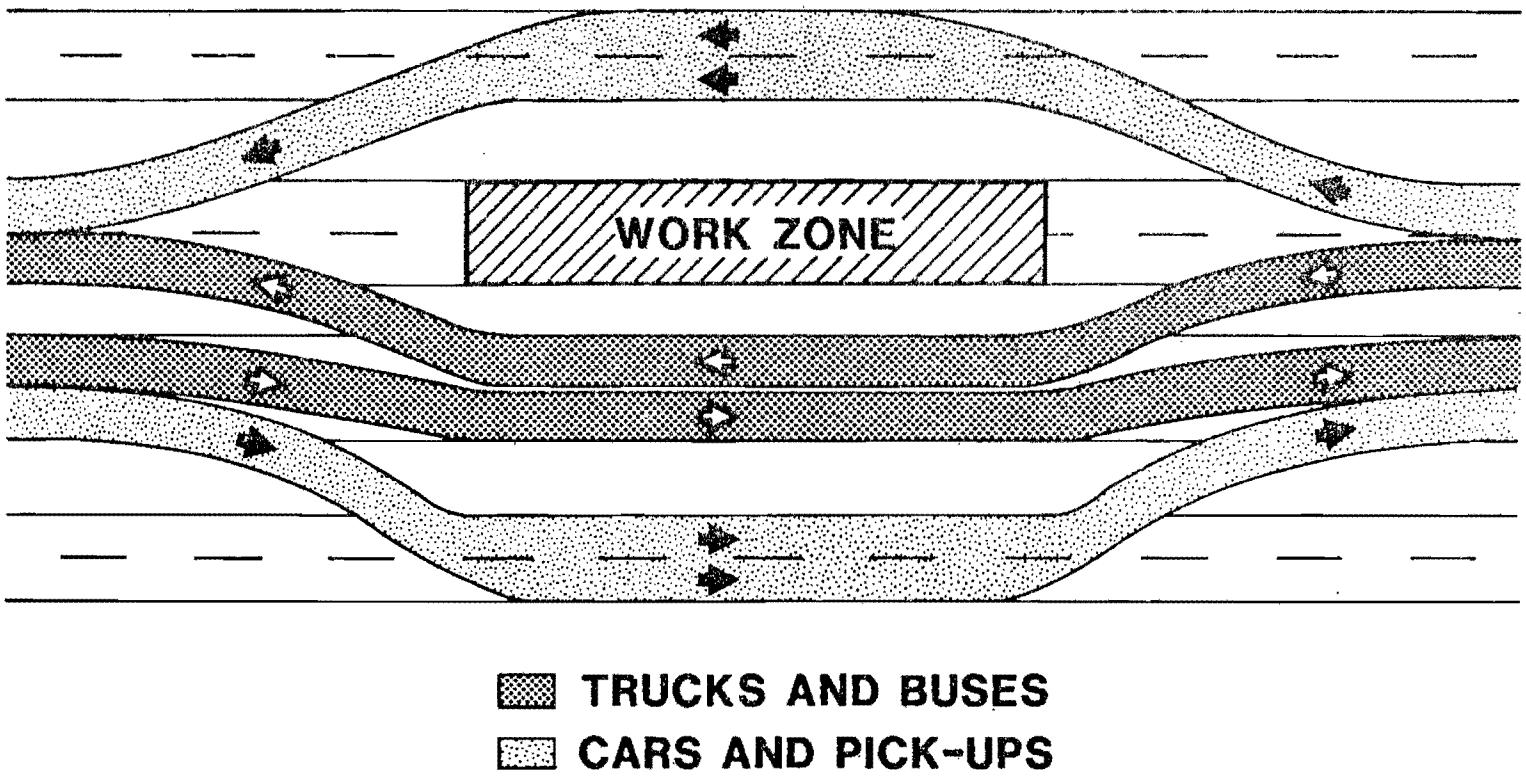


Figure 6. Work Zone Traffic Control Strategy

HAR Installation

Although every effort was made to effectively sign and channelize the work area, there was uncertainty regarding the safety and operational efficiency of the innovative traffic control strategy. Therefore, an HAR was used to supplement the visual traffic control devices. By the time the HAR equipment had been ordered and installed, and the system licensed, most of the road work had been completed, however. The HAR system was in operation for less than one month at the worksite. Nevertheless, this was sufficient time to evaluate the performance of the HAR.

Two 10-watt field transmitters were installed at the work zone, one on each end of the project. The transmitters broadcasted independently utilizing vertical monopole antennas tuned to 1610 kHz. A work zone traffic advisory message was recorded on 8-track cartridge and continuously broadcasted from both transmitter locations.

Motorists approaching the work zone, from either the east or west, were informed of the HAR broadcasts by a series of three signs shown in Figure 7. The first sign in the series was located 1-1/2 miles upstream of the transmitter and it instructed drivers to tune to 1610 one mile ahead for a radio traffic alert. The next sign, designating the beginning of the broadcast zone, was located 3/4-mile upstream of the transmitter. The last sign, located 3/4-mile downstream of the transmitter, designated the end of the radio zone.

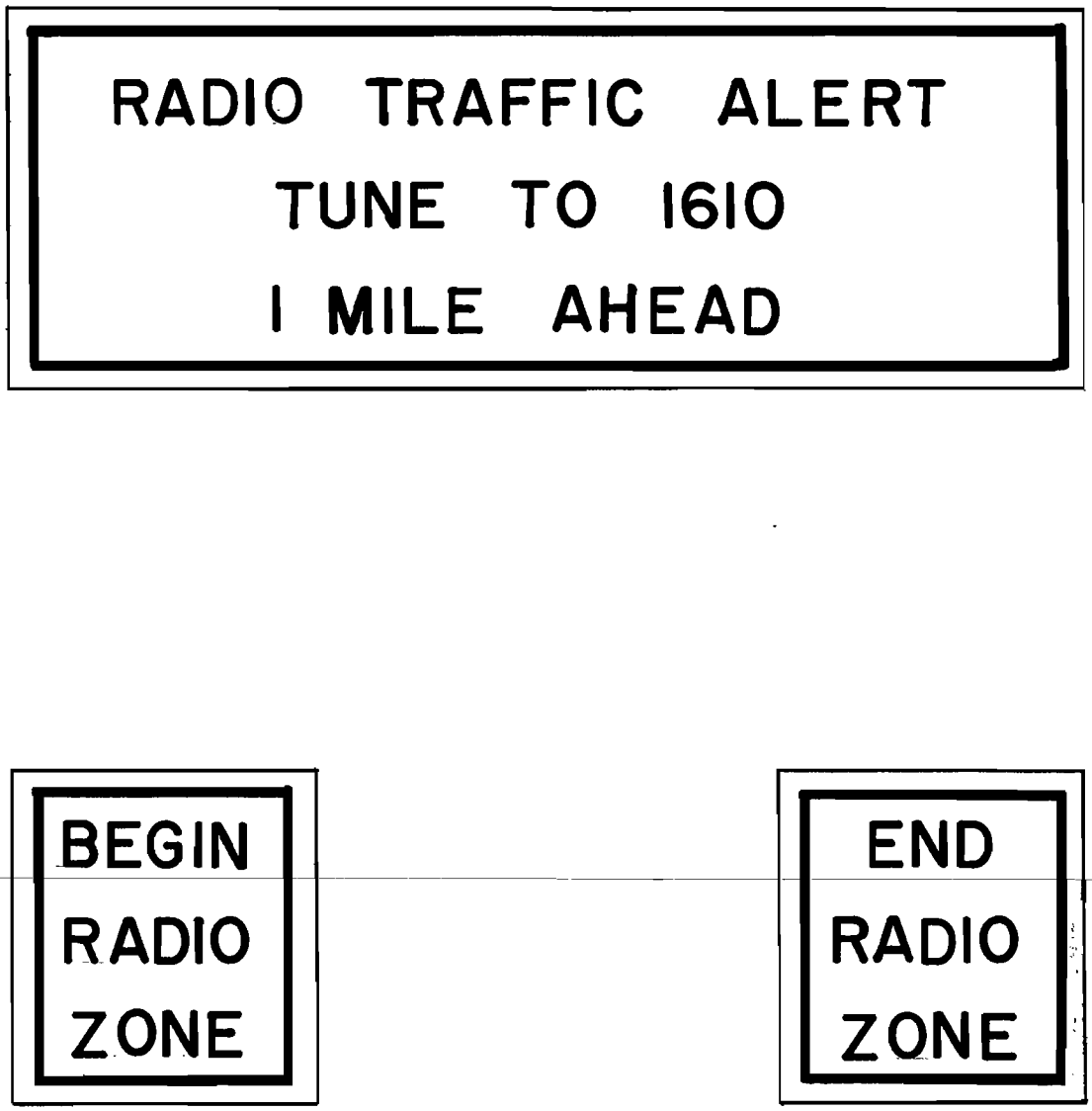


Figure 7. Advance Signing for HAR

Field Studies

Field Studies were conducted to evaluate the effectiveness of the innovative traffic control strategy and the HAR system in warning motorists of conditions at the work zone. They included speed, lane distribution, volume, and vehicle classification studies on the mainlanes and frontage roads. The studies were conducted one week before the HAR system was installed and a week after the system had been in operation, providing data for a "before and during" evaluation. In addition, a motorist questionnaire survey was administered to 53 motorists who had an opportunity to hear the HAR broadcasts.

Effectiveness of Innovative Traffic Control Strategy

The results of the field studies revealed that the innovative traffic control strategy used at the work zone (see Figure 6) was very successful, both with and without the HAR. Without the HAR, the conventional signs and channelizing devices encouraged up to 94 percent of all cars, pick-ups, and vans to use the frontage roads and the same high percentage of trucks to use the mainlanes. When the HAR system was installed, these percentages rose only slightly to 97 percent. As seen by these data, the innovative strategy was so effective with only the conventional signs and channelization devices that it was difficult to evaluate the additional influence of the HAR on traffic flow patterns.

Work Zone Accidents

A limited study of accidents occurring at the work zone was conducted. The study found that the number of accidents actually decreased during the

time period when the work activity occupied the roadway. Thus, the innovative traffic control strategy, with and without the HAR, provided an acceptable level of safety.

Speed Studies

Spot speed studies were conducted by District 20 personnel at several locations within the work zone. The speed data were collected during periods before and after implementation of the HAR system. The speed studies revealed that the 85th-percentile speeds of trucks (on the mainlanes) and cars (on the frontage roads) were above 60 mph. The posted speed limit on the mainlanes and frontage roads was only 50 mph in the work zone. The studies also indicated that the HAR broadcasts had no measurable effect on 85th-percentile speeds.

Motorist Survey Findings

As noted earlier, a questionnaire survey was administered to work zone motorists (passenger car drivers only). The survey data were used primarily to estimate the percentage of motorists who saw the HAR signing and the percentage that attempted to tune to the HAR station.

Table 2 shows the number and percentage of survey participants who attempted to tune to the HAR broadcasts, based on survey results. From the table, only 30 percent of the participants reported that they tried to tune to the HAR station. Most of those drivers who did not try to tune said they did not see the HAR signing. It was concluded that the advance signing for the HAR system was inadequate.

TABLE 2. FREQUENCY OF HAR USE BY MOTORISTS

Direction of Travel	Motorists Sampled	Number Attempting to Use HAR	Percent Attempting to Use HAR
Eastbound	25	8	32
Westbound	28	8	29
East and Westbound	53	16	30

Conclusions

The innovative work zone traffic control strategy shown in Figure 6 was apparently very effective and safe. Thus, the strategy may be considered as a practical alternative for handling traffic at work zones with characteristics similar to those at the I-10 reconstruction work zone. The strategy may be best suited for long term work projects, since commuting drivers will become familiar with the unusual traffic flow patterns. It is recommended that if the strategy is used, a well-planned system of traffic control devices (signs, channelizing devices, etc.) be installed and maintained for the duration of the project.

Even though the HAR did not improve traffic operations at the I-10 work zone, the studies indicated that HAR may have good potential for work zone traffic management in other applications (e.g., for displaying long or complicated diversion messages at long-term work zones). The studies also revealed that existing HAR hardware performs adequately. If an HAR system

is to be effective, however, the advance signing must be adequate. It is therefore recommended that the advance signing for a work zone HAR system on an urban or rural freeway be designed to at least the same standards as Interstate guide signing (e.g., same sign size, letter size, letter series, etc.).

In addition, guidelines need to be developed for the use and operation of HAR in work zones. These guidelines should identify conditions warranting the use of HAR at work zones. These conditions might include:

1. DELAY - Work zones where delay is excessive and more favorable alternate routes exist.
2. SIGNING EFFECTIVENESS - Work zones where normal construction warning techniques are ineffective or inappropriate.
3. ACCIDENTS - Work zones which have higher than normal accident and/or fatality rates.

WORK ZONE SAFETY PROGRAM REVIEW

Background

In response to the increasing number of work zone traffic accidents nationwide, FHWA in 1978 issued a directive concerning traffic control and safety on Federal-aid highway construction projects. This directive was incorporated into the Federal Highways Program Manual (FHPM 6-4-2-12) and it established the following policy guidelines (3):

1. *A Traffic Control Plan (TCP) must be prepared for all Federal-aid projects. A TCP is a plan for handling traffic through a work zone and may range in scope depending on the complexity of a project and resulting traffic interference.*
2. *A Responsible Person must be appointed by the highway agency to oversee traffic control on a specific project. This person must be properly trained in work zone safety and have full authority to implement the TCP.*
3. *Unit pay items should be established in the Construction Plan Specifications and Estimates for installing and maintaining work zone traffic control devices.*
4. *All persons responsible for the development, design, implementation, and inspection of traffic control at work zones must be adequately trained.*
5. *The safety of work zones in each state must be formally reviewed on an annual basis. Accidents occurring at each work zone must be monitored and continuously reviewed so that safety problems can be identified and corrected.*

As part of Study 263, a survey was conducted to determine how Texas and other states were responding to FHPM 6-4-2-12. Innovative and effective approaches used by other states were identified in the survey and were summarized for the Department. The findings of the survey are documented in Report 263-5 (15).

Survey Administration

The survey was mailed to appropriate highway agencies in all 50 states in January 1980. A total of 44 state highway agencies responded to the survey. The agencies provided information on their work zone traffic safety programs including formal written policy statements, procedural recommendations, traffic control plans and guidelines, flowcharts, checklists, descriptions of informal policies, normal procedures, etc.

General Response

The survey revealed that 84% of the 44 states surveyed prepared a formal written policy statement in response to FHPM 6-4-2-12 (as of January 1980). However, only about one-half of these policy statements address all 5 areas of concern in the Federal directive. Most of the policy statements are similar in content and wording to the Federal directive.

Traffic Control Plans

All 44 highway agencies surveyed currently require a Traffic Control Plan (TCP) for every Federal-aid highway construction project. Several of the agencies also require a TCP for all major construction projects, and a few have promoted TCPs for maintenance projects. At least 7 states have developed formal checklists and/or flowcharts for preparing TCPs.

Responsible Person

About half of the state agencies surveyed assign the traffic control responsibility to the Project Engineer. About one-fourth assign the responsibility to the Resident Engineer. The remaining agencies surveyed (again about one-fourth) normally give the responsibility for traffic control on a project to a subprofessional (e.g., a Project Inspector). One state currently requires the Responsible Person at a work zone to be certified.

Pay Items

There was considerable variation among the state agencies in the way they handle pay items associated with work zone traffic control. Only about 20% of the states use unit pay items exclusively, as recommended in FHPM 6-4-2-12. Fifteen of the responding states require unit pay items on special traffic control devices (e.g., barriers, illumination, etc.), and permit lump sum bidding particularly on very small projects. One agency surveyed reported that it still allows traffic control at all work zones to be bid as an incidental item.

Training

All the state highway agencies interviewed have initiated statewide programs to train their employees in the fundamentals of work zone traffic control and safety. Approximately one-half of the states are sponsoring preexisting courses for this purpose (e.g., the National Highway Institute (NHI) or Institute of Transportation Engineers (ITE) courses on work zone safety). Several states have developed and administer their own training courses. Two states reported that they paid a consultant to develop and administer their training courses.

In addition, 4 of the responding state agencies sponsor several different training courses aimed at different levels of employees (e.g., supervisors, foremen, work crew, etc.). Seven of the responding states are attempting to train city, county, and/or contractor employees.

Statewide Program Reviews

FHPM 6-4-2-12 requires each state to conduct annual reviews of safety and traffic control at randomly selected work zones. From the survey findings, some states designate a multidisciplinary group to conduct these reviews (e.g., representatives from design, construction, maintenance, traffic, etc.). Other states assign the review task to a single department (e.g., traffic safety).

One state has two teams which annually review work zone safety at selected sites. One team conducts field evaluations, while the other collects and analyzes historical accident information. About one-half of the states surveyed formally invite local FHWA representatives to participate in their review program.

Accident Evaluations

Many states reported that they have difficulty collecting and analyzing work zone accident data in a timely manner. Usually, the highway agencies must interact with other state and local agencies to obtain accident data, and time delays are experienced. It is also difficult to properly locate work zone accidents relative to traffic control features.

Twenty-two of the responding states indicated that they have adopted statewide policies and procedures for the collection and analysis of work zone accident data. There is great variation among the states which do have

policies and procedures regarding how the data are collected and who collects the data.

CONCLUSIONS AND DISCUSSION

Study 263 revealed that certain work zones on Texas highways are plagued by traffic safety and operational problems. The Study indicated a particular need to enhance traffic management at freeway reconstruction work zones and rural highway work zones. Freeway reconstruction work zones, for example, produce the largest number of work zone accidents in the State, and they generally result in serious traffic disruptions. Rural work zones account for most of the State's work zone deaths and injuries.

The Study found that work zone safety and operational problems stem from a variety of sources. Some deficiencies result from the failure to implement existing standards and technology. Others result from voids in technology and their improvement requires the implementation of innovative traffic management strategies and/or traffic control devices. Study 263 addressed both of these problem sources. Common misapplications of traffic control strategies and devices were identified and reported to the Department, and several innovative traffic management approaches were evaluated including: HAR, selective frontage road diversion, freeway-to-freeway diversion, and work area load zoning. The Study provided useful and timely input to District and Division personnel in their efforts to enhance work zone traffic safety and flow.

Study 263 also found that the Department's work zone traffic safety program compares favorably to programs in other States. Based on the research findings, however, there is an apparent need to develop guidelines for TCP preparation. Specifically, the Districts need guidance for determining the scope and extent of TCPs for various types and sizes of projects.

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APPENDIX

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F