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16. Abstract

Urban arterial work zones have several unique characteristics which have not been addressed in previous work zone research. This research study was established to identify these characteristics and to develop guidelines for traffic control in urban arterial work zones.

Study activities -- including a literature review, analysis of accident, traffic volume, and travel time data from three study sites, surveys of motorists, a study of arterial lane closure capacity, and analysis of other factors -- were used to identify the unique characteristics of urban arterial work zones and develop the guidelines to related to those unique characteristics. A number of guidelines were developed addressing several topics including: project and work activity scheduling, construction planning, speed control, intersections, signalized intersections, construction signing, lane closures, channelizing devices, median crossovers, pavement markings, public relations, accidents, and inspection of traffic control devices.

This Technical Report (Volume 2) describes all of the study activities in detail. It also describes the basis for each of the guidelines developed in the course of this research study. Volume 1 of this report is an Executive Summary which includes all of the guidelines, but not the basis of those guidelines. It also includes a brief description of all the study activities.

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	centimetres	cm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	centimetres squared	cm^2
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yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

TEMPERATURE (exact)

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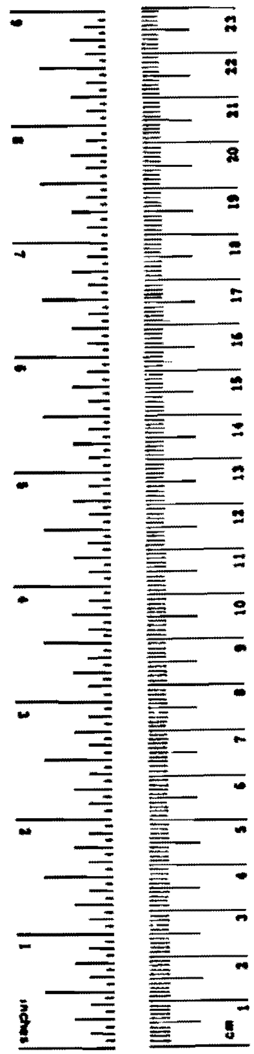

APPROXIMATE CONVERSIONS TO SI UNITS

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m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
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km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

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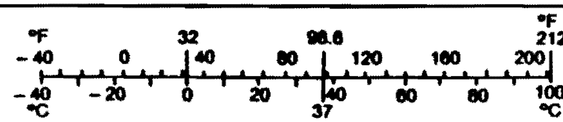

These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

TRAFFIC CONTROL GUIDELINES FOR URBAN ARTERIAL WORK ZONES

VOLUME 2 - TECHNICAL REPORT

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Research Report 1161-5, Volume 2
Study Number 2-18-89-1161

Design Process for Work Zone Speed Control
and
Traffic Control Guidelines for Urban Arterial Street Work Zones

Sponsored by
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IMPLEMENTATION STATEMENT

The objective of this study was to develop improved traffic control guidelines applicable to urban arterial work zones. The study identified many characteristics unique to urban arterial work zones and developed numerous guidelines related to the planning of urban arterial work zones and the implementation of traffic control in these work zones. These guidelines should lead to improved operations and safety for both workers and drivers in urban arterial work zones.

DISCLAIMER

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SUMMARY

This three-year study evaluated two aspects of work zone traffic control. One objective of the study was to develop guidelines for traffic control in urban arterial work zones. This report describes the activities and findings of that objective. The second objective of the study was to develop a comprehensive design process for selecting and implementing appropriate speed zones, devices, and techniques for speed control in work zones. The results of research on the second objective are reported in Research Report 1161-6.

Urban arterial work zones have several unique characteristics which distinguish them from rural highway or freeway work zones. Among the most important of these characteristics are relatively low speeds, higher speed variations, high volumes, limited maneuvering space, frequent turns and cross movements, limited right-of-way, multiple access points, higher pedestrian movement, and frequent traffic obstructions. These characteristics were evaluated through the completion of several research activities which included a literature review, analysis of accident, traffic volume, and travel time data from three study sites, surveys of motorists, and a study of arterial lane closure capacity.

The literature review indicated that there is a lack of information and previous research on urban arterial work zones. However, some of the information identified in the literature review has application to specific aspects of urban arterial work zones. Three urban arterial work zone study sites, two in Houston and one in Dallas, were selected for study. Accident, traffic volume, and travel time data were collected at all three sites. This data was then analyzed to determine trends specific to urban arterial work zones and to identify characteristics of arterial work zones which needed to be addressed in the guidelines. The analysis of accident data indicated that accidents do increase when construction begins on an urban arterial. Intersection and driveway related accidents increased more than the average amount due to the construction. The analysis of traffic data indicated that traffic volumes typically decrease during construction, and that they are lowest when the work area is in the center of the road between opposing traffic flow. No specific trends could be determined from the travel time data.

Motorists were surveyed in two separate surveys conducted in Houston and Dallas, attempted to evaluate driver comprehension of a variety of construction traffic control devices and to identify some of the more significant driver concerns related to urban arterial construction.

Other study activities included a survey of local traffic engineers addressing their concerns about urban arterial work zones. This survey confirmed earlier findings about the lack of useful guidelines and helped to identify specific concerns. The capacity of a urban arterial lane closure was also measured and found to be approximately 50 percent of the capacity of a freeway lane closure. This information was used in an analysis of traffic flow at a lane closure located downstream of a traffic signal. The analysis provided the minimum separation needed between the intersection and lane closure to prevent queue backup.

A research activity related to this topic, but not part of this study, was the development of a low-profile temporary barrier for use on low speed arterials. This barrier was developed by TTI at the same time that this research was taking place. It is briefly described in this report.

The results of these research activities were used to develop a series of guidelines addressing traffic control planning and implementation of urban arterial work zones. The guidelines address a variety of topics including: project and work activity scheduling, construction planning, speed control, intersections, signalized intersections, construction signing, lane closures, channelizing devices, median crossovers, pavement markings, public relations, accidents, and inspection of traffic control devices. These guidelines and the basis for them are described in Chapter 9 of this report.

CHAPTER 1
INTRODUCTION

The arterial street systems of major Texas cities are being forced to carry an expanding share of the traffic burden as a result of the continued increase in congestion on the freeways in these cities. The Texas Department of Transportation (TxDOT) recognized this fact and in September 1987, the Highway Commission gave approval to a $100 million project for the overhaul and upgrading of major urban arterial streets. The intention of this program is to relieve a portion of freeway traffic congestion by providing additional capacity and improving traffic flow on urban arterials. This ambitious program is entitled PASS (Principal Arterial Street System) and is fully endorsed by the cities of Arlington, Austin, Corpus Christi, Dallas, El Paso, Fort Worth, Houston, and San Antonio.

Successfully completing the construction associated with the PASS program requires the assurance of safety for motorists and workers within major urban arterial work zones while maintaining traffic at acceptable speeds and volumes. Urban arterial work zones possess many unique characteristics not found in rural or freeway work zones. Some of the major differences between typical work zones and urban arterial work zones are described below. The unique characteristics of urban arterial work zones require special consideration when preparing a traffic control plan for construction. Unfortunately, urban arterial work zones are not sufficiently addressed in current work zone guidelines and the topic has not been adequately addressed in previous research. Therefore, this research study was funded in order to identify the unique characteristics of urban arterial work zones and to develop guidelines addressing the planning and implementation of traffic control for major urban arterial work zones.

Arterial Work Zone Characteristics

Urban arterial work zones have several characteristics that differentiate them from other types of work zones. These unique characteristics are primarily related to geometrics, traffic conditions, traffic signals, and limitations on work zone traffic control.

Urban Arterial Geometrics

Urban arterials have a combination of geometric characteristics unique to this type of facility. Operational speeds of arterials are typically lower than those found on rural highways or freeways. Urban arterials also have many more intersections and driveways per mile than rural highways. Urban arterials can be undivided, with no protection for left-turning vehicles, they can be divided with a raised median that provides left-turn bays at specified intervals, or they can be divided with a flush median that typically serves as a continuous two-way left-turn lane providing access to all driveways and intersections. Flush medians are also used by some drivers as acceleration lanes when turning left onto the arterial. Median barriers, which are common on freeways and rural highways, are rarely used on urban arterials.

Many properties located along an arterial have access directly to the arterial, as opposed to having access to a street intersecting the arterial. Some level of access must be provided to all properties along an arterial during construction. This requirement has an impact on the amount of the arterial which can be under construction at any given time and, in addition, has an impact on the construction phasing. The large amount of access through driveways and intersections also impacts the use of barriers during construction.

The right-of-way for urban arterials is often limited and typically restricted. This usually requires narrow lanes for construction and limits the amount of roadway which can be under construction at any one time. The inability to provide a buffer zone between traffic and the work area creates a need for barrier protection. However, the barriers currently available for arterial work zones have limitations, such as potential sight distance restrictions, numerous end treatments, and limits on the area available for deflection.

Urban Arterial Traffic Conditions

There can be differences in the speed limits between urban arterials, and there can also be significant differences in the actual operating speeds of vehicles on a given urban arterial. The differences in operating speeds between different arterials depend on the geometrics and traffic volumes of the road. Differences in vehicle speeds on a given arterial are mainly due to vehicles entering and leaving the traffic stream and the presence of signals and other traffic control devices. The variations in speeds that exist between different arterials or between vehicles on a single arterial are generally greater than those existing on rural highways or freeways.

The frequent turning and crossing movements are unique to arterials and present numerous challenges to traffic control in a work zone. These movements are created by the many driveways and intersections present on an urban arterial. The geometrics of the driveways and intersections require vehicles to slow to speeds below the speed limit and usually below the operating speed in order to perform a turning maneuver.

Pedestrians are another characteristic unique to urban arterials. Pedestrians are present in larger numbers on arterials than on rural highways or freeways. The primary concerns associated with arterial pedestrians are crossing protection at intersections and providing a walking area along the arterial.

Traffic Signals on Urban Arterials

Urban arterials have many more traffic signals per mile than other types of major roadway facilities. While these signals serve an important traffic control function, in doing so they typically prevent continuous traffic flow over the entire arterial. Progression can be provided to allow platoons of traffic to travel long segments without being stopped by a signal. However, the effectiveness of progression is dependent on the signal operation, turning traffic between signals, and traffic volume levels. Unfortunately, progression can be negatively impacted by construction activities on the arterial. Construction activities may also eliminate the detection capability of actuated traffic signals, requiring them to operate in a pretimed mode.

Limitations on Work Zone Traffic Control

The characteristics listed above affect how traffic control devices are used in urban arterial work zones. The many driveways and intersections may limit the ability to provide advance information of work zone activities. If a barrier is used, these locations create the need for many barrier end treatments. Additionally, the height of temporary barriers may create a sight distance restriction.

Queues forming as the result of lane closures or signal operation may block upstream driveways and intersections. Narrow lanes may make it more difficult for vehicles to turn into or out of driveways and intersections. The demands of construction phasing may limit the availability of locations for making left-turns, thereby concentrating left-turn demand at a limited number of locations. There are also many more driver distractions in the urban environment and traffic control devices must compete against these distractions.

Study Objectives

Research study 1161 is a three-year study intended to address two work zone issues. These issues are urban arterial work zones and work zone speed control. The study objectives associated with these two issues are:

1) Develop improved guidelines for selecting and implementing work zone traffic control on urban arterials.
2) Develop a comprehensive design process for selecting and implementing appropriate speed zones, devices, and techniques for speed control in work zones.

The research activities associated with the first objective are described in this two-volume report. Volume 1 of Report 1161-5 is an Executive Summary focusing on the guidelines resulting from the study activities. Volume 2 (this volume) describes the study activities in detail and also describes the basis for the guidelines developed in the course of the study. Previous research reports (1161-1 (1) and 1161-3, Volumes 1-3 (2, 3, 4)) described the urban arterial work zone research associated with the first and second year of the study, respectively. Research efforts related to the work zone speed control objective are described in research reports 1161-2, 1161-4, and 1161-6.

CHAPTER 2
LITERATURE REVIEW

The first effort of the research study was to conduct a literature review in order to identify publications addressing work zone traffic control for urban arterials. Pertinent information was collected and used to determine areas not sufficiently addressed and to develop potential guidelines for urban arterial work zone traffic control. The literature review was initiated with a computerized search of the Transportation Research Information Service (TRIS) data base. Additional information not cited in the TRIS search was also identified through reference lists and other sources. The publications identified in the search address a wide variety of issues related to work zones. It was found that the majority of work zone literature addresses freeway or rural highway work zones. Little research was found that specifically addresses urban arterial work zones, although specific aspects of arterial work zones are briefly addressed in some of the literature. The information that was identified as pertinent to the study was collected and reviewed for applicability to the development of arterial work zone guidelines.

Guidelines for work zone traffic control on urban arterials have not been developed to the same extent as rural highways and freeways. This lack of useful information on urban arterial work zones has been confirmed by a previous research study (5). As a result, rural and freeway work zone guidelines found in the *Texas Manual on Uniform Traffic Control Devices* (MUTCD) (6) and the *Traffic Control Devices Handbook* (TCDH) (7) have been applied to urban arterial conditions. Sometimes, these guidelines have been modified or adapted to fit the demands of urban arterials, without any research support for the changes.

The literature review addresses a number of specific issues related to urban arterial work zones. Some of these issues include the traffic control plan for urban arterial work zones, the application of MUTCD standards to traffic control devices in urban arterial work zones, the use of traffic control devices in urban arterial work zones, and driver behavior in work zones.

Traffic Control Plan

The Traffic Control Plan (TCP) is a part of the construction plans that show the type and placement of traffic control devices to be used in each phase or stage of a construction project. The traffic control plan process assures adequate consideration for safety. The detail needed in the TCP depends on the complexity of the work and on the conflicts between traffic flow and the construction activities.

Purpose and Considerations of a Traffic Control Plan

The purpose of the traffic control plan (TCP) is to permit the contractor to work efficiently and safely while maintaining a safe, smooth flow of traffic. The goals of a TCP should be to: maximize motorist safety, maximize worker safety, minimize traffic delays, maintain existing operational speeds, and maintain existing traffic flow rates. The development of the TCP requires the consideration of a number of factors to determine the best manner in which traffic can be safely guided through the work zone. Table 2-1 lists some of the most important factors to be considered in developing a TCP for an urban arterial work zone.

Findings of Traffic Control Plan Evaluations

A 1981 study entitled *Effectiveness of City Traffic-Control Programs for Construction and Maintenance Work Zones* (8) evaluated the present state-of-the-art of city (i.e., urban) traffic control programs for construction and maintenance work zones. The study consisted of two efforts: 1) a survey of 49 cities, and 2) field inspections of work zones in 8 of the 49 cities. The general findings were that the importance of work zone traffic control programs varied widely, and the majority of the cities surveyed could do a better job of controlling construction and maintenance activity in urban arterial work zones.

Table 2-1. Traffic Control Plan Considerations

Economic and Community	Commercial business districts. Residential locations. Recreation areas. Shopping centers. Railroad crossings. Other work planned adjacent to or within the area of the project. Public information programs.
Traffic	Volumes. Peak hours (including holiday, special event and recreation traffic). Pedestrians and bicycle traffic. Large vehicles such as trucks and buses. Speed of traffic. Capacity of roadway. Traffic signal operation (including effect on existing vehicle detectors). Transit routes and bus stops.
Seasonal Changes and Weather	Maintaining traffic control during seasonal shutdowns. Loss of visibility and damage to devices during rain or snow. Drainage during heavy rain. Temperature restrictions for some phases of construction. Maintenance of traffic control devices.
Worker Provisions	Parking of private vehicles. Protection. Flaggers. Access to each part of work area and break area.
Potential Hazards	Potential hazards created by the work activity within the recovery area such as boulders, drainage basins, pipe headwalls, blunt ends of guardrail, and sign supports.

Source: Reference (3)

In the first effort of the study, existing city programs were analyzed through a questionnaire that was sent to 100 cities with populations between 50,000 and 1,000,000. It consisted of a series of 12 questions addressing four general areas: 1) permit and authorization procedures, 2) development, approval, and implementation of a traffic control plan and field inspection, 3) enforcement and training policies, and 4) general problems and areas for improvement identified by the cities.

Evaluation of the questionnaire was split into two groups: 1) answers to five rated questions that determined how active a role the cities had in regulating the traffic control for construction and maintenance activity, and 2) seven non-rated questions that determined typical practice for the cities. A significant finding of the study was that, although the majority of cities' traffic control programs were less than satisfactory, 60 percent thought they had an adequate program. The findings also indicated that cities, in general, do not place heavy emphasis on urban traffic control. This was evidenced by the fact that primary responsibility for developing and inspecting traffic control did not lie with the cities, and that most cities did not conduct training programs.

The second effort of the study, a field investigation of 8 sites, was conducted using a panel of traffic control experts to review slides of construction and maintenance zones in 8 of the survey cities. Deficiencies at each of the work zones were ranked on potential hazard, risk, and preventability. The results of the field investigation indicate that the quality of the traffic control in work zones is dependent on the degree of involvement the cities have in regulating construction and maintenance work zones. Good traffic management programs are apparently effective in achieving improvement in traffic control through work zones.

The findings of this research are significant because they indicate that there are weaknesses in traffic control on urban arterial work zones. The reasons for the weaknesses are not fully apparent from the questionnaire results, but the results do indicate that agencies need to be informed of the need for better and more effective traffic control.

An Alabama study entitled *Work Area Evaluation of Traffic Control Devices* (9) performed a comprehensive evaluation of implemented traffic control plans so that more effective guidelines for work area traffic control could be developed. The principle objectives were to assess current practices in the design, installation, and operation of work area traffic controls and to provide quantitative information on the effects of traffic control devices on motorist behavior in construction work zones. Three work zone sites were selected for evaluation, one of which was an urban arterial involving construction of an urban interchange.

The majority of the analysis used speeds in different sections of the work zone to evaluate the effectiveness of the traffic control devices. Comparisons were also made between the TCP and the field reviews of the work zone. Table 2-2 describes the findings, conclusions, and recommendations of this research study.

Table 2-2. Urban Arterial Work Zone Research Results

Findings
• Motorist confusion in distinguishing between signs for frontage road traffic and those for detoured cross street traffic. • Lack of advisory speed signs at warranted locations. • Motorist confusion due to the large number of traffic control devices competing for attention. • Motorist difficulty in following guide signs for a designated route. • Unusually short lengths of crossovers for the prevailing speeds. • Unusually short spacing between successive construction signing. • Inadequate pavement markings on entering a detour route. • Improper placement of some traffic control devices. • Inadequate continuous visibility of some construction signing. • Inconsistencies between advisory and regulatory speed limit signs. • Improper storage of traffic control devices. • Damaged traffic control devices.
Conclusions
• The field installations were found to be in compliance with the appropriate traffic control plans. • Traffic control plans prepared without sufficient consideration of the specific horizontal and vertical alignment characteristics at the construction site are not effective. • Advance warning signs were found to be inconsistent in their effect on reducing motorists' speeds. Variances, such as visible construction activities, sight distances, lane changes, and detours were found to be more critical in causing speed reductions. • Advance speed signs in construction work zones are not effective in controlling speeds unless drivers perceive that such speeds are reasonable for the locations at which they are used. • Excessive use of traffic control devices on construction projects reduces the effectiveness of individual devices.
Recommendations
• Design the traffic control plan to fit the existing alinement characteristics at the project location. • Avoid the use of on-site detours to the maximum possible extent. When unavoidable, use higher traffic control standards for on-site detours, particularly in transition areas. • Design traffic control plans requiring reductions in prevailing approach speeds only when necessary. • Use advisory speeds carefully in construction work zones, recognizing that it may be necessary to supplement such speed guidance with other more positive means of controlling driver behavior. • Select advisory speeds consistent with site conditions. • Keep the traffic control plan as simple as possible; avoid overuse of unwarranted traffic control devices. • Establish an ongoing program of field evaluation of the effectiveness of implemented traffic control plan. • Continue to provide training in work area traffic control for field personnel.

Source: Reference (9)

Manual on Uniform Traffic Control Devices

The *Texas Manual on Uniform Traffic Control Devices* (MUTCD) (6) is the state standard for all traffic control devices. It sets forth the basic principles that govern the design and usage of traffic control devices. These devices are used to direct and assist vehicle operators in the guidance and navigation tasks required to safely traverse any facility open to public travel. Part VI of the Texas MUTCD is devoted to "Traffic Controls for Street and Highway Construction and Maintenance Operations." Part VI of the Texas MUTCD is also available as a separate document (10) containing exactly the same information found in Part VI of the entire Texas MUTCD. The 1980 Texas MUTCD is based on the 1978 National *Manual on Uniform Traffic Control Devices* (11), including revisions 1 through 4. A new edition of the National MUTCD was published in 1988 (12), The Texas MUTCD basically follows the National MUTCD, although changes have been made to meet State laws or more closely fit conditions in Texas. However, the revisions in the 1988 MUTCD have not yet been incorporated into the Texas MUTCD. References to the MUTCD in this report refer to the Texas MUTCD, unless otherwise noted.

Early Standards for Arterial Work Zones

The 1961 edition of the National MUTCD (13) included, for the first time, a separate part (Part V) of the manual on traffic control devices for highway construction and maintenance operations. Section 5F the 1961 MUTCD dealt with urban applications of work zones. The 1961 MUTCD recognized the unique characteristics of urban work zones and directly addressed the most important of these in three sections, portions of which are cited below. However, these sections were deleted from the 1971 edition of the National MUTCD, although some of the text was relocated to other sections of the manual.

5F - Urban Applications

Section 5F-1 - Urban Characteristics

The general principles outlined in the Manual are applicable to both rural and urban areas. Discussion of their application, however, has emphasized rural conditions. The differences between rural and urban situations warrant some separate treatment *of urban traffic control requirements, though basically it is possible only to point out certain ways in which the standards already set forth can be adapted to peculiarly urban problems.*

Urban traffic conditions are characterized by relatively low speeds, high volumes, limited maneuvering space, frequent turns and cross movements, and a significant pedestrian movement. Traffic obstructions particularly in the form of parked vehicles, are common. Construction and maintenance operations are more numerous and varied, including such diverse activities as pavement cuts for utility work, pavement patching and surfacing, pavement marking renewal, and encroachments by adjacent building construction.

There is already ample conflict inherent in urban traffic movement, and further conflict due to construction or maintenance operations should be kept to a minimum. On arterial streets such work should, if possible, be restricted to off-peak hours. Some cities have resorted to extensive night work in order to minimize interference with traffic.

The amount of street space taken up by construction and maintenance work should be no more than is absolutely necessary, though this does not justify any failure to use such signs, warning devices, and channelization as may be required in the roadway for public protection and guidance.

Section 5F-2 - Signs

Additional regulatory signs will be needed to control traffic under changed operating conditions. Because of the unfamiliar and possible unusual conditions, larger sizes may be warranted than the standard sizes normally specified for these signs in urban use.

Because of the lower speeds associated with urban traffic conditions as compared with rural, fewer advance warning signs are required. Under some circumstances warning signs may not be necessary, but other devices capable of being clearly seen and recognized at a safe distance are essential.

Warning signs of standard size should generally be used. Larger signs may be needed than are called for by speed criteria alone due to high traffic volumes, wide streets, and competition from advertising displays and distracting backgrounds.

Warning signs should be placed at distances of 150 to 250 feet in advance of the condition to which they are calling attention, the actual distance being determined by such factors as speeds, volumes, degree of hazard, and sight distance.

Section 5F-3 - Barrier, Warning, and Channelizing Devices

All of the devices described in the section Barriers and Channelization are applicable to urban situations. Because of space limitations, cones may find greater use than barricades. Although most city streets are lighted at night, special attention must be called to the existence of obstructions and hazards, due to construction or maintenance work, during hours of darkness.

Current Standards for Arterial Work Zones

The construction and maintenance part of the Texas MUTCD set forth the basic principles and prescribe standards for the design, application, installation, and maintenance of the various types of traffic control devices required for road or street construction, maintenance operations, and utility work. Minimum standards of application are prescribed for typical situations, and for methods of controlling traffic through work areas. The requirements in the Texas MUTCD are applicable to all public highways, streets and roads in the State of Texas, whether maintained by the Department, a county, a municipality, or other public agency, and all traffic control devices used on street and highway construction or maintenance work shall conform to the applicable specifications of the Texas MUTCD.

No section of Part VI directly addresses traffic control on urban arterials, as does a section on expressways and limited access facilities. However, urban conditions are addressed in several illustrations and briefly in the introductory section (6A-3) which contains the following statements regarding urban arterial work zones:

- *The general principles outlined are applicable to both rural and urban areas. As used in this Part, the term street refers to all the streets in any municipality, including cities, towns, villages, or other local jurisdictions.*
- *Traffic conditions on streets are characterized by relatively low speeds, wide ranges of volumes, limited maneuvering space, frequent turns and cross movements, a significant pedestrian movement and other obstructions. Construction and maintenance operations are more numerous and varied, including such diverse activities as pavement cuts for utility work, pavement patching and surfacing, pavement marking renewals and an encroachment by adjacent building construction. Work on arterial streets should be restricted to off-peak hours to minimize conflicts with traffic.*
- *In particular situations not adequately covered by the provisions of this Manual, the protection of the traveling public, pedestrians, and of the workmen on the scene will dictate the measures to be taken, consistent with the general principles set forth in this section.*

The other sections of Part VI address the use of signs, channelizing devices, markings, lighting, control of traffic, and limited access facilities. In most instances, the use of devices is described for a rural highway type environment. However, there are some cases where traffic control for urban streets is illustrated. Table 2-3 indicates the work zone illustrations in the MUTCD which apply to urban applications. The spacing of signing and channelizing devices is based on the arterial speed and is described later in this chapter. The lower speeds found on urban streets generally require shorter spacing of traffic control devices. Part VI does not address how traffic signals impact the planning and implementing of work zone traffic control on urban arterials. Additionally, there are no guidelines which indicate how to provide traffic control for a work zone located in the center of the roadway, a situation which existed at all three study sites.

Table 2-3. Texas MUTCD Illustrations for Urban Work Zones

Figure Number	Page Number	Figure Title
6-4	6B-6	Typical Application - Detour Signs on an Urban Street in a Street Grid
6-4.1	6B-6.1	Typical Sidewalk and Curb-Lane Closure for Pedestrian Control
6-5.1	6B-7.1	Typical Application - Minor Operation on 2-Lane Low Volume Low Speed Urban Street Where One Lane is Closed
6-7.1	6B-9.1	Typical Application - Major Operation on Urban 4-Lane Undivided Street Where Half the Roadway is Closed
6-7.4	6B-9.4	Typical Application - Urban Right Lane Closure Far Side of Intersection
6-7.5	6B-9.5	Typical Application - Urban Left Lane Closure Far Side of Intersection
6-7.6	6B-9.6	Typical Application - Urban 2-Lane Closure Far Side of Intersection
6-7.7	6B-9.7	Typical Application - Urban Lane Closed in Center of Intersection
6-7.8	6B-9.8	Typical Application - Urban 2-Lane Farside Closure With Left Turn Lane
6-7.9	6B-9.9	Typical Application - Urban Flagger Control for Intersection Closure
6-7.9.1	6B-9.9.1	Typical Application - Urban Side Street Closing to a Major Thoroughfare
6-8.1	6B-10.1	Typical Application - Major Operation on 4-Lane Divided Urban Street Where One Side of the Roadway is Closed

Future Revisions to Work Zone Standards

Part VI of the National MUTCD (12) is currently undergoing a revision process. The third draft of revisions (14) indicates an increase in references to urban area work zones. **It should be noted that the proposed revisions have not been adopted and may change substantially before being officially adopted.** Proposed revisions related to urban arterial work zones include:

- Within an urban area, the placement of advanced warning signs from the condition of which they warn normally ranges from four to eight times the speed limit (mph) in feet.
- When multiple advance warning signs are in use, the recommended spacing between advance warning signs in urban areas is 200 feet.
- Post-mounted signs shall be mounted laterally at a minimum of 2 feet from the edge of the traveled way, and the bottom of the sign shall be a minimum of 7 feet from the ground. Signs on fixed supports are usually mounted on a single post, although those wider than 36 inches or with areas greater than 10 square feet should be mounted on two posts.

Other revisions to the MUTCD include topics that are applicable to both urban and rural arterial work zones. Each of the items discussed below are presently discussed in some detail in the 1988 MUTCD (12). However, in the revisions more detail and/or expanded information is provided, and in some cases includes a separate section devoted to each item. Proposed revisions include:

- A chapter on portable changeable message signs (PCMS) includes sections on design and application of PCMS. The design portion includes information on: the message sign panel, the control system, and the power source. The application portion includes information on: width restriction, advisories on construction scheduling, traffic management and diversion, warning of adverse conditions, and operational control. Coinciding with application of PCMS are two added topics: placement of the PCMS and the displayed message. Here, only general suggestions and recommendations are given for application of PCMS within work zones.
- A chapter on the arrow panel includes sections on the application and specification on the arrow panel. The application portion identifies that it can operate in several modes, such as: flashing arrow, sequential arrow, or sequential chevron. Each of these modes is addressed. The portion on specifications for the arrow panel describes: sign size, minimum legibility distance, and minimum number of elements.
- A chapter on channelization includes sections on spacing and reflectorization requirements. In addition, there are sections on cones, tubular markers, vertical panels, drums, barricades, portable barriers, and temporary raised islands. The spacing for channelization should not exceed a distance in feet equal to the speed limit when used for the taper, and a distance in feet of twice the speed limit when used for the tangent of the channelization. For individual channelization items, such as those previously mentioned, information on the design and application is given. For items such as drums, barricades and portable barriers, the information is similar to that found in the 1988 MUTCD.
- A pavement markings section includes information on placement of pavement markings and supplementing pavement markings with warning signs. A separate section is allocated to short-term markings. This section contains much of the information contained in the 1988 MUTCD and includes new information on edge lines, channelization lines, lane reductions, and other longitudinal markings. Raised

pavement markers are permitted as an option or as a supplement to markings and in short-term work zones. Raised pavement markers are suggested for use along a surfaced detour or temporary roadways, and other changed or new travel lane alignments, because of the need to accentuate changed travel paths and their wet weather performance capabilities.

Introduced in these MUTCD revisions is the topic of temporary traffic control. A section on typical temporary traffic control situations is organized according to duration, location of work, and highway type. Layouts of typical temporary traffic control situations are organized by the same headings. The highway types which are addressed in these revisions include rural two-lane, urban arterials, other urban streets, rural or urban multi-lane divided and undivided highways, intersections, and freeways.

In the section which addresses work located on the travel portion of urban arterial, the MUTCD revisions includes the following descriptions about traffic control in urban arterial work zones.

Urban temporary traffic control zones may be divided into segments. Decisions must be reached as to how to control vehicular traffic, how many lanes are required, or whether any turns should be prohibited at intersections. Pedestrian traffic must be considered. If work will be done on the sidewalk, will it be necessary to close the sidewalk and assign the pedestrians to another path? Next, decisions must be reached as to how to maintain access to business, industrial, and residential areas. Even if the road is closed to vehicles, pedestrian access and walkways must be provided.

To supplement this information, two figures are given to illustrate traffic control for lane closures on urban streets or arterials, and two figures are given to illustrate urban detours.

Traffic Control Devices Handbook

The *Traffic Control Devices Handbook* (TCDH) (7), published in 1983, is primarily intended to augment the National MUTCD by serving an interpretative function. Texas does not have its own version of the TCDH. The TCDH offers guidelines for implementing the standards and applications contained in the National MUTCD. It should be noted that the requirements of the MUTCD take precedence over the TCDH in all cases. The part of the TCDH dealing with work zones is designed and written to be used with, not to replace, the National MUTCD and explains how to apply the standards to various work situations. Throughout Part VI of the TCDH, work zone applications on urban streets are specifically mentioned. Some of the specifics of these urban arterial conditions are mentioned below:

- Length of Advance Warning Area should be at least one block for urban streets.
- Rule of Thumb for Sign Spacing:
  - 250 feet for urban, residential, or business districts or speeds under 40 mph.
  - 500 feet for urban arterials and rural roads or speeds over 40 mph.
- Other Considerations for the Location of Advance Warning Area:
  - Urban: distance restrictions can be imposed by the length of city blocks; additional advance warning may be necessary due to extra intersections created by alleys, shopping centers, and side streets.
  - Signs should not block the view of vehicles entering the area from gas stations, restaurants, cross roads, etc.
  - Existing signs not needed during the work activity should be removed or covered.

The TCDH also addresses typical applications or layouts for work zone traffic control for different situations. Pedestrians, bicycles, and intersections are also addressed, with pedestrian movement through a work zone discussed in detail. Diagrams of typical work zone layouts for different situations are provided and some of the major concerns are briefly mentioned.

Traffic Control Devices

The main traffic control devices usually associated with work zones in urban areas are signs and channelization devices such as cones, vertical panels, drums, barricades, pavement markings, and other delineators. Signs are mainly used to warn and alert drivers of speed reductions and potential hazards created by work zone activities, whereas channelization devices are used to guide and direct traffic safely through the work zones. This section describes the safety considerations of different traffic control devices used in urban arterial work zones.

Signs

Signs for use in urban arterial work zones fall into three major categories as do other traffic signs; namely, regulatory, warning, and guide signs. The design, illumination and reflectorization of signs for use in urban arterial work zones are the same as for highway work zones. However, placement and spacing of signs is crucial to the urban arterial work zone. The Texas MUTCD provides guidelines for sign spacing and size for all types of work zones. Table 2-4 lists sign spacing and sizes for warning signs based on the posted speed.

Table 2-4. Typical Construction Warning Sign Spacing and Size

Posted Speed (mph)	Sign Spacing[1] (ft)	Major Approach Warning Signs[2]		Minor Approach Warning Signs[3]	
		Standard	Minimum	Standard	Minimum
30	80	48"x48"	36"x36"	30"x30" or 36"x36"[4]	24"x24" or 30"x30"
35	120	48"x48"	36"x36"	30"x30" or 36"x36"	24"x24" or 30"x30"
40	160	48"x48"	36"x36"	30"x30" or 36"x36"	24"x24" or 30"x30"
45	240	48"x48"	48"x48"	30"x30" or 36"x36"	30"x30" or 36"x36"

Notes: 1 - Minimum distance from work to 1st Advance Warning sign and/or distance between each additional sign.
2 - These signs include signs such as **ROAD CONSTRUCTION AHEAD, DETOUR 1000 FT, ONE LANE ROAD 1500 FT.**
3 - These signs include signs such as **ROAD WORK AHEAD, WORKERS AHEAD.**
4 - Size dictated by Texas MUTCD standards.

Source: (6) pg. 6B-2.2

Channelization Devices

Channelizing devices include cones, vertical panels, drums, barricades, and barriers. The purpose of these devices is to guide and direct drivers safely past potential hazards created by construction activities. The most important aspect of channelizing devices is the taper associated with a change in lane position. The minimum desirable taper length is based on the speed and offset of the taper. When the speed is 45 mph or greater, Equation 2-1 is used. Equation 2-2 is used for speeds of 40 mph or less.

For speeds ≥ 45 mph

$$L = W \times S$$ Equation 2-1

For speeds ≤ 40 mph

$$L = \frac{W \times S^2}{60}$$ Equation 2-2

where L = taper length (feet)
S = posted speed limit (mph)
W = offset or lane width (feet)

The spacing of channelizing devices on a taper is the same as the posted speed limit. The spacing of channelizing devices on a tangent is twice the posted speed limit.

Pavement Markings

Urban arterial work zones often require temporary changes in travel paths. Therefore, pavement marking materials are an important consideration. Urban arterial work zones can be a short duration or long duration operation. The Texas MUTCD defines a short duration work zone operation as one that is performed in two weeks or less. Whereas long duration projects can last a month or longer. The MUTCD states that short duration operations can be adequately marked with pressure sensitive traffic marking tape or temporary raised pavement markers. Either of these types can be applied simply and quickly and can be removed with little or no difficulty when changing traffic patterns. For long duration projects, the requirements of pavement markings are more restrictive because they are subject to severe weather conditions such as rain, sleet and snow. Furthermore, the urban arterial work zone normally possess high volumes and speeds, multiple lane change maneuvers, and construction vehicles interacting with the traffic stream.

The primary materials used for pavement markings are paint, thermoplastic, marking tape, and raised pavement markers. For operations of any duration, material qualities and/or characteristics such as adhesions, play a significant role in the choice of material used. For short duration operations, some materials can be cost prohibitive and therefore not warranted.

Painted markings used alone or in combination with other devices comprise the most commonly used delineation technique (7). However, paint has limited application in arterial work zones because the paint removal process leaves a scar leading to false presence of delineation. Painted markings are an inexpensive material when compared to alternative markings. An application of painted markings in arterial work zones would be either a construction phase continuing for several months or a construction phase including a pavement overlay where pavement markings no longer applicable are paved over. From the literature review, the application of painted markings for anything other than permanent application is limited.

Thermoplastic markings are regarded as a highly durable marking material when compared to conventional painted markings. A special type of the preformed plastic has been introduced for use as temporary markings in construction work zones. The major advantage of this material is its ease of removal. It can be removed intact from either asphalt or concrete pavement surfaces manually or with a roll-up device without the use of heat, solvents, grinding, or sandblasting.

Two studies (15, 16) describe pressure sensitive preformed construction grade tape as an acceptable means of temporary delineation. The pressure sensitive tape employs a different adhesion characteristic than the permanent installation grade (such as aluminum or foil-backed tape) that reduces the effort needed to remove the tape following temporary change in travel paths. Pressure sensitive tape has worked well in urban arterial work zones. However, high volumes, numerous turning and/or lane change maneuvers will damage this style of tape (16). Pressure sensitive tape can be applied with acceptable results for short duration projects and applied with a varying degree of acceptable results on long duration projects. For complex short duration and most long duration projects, an acceptable alternative to pressure sensitive tape is the raised pavement marker.

Raised pavement markers (RPM) have been used with acceptable results for application in urban arterial work zones. A 1984 FHWA study (17) evaluated the effectiveness of RPM and identified some of the advantages of RPMs. The application and removal aspects of RPMs were studied in two other FHWA studies (18, 19). The first (18) found that RPMs are easy to install and remove and, after removal, do not leave a misleading indication to confuse drivers. And despite the apparent safety benefits, the relatively high cost of these devices has retarded their use. The second report (19) studied the cost, spacing, ease of application and removal, and the ability of the markers to guide traffic and produce public acceptance. Table 2-5 describes some of the major findings of research on RPMs.

Table 2-5. Major Findings of Raised Pavement Markers Research

- The use of RPMs in high potential hazard locations enhanced delineation and improved the overall safety.
- The use of RPMs to supplement the standard striping and signing results in a high degree of improved visibility for the motorists.
- The use of RPMs provides improved night-time pavement delineation when compared to and used in conjunction with conventional paint stripes.
- Raised pavement markers are effective and provide daylight and nighttime guidance through both wet and dry periods.
- The additional safety, improved operations, and unanimous favor of the public, government and construction personnel justify their expanded use.
- On an economic basis, the cost of markers and paint was equal to or less than the cost of paint striping and removal.
- The use of reflective raised pavement markers on construction detours tends to reduce the number of accidents.

Source: Reference (17, 18, 19)

Urban arterial work zones often require multiple phasing and staging of construction operations in order to reduce delay and inconvenience to the general public and commercial businesses located adjacent to the arterial. The different phases require detours thereby altering lane paths. Changing lane patterns requires removal of existing or invalid pavement markings. Removing pavement markings is a difficult undertaking due to the improved durability and adhesion of pavement markings.

Traditional methods of removal include grinding, burning, chipping, appropriate chemical treatment, high pressure water, steam or superheated water, burning, overlaying with asphalt concrete mix and sandblasting. The MUTCD specifically disallows overpainting of markings with black paint and/or bituminous solutions. This treatment has proved unsatisfactory as the original line eventually reappears as the overlying material wears away under traffic. A prime requisite to determining the best method for stripe removal is that the treatment should cause minimum damage to the pavement surface or texture. Primarily due to this reason, temporary pressure sensitive pavement tape has often been used for short duration lane delineation on urban arterial work zones. This material can simply be dislodged and removed by hand or rolled up with standard equipment. This type of operation will leave no lasting scar. For long duration projects, the use of markings that possess properties that enhance durability (such as thickness, and integral bond with pavement) serves as deterrents to easy removal. Raised pavement markers are relatively easy to install and remove and, after removal, do not leave a misleading indication to confuse drivers. Raised pavement markers can be applied with the self-adhesive pressure-sensitive butyl backing or epoxies. The later application is used on long duration work zone applications and permanent locations because of the adhesion characteristics. The aluminum or foil-backed material is more difficult to remove if primer was used and/or if the marking has been in place for a long period. In these cases, the aluminum base can be heated to break the adhesive bond. The markings must then be scraped from the roadway surface. For these reasons, and others, TxDOT disallows the use of aluminum or foiled-backed material for temporary removable construction markings.

Part VI of the MUTCD addresses pavement marking applications for work zone operations. Some of the key points are:

- When construction work necessitates the use of vehicle paths other than the lanes normally used, daytime and nighttime drive-through checks should be made to evaluate the path and the possibility that the pavement markings might inadvertently lead drivers from the intended path.
- Markings no longer applicable that might create confusion in the minds of vehicle operators and pedestrians shall be removed or obliterated as soon as practicable.
- Conflicting pavement markings shall be obliterated to prevent confusion to vehicle operators. Proper pavement marking obliteration leaves a minimum of pavement scars and completely removes old pavement paint. Painting over existing stripes does not meet the requirements of removal or obliteration.
- The intended vehicle path should be clearly defined during day, night, and twilight periods under both wet and dry pavement conditions.

Safety Considerations of Traffic Control Devices

A 1990 report, *Accident Characteristics at Construction and Maintenance Zones in Urban Areas* (20), studied the accident characteristics at urban work zones and evaluated the effectiveness of traffic control devices in reducing accident rates. This is the only research study that could be identified which specifically addresses urban arterial work zones in any detail. The objectives of this study were to: 1) analyze accident data for urban work zones in Virginia, 2) identify traffic characteristics that have significant impacts on these accidents, 3) evaluate traffic control devices commonly used in urban work zones, and 4) develop guidelines for selecting traffic control devices for urban work zones that will be effective in reducing accident rates.

The study analyzed the statistical relationships between urban arterial work zone accident characteristics (rates, severity, type, number of vehicles, and alcohol effects) and factors such as geometrics (two-lane or multilane), traffic control (flaggers, barricades, cones, flashing arrows, and signs) and traffic characteristics (volumes, speeds, and headways). The statistical models developed from the analysis were used in developing conclusions about urban arterial work zones. The primary finding of the study was that traffic control devices have a positive effect on safety in urban work zones, but the effectiveness depends on the type of traffic control used and the preconstruction accident rate. The study generated the following conclusions about urban arterial work zones.

- Accident rates on urban multilane highways increased on average about 57 percent when compared to the accident rate prior to the work zone, although the amount of increase depended on the type of traffic control used.
- Accident rates on urban two-lane highways increased on average about 168 percent when compared to the accident rate prior to the work zone, although the amount of increase also depended on the type of traffic control used.
- Although there is a general lowering of average speeds, speed variance tends to increase during urban work zone activities.

- Statistical analysis of accident and traffic control data also indicated that accident frequency was higher when barricades were included with the other traffic control devices than when the other devices were used without barricades. No explanation was provided as to why barricades had such an impact on accidents.
- Statistical analysis of accident and traffic control data indicate that the effective combinations of traffic control devices on urban two-lane highway work zones are 1) cones and flagmen or 2) static signs and flagmen. The analysis also showed that flagmen are a very effective means of traffic control on urban two-lane work zones.
- Statistical analysis of accident and traffic control data indicate that the most effective combination of traffic control devices for urban multilane highway work zones is cones, flashing arrows, and flagmen. The use of this combination results in an average increase in the accident rate of about 46 percent.

Safety Design and Operational Practices for Streets and Highways (21) address highway safety from a number of perspectives. One of these areas is traffic operations and planning, of which safety design in construction and maintenance operations is a concern. Work zones on urban streets are addressed briefly in the following manner:

Urban Multi-lane Facilities

Because facilities of this type are likely to exhibit relatively high traffic volumes, maintaining adequate capacity and a reasonable level of service becomes a primary concern. Traffic may need to be detoured over other major arterials or work activities may have to be prohibited during peak traffic periods. During non-peak periods when traffic is flowing more freely, the speed differential between normal traffic and traffic in work areas may become more critical.

Urban Two-lane Facilities

This type of roadway includes residential streets and other relatively low volume city streets. A major concern is the provision of access to abutting property during street renovation work. Capacity and speed differential problems are relatively minor.

Driver Behavior

A study prepared for John Deere and Company reflected drivers' attitudes toward construction zones in general. The report, *A Study Concerning Drivers' Attitudes Toward Construction Zones*, (22) surveyed motorists in four states to determine whether there is a large amount of confusion concerning signage and also to observe objectively how motorists act in construction zones. The Deere study surveyed 400 drivers nationwide on a variety of issues involved with construction work zones, including the effectiveness of individual construction zone signs. The results indicated that 52 percent of the drivers did not reduce their travel speed immediately upon entering a construction zone, marked with appropriate signing. This reaction agreed with a speed study that showed that no noticeable speed reduction actually occurs by drivers inside construction areas. Specific results and conclusions from the signing survey include:

- 48 percent of drivers reduced their speeds upon sight of a man with shovel pictograph and no workers, 74 percent stated they reduced their speed when workers were in the area.
- 50 percent of drives stated they slowed down when seeing a "**ROAD CONSTRUCTION AHEAD**" sign with no workers present; 94 percent of drivers surveyed responded they slowed down after sighting workers.
- A substantial discrepancy between drivers' perceptions of their actions and their demonstrated behavior.
- Drivers essentially maintain their speed after entering a construction work zone, therefore, construction signs need to be made more specific with more human elements in them.
- Mechanical means should be employed at all construction zones to force drivers to slow down.

Conclusions from the Literature Review

The review of published material addressing urban arterial work zones indicated a lack of detailed information about the subject. Some previous research efforts have documented the lack of information on urban arterial work zones and indicate a need to expand the

National MUTCD in this area. While there was no evidence of a comprehensive discussion of guidelines for urban arterial work zones in any one document, the literature review did identify several instances where urban arterial work zones were briefly addressed. Some general comments and potential guidelines about urban arterial work zones that were identified in the literature review include:

Urban Arterial Characteristics

- Urban traffic conditions are characterized by relatively low speeds, high traffic volumes, limited maneuvering space, frequent turns and cross movements, and a significant pedestrian movement.

Traffic Control

- Equation 2-1 is used to determine the minimum taper length for urban arterials with posted speeds of 45 mph and higher, and Equation 2-2 is used for speeds of 40 mph and lower.

$$L = W \times S \qquad \text{Equation 2-1}$$

$$L = \frac{W \times S^2}{60} \qquad \text{Equation 2-2}$$

Where L = taper length (feet)
S = posted speed limit (mph)
W = offset of taper (feet)

- On urban arterial roadways with moderate traffic volume and speeds advance warning signs may be spaced at the intervals found in Table 2-6.
- Guidelines for approach warning sign size is based on the arterial posted speed and typical values are shown in Table 2-7.
- Based on the *Traffic Control Devices Handbook*, the rule of thumb for sign spacing is 250 feet for urban streets with speeds under 40 mph and 500 feet for urban arterials with speeds over 40 mph.
- The most effective combination of traffic control devices for urban multilane highway work zones is cones, flashing arrows, and flagmen.

Table 2-6. Typical Construction Warning Sign Spacing

Posted Speed (mph)	Sign[1] Spacing in Ft (approx.)
30	80
35	120
40	160
45	240

Notes: 1 - Minimum distance from work area to first Advance Warning sign and/or distance between each additional sign.

Table 2-7. Typical Construction Warning Sign Size

Posted Speed (mph)	Major Construction or Major Maintenance Approach Warning Sign[1]		Minor Construction or Minor Maintenance Approach Warning Sign[2]	
	Standard (in)	Minimum (in)	Standard (in)	Minimum (in)
30	48×48	36×36	30×30 or 36×36[3]	24×24 or 30×30
35	48×48	36×36	30×30 or 36×36	24×24 or 30×30
40	48×48	36×36	30×30 or 36×36	24×24 or 30×30
45	48×48	48×48	30×30 or 36×36	30×30 or 36×36

Notes: 1 - These signs include signs such as **ROAD CONSTRUCTION AHEAD, DETOUR 1000 FT, ONE LANE ROAD 1500 FT.**
2 - These signs include signs such as **ROAD WORK AHEAD, WORKS AHEAD.**
3 - Size dictated by Texas MUTCD standards.

Other Traffic Control Considerations

- Signs should not block the view of vehicles entering the area from gas stations, restaurants, cross roads, etc.
- Advance speed signs in construction work zones are not effective in controlling speeds unless drivers perceive that such speeds are reasonable for the locations at which they are used. A mechanical means may be appropriate to force drivers to slow down.
- Work on arterial streets should be restricted to off-peak hours to minimize conflicts with traffic.
- Use advisory speeds carefully in construction work zones, recognizing that it may be necessary to supplement such speed guidance with other more positive means of controlling driver behavior. Select advisory speeds consistent with site conditions.
- Although there is a general lowering of average speeds during reconstruction, speed variance tends to increase during work zone activities.

Pavement Markings

- The use of raised pavement markers in high potential hazard locations enhances delineation and improve the overall safety.
- The use of raised pavement markers to supplement the standard striping and signing results in a high degree of improved visibility for the motorists.
- The use of raised pavement markers provides improved night-time pavement delineation when compared to conventional paint markings. Raised pavement markers are effective in providing both daylight and nighttime guidance through both wet and dry periods.
- Construction grade removable tape possesses good durability on both bituminous and portland cement concrete pavements. Also, the tape is easily removed manually. Reflectivity is initially high and remains good when used as edgeline and adequate when used as a centerline.
- On an economic basis, the cost of markers and paint was equal to or less than the cost of paint striping and removal.
- The use of reflective raised pavement markers on construction detours tends to reduce the number of accidents.

CHAPTER 3

STUDY SITE DESCRIPTION

Three construction work zone sites on highly developed urban arterials were selected for study. Qualifications that a study site had to meet included: located on an arterial street in an urban area, construction duration of at least one year, and a convenient location for data collection. Two of the project sites were F.M. 1960 and S.H. 6, which are both located in Houston, Texas, as shown in Figure 3-1. The construction at the F.M. 1960 site began in January 1988 and in July 1988 at the S.H. 6 site. The third project site was Abrams Road located in Dallas, Texas, as shown in Figure 3-2. The construction began in July 1989. Table 3-1 provides a descriptive summary of the most important features of each of the study sites.

Table 3-1. Description of Pre-Construction Conditions at Study Sites

Study Site	F.M. 1960	S.H. 6	Abrams Rd.
City	Houston	Houston	Dallas
Length (miles)	8.2	6.3	2.1
Start of Construction	Jan 88	Sep 88	Jul 89
End of Construction	Dec 89	Apr 91	Oct 91
Speed Limit (mph)	40	40	40
Preconstruction Median	2WLTL	2WLTL	None
Postconstruction Median	2WLTL	2WLTL	Raised
Number of Intersections	50	25	12
Intersections per mile	6.1	4.0	5.7
Number of Signals	27	11	4
Signals per mile	3.3	1.7	1.9
Number of Driveways	360	155	17
Driveways per mile	43.9	24.6	8.1

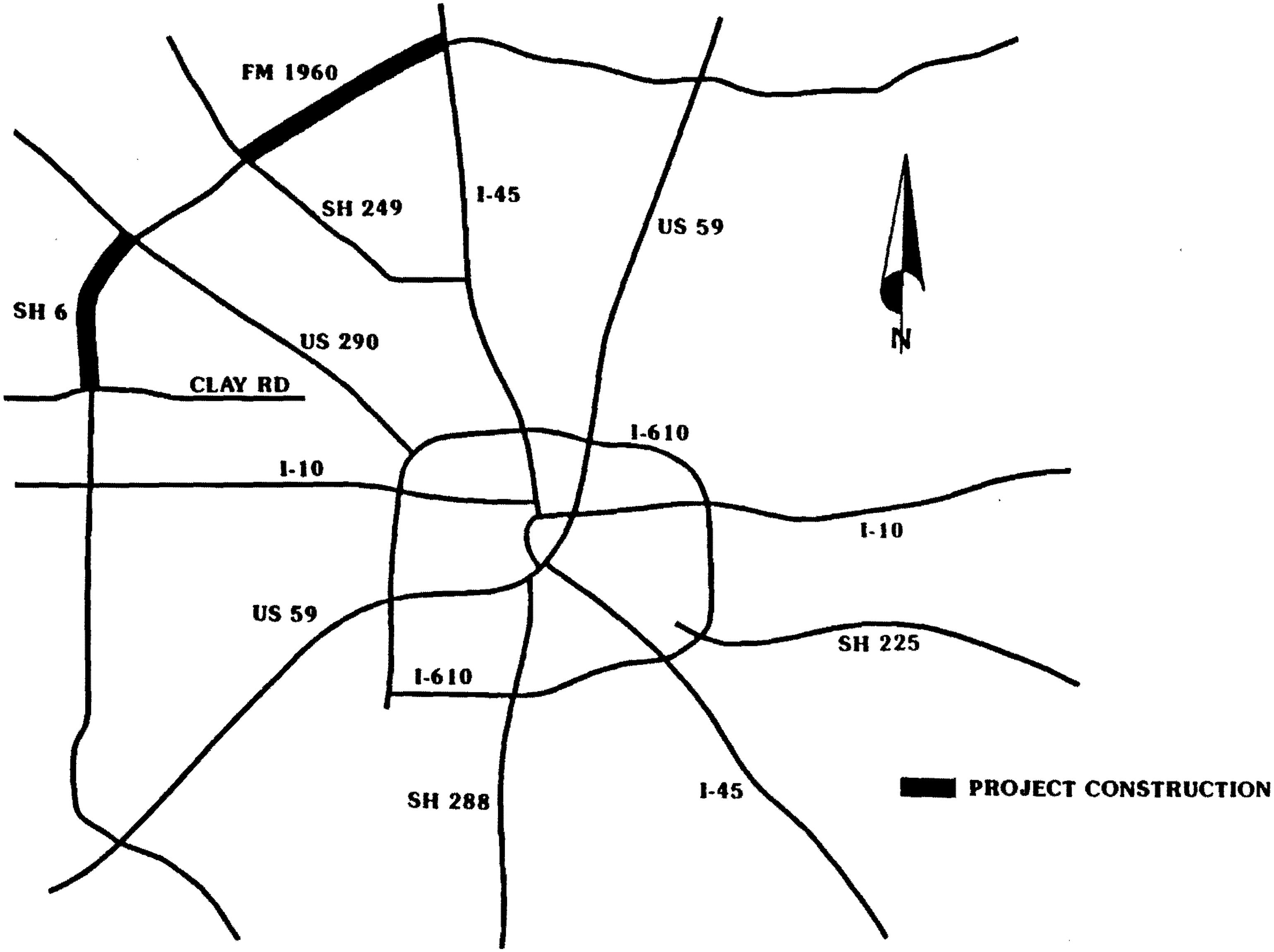


Figure 3-1. F.M. 1960 and S.H. 6 Study Site Locations

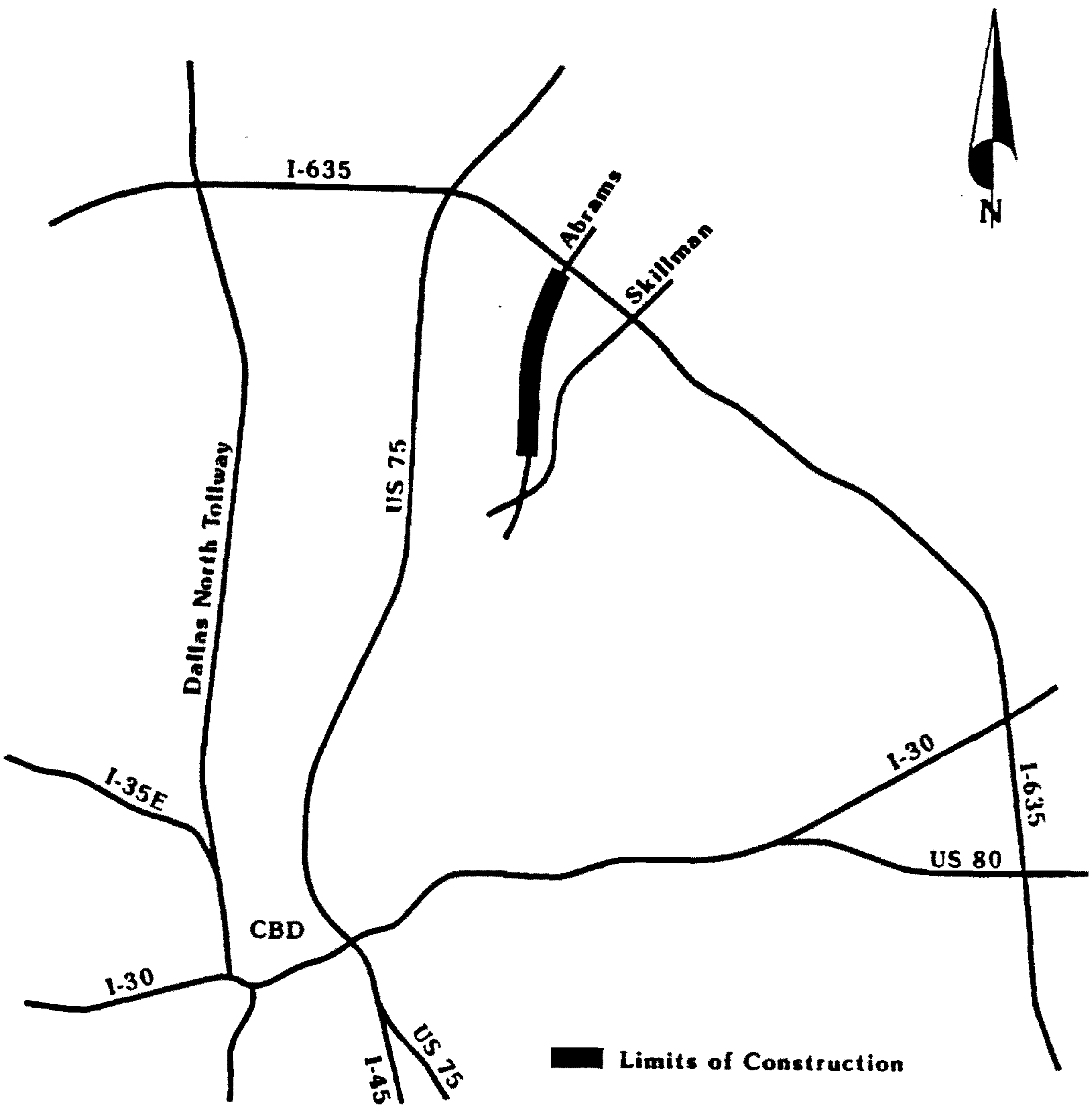


Figure 3-2. Abrams Road Study Site Location

Construction Phasing

The construction phasing used at the three study sites was nearly identical. In each case, construction was divided into four phases, as described in Table 3-2. Figure 3-3 provides a plan view of the roadway construction sequence.

Project phasing provided two lanes of traffic in each direction throughout construction. This was accomplished by eliminating the center left-turn lane and using reduced lane widths of 10 to 11 feet. There were often significant elevation differences between old and new pavement. The construction work area was generally between 25 and 40 feet wide. Drums were typically used to separate traffic from the work area.

Table 3-2. Typical Construction Phasing

First Phase Temporary Shoulder Overlay	In the initial construction phase, the left turn lane was eliminated and the traffic lanes were shifted to one side of the roadway while the existing shoulder on the other side of the road was widened and overlaid with temporary pavement in order to accommodate traffic during the next two phases.
Second Phase Side Construction - Opposite Overlay Side	During the second phase, traffic was shifted onto the side of the roadway with the widened shoulder and construction took place on the opposite side of the roadway.
Third Phase Center Construction	Construction took place in the center of the roadway during the third phase. Traffic on one side of the center construction area traveled on the new pavement completed during the second phase, while traffic on the other side traveled on the temporary pavement completed in the first phase.
Fourth Phase Side Construction - Overlay Side	During the fourth and final phase, construction took place on the same side of the road as during the first phase. Traffic traveled on new pavement constructed during the second and third phases. The temporary pavement placed in the first phase was removed and permanent pavement constructed. Construction phasing was completed by installing pavement markings for the final configuration.

F.M. 1960 Study Site

F.M. 1960 is a major urban arterial located in the Houston area. It is roughly concentric to I.H. 610, being approximately 14 miles outside the loop. F.M. 1960 begins at U.S. 290 northwest of Houston and extends eastward past U.S. 59 to the northeast part of Harris County. The total length of F.M. 1960 in Harris County is approximately 37 miles.

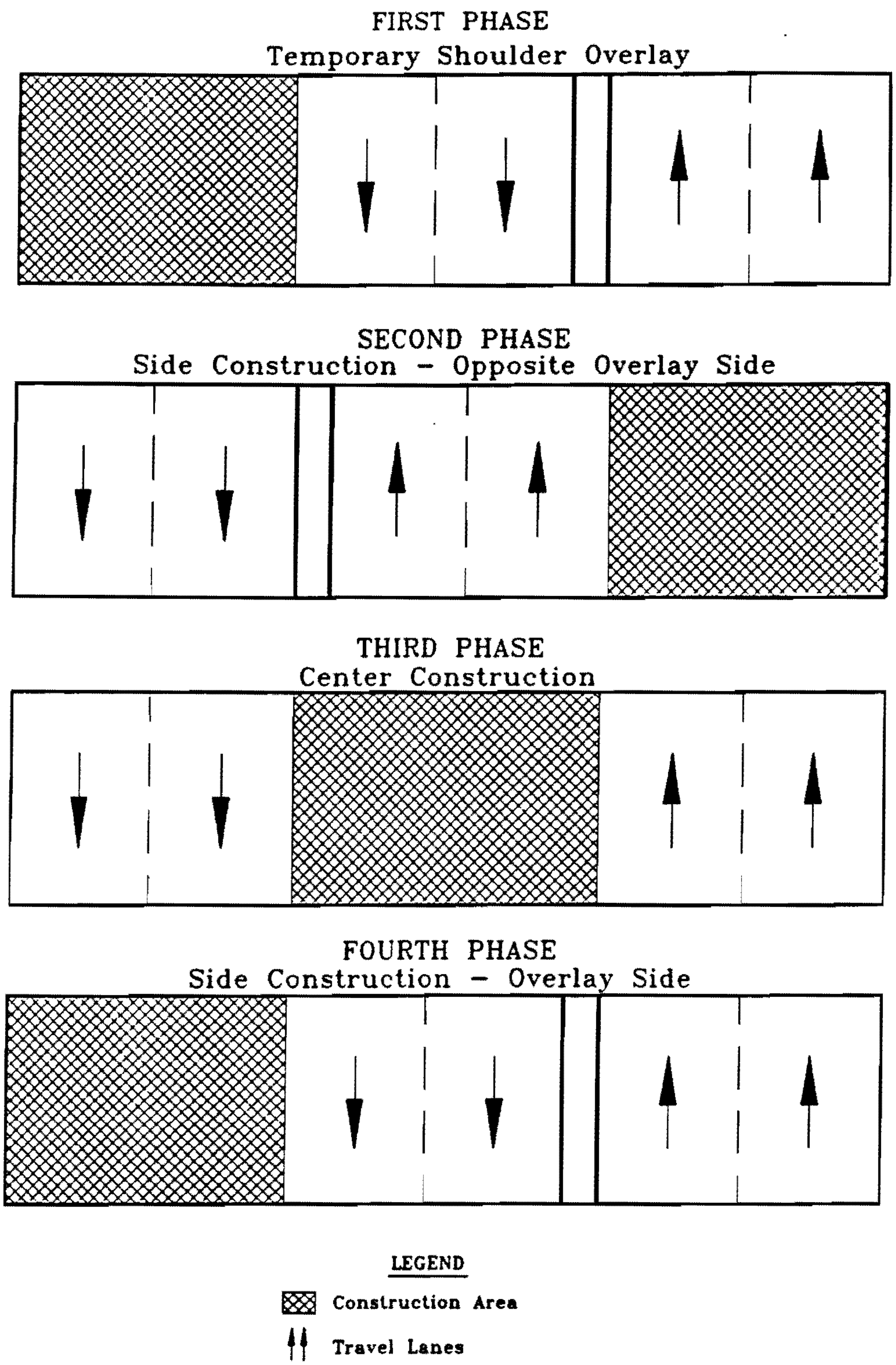


Figure 3-3. Typical Construction Phasing

Construction at the F.M. 1960 study site is now complete. The construction study site was approximately eight miles long and was located between I.H. 45 (North Freeway) and S.H. 249, as shown in Figure 3-1. Land use along F.M. 1960 consists mainly of commercial strip development and residential areas. Much of the development (banks, fast-food restaurants, gasoline stations, etc.) fronts directly on F.M. 1960 and therefore creates a very congested area.

F.M. 1960 preconstruction geometrics included two lanes in each direction, a center continuous left-turn lane and drainage ditches along both sides of the roadway. The construction zone along F.M. 1960 was highly commercial and hence there were 360 access driveways. There are a total of 50 intersections within the limits of the construction zone, of which 27 are signalized. The completed cross section includes three lanes in each direction with a center continuous left-turn lane and storm sewer.

Construction phasing on F.M. 1960 was identical to that described in Table 3-2 with construction beginning on the north side in the first phase. The project was originally scheduled to begin in October 1987, but was delayed due to citizen objections to the loss of the continuous left-turn lane during the Christmas shopping season. The project was intended to be completed within 42 months. Table 3-3 shows the scheduling of each construction phase. This project was completed 19 months ahead of schedule for several reasons, including public pressure, good weather, and accelerated construction practices. The contractor worked well with the Department to speed up progress. One change to the original plans that accelerated progress was the use of high early strength concrete on intersections and driveways. Another early change was the addition of left-turn lanes at major signalized intersections. The original traffic control plan did not include left-turn lanes, but the resulting traffic operations led to their installation after construction began.

Table 3-3. F.M. 1960 Construction Schedule

Phase	Dates of Construction
First	1/88 - 2/88
Second	3/88 - 12-88
Third	1/89 - 4/89
Fourth	4/89 - 12/89

S.H. 6 Study Site

State Highway 6 appears as an extension of F.M. 1960 to the south of U.S. 290. Construction on S.H. 6 extended from U.S. 290 (Northwest Freeway) south to Clay Road, as shown in Figure 3-1. S.H. 6 is one of the state's longer state highways. It extends from the Oklahoma border near Vernon to the Gulf of Mexico near Texas City.

The portion of the highway evaluated in this study is located in an urban part of the greater Houston area. The length of construction on S.H. 6 was approximately 6 miles. Land use in the area consists of residential areas with some commercial development. The development along S.H. 6 is much less congested than along F.M. 1960.

Preconstruction geometrics included two lanes in each direction with a continuous center left-turn lane. There were 25 at-grade intersections, of which 11 are signalized, and 155 access driveways within the construction zone. The completed cross section of S.H. 6 includes three lanes in each direction with a center continuous left-turn lane. Reconstruction of this highway took approximately two and one-half years. The project was split into three segments as listed in Table 3-4.

Each segment included four phases of construction. The description and layout of each phase is identical to that of Table 3-2 with first phase construction beginning on the east side of S.H. 6. Although the first phase began simultaneously for all three segments, subsequent phase changes for each segment did not occur simultaneously. Table 3-4 shows the progress of construction by segment and phase.

Table 3-4. S.H. 6 Construction Schedule

Segment	Phase	Dates of Construction
U.S. 290 to F.M. 529	First Second Third Fourth	9/88 - 10/88 10/88 - 8/89 8/89 - 3/90 4/90 - 10/90
F.M. 529 to Kieth Harrow	First Second Third Fourth	9/88 - 12/88 12/88 - 11/89 12/89 - 6/90 7/90 - 11/90
Kieth Harrow to Clay Road	First Second Third Fourth	9/88 - 3/89 3/89 - 12/89 1/90 - 9/90 10/90 - 4/91

Abrams Road Study Site

Abrams Road is located on the north side of Dallas, Texas. It is a north/south arterial connecting I.H. 635 to inner city routes. Construction on Abrams Road extends from Kingsley Road (north of the Skillman Street intersection) to Meadowknoll (south of I.H. 635) as shown in Figure 3-2. The length of construction is approximately 2 miles. Land use in the area is mainly residential with some commercial development. Preconstruction geometrics included two lanes in each direction with no median or continuous left turn lane. There are 12 intersections of which 4 are signalized, and 17 driveways within the construction zone. The project began construction in July 1989 and is scheduled for completion in the fall of 1991.

Skillman Avenue was the original study site for an urban arterial work zone in Dallas. However, delays in starting construction pushed the beginning of construction to near the end of the research study period. Therefore, Abrams Road was selected as the urban arterial study site in Dallas. However, it was selected after construction had already begun, therefore, it was not possible to obtain pre-construction traffic volume and travel time data.

The completed cross section of Abrams Road will include three lanes in each direction with a raised median. There are four phases of proposed construction which are very similar to those utilized on S.H. 6 and F.M. 1960. The only difference is that the median is constructed within the last phase, while the other two reconstruction projects are incorporating a continuous left turn lane. Construction was in progress at the time the site was chosen for study. Table 3-5 contains the construction schedule for Abrams Road. It should be noted that there was a three month suspension during the first phase so that utilities could be adjusted.

Table 3-5. Abrams Road Construction Schedule

Segment	Phase	Dates of Construction
Northern	First	7/89 - 9/89
	Second	9/89 - 6/90
	Third	6/90 - 5/91
	Fourth	5/91 - 10/91
Southern	First	7/89 - 9/89
	Second	9/89 - 10/90
	Third	10/90 - 6/91
	Fourth	6/91 - 10/91

CHAPTER 4
ACCIDENT ANALYSIS

The safety impacts of work zones on urban arterials were assessed by evaluating accident data obtained for the three study sites. The accident data for both of the Houston study sites were obtained from the Department of Public Safety (DPS) Master Accident File. These data are a computerized summary of accidents, which can be adapted to many different formats for analysis. Accident data for the years 1985 through 1990 were used in the analysis of F.M. 1960 and S.H. 6.

Accident data for the Abrams Road site was obtained from the Dallas Police Department. This accident data consist of individual accident reports and is not available in the same summary format as the DPS data. Therefore, the research team manually summarized this data for use in the analysis procedures. The Abrams Road accident data includes the years 1987 through 1990.

Accidents were analyzed by dividing the data into several different categories and comparing the differences between the pre-construction and during-construction accidents for the three study sites. The categories into which the accidents have been divided include: accident frequency, accident rates, accident type and cause, location of accidents, and accident periods. Statistical comparisons of accident data between the pre-construction and during-construction periods were made to identify where significant changes in accident categories may be related to construction activities. Post-construction accident data are available for only one year at the F.M. 1960 study site. The research study ended before post-construction data could be obtained for the S.H. 6 and Abrams Road sites. Therefore, changes in accident trends following construction can not be assessed with any certainty. The F.M. 1960 accident data are for the segment between I.H. 45 and S.H. 249 and the S.H. 6 accident data are for the segment between U.S. 290 and Clay Road. The Abrams Road accident data are for the segment between Kingsley and Meadowknoll.

It should be noted that the accident data analyzed as part of this project represent only three urban arterial work zone sites. Therefore, **caution should be used in generalizing any findings of the accident analysis to other urban arterial work zones.**

Accident Frequency

The number of accidents per year at each of the three sites is shown in Table 4-1 and graphically illustrated in Figure 4-1. At each site, the number of accidents per year increased for the years during which the roadways were under construction. Table 4-2 and Figure 4-2 show the average pre-, during-, and post-construction accident frequencies for the three sites. Table 4-3 and Figure 4-2 show the percentage change in accident frequencies associated with changes in construction conditions. The percent increase in accident frequency attributable to construction ranged between 35 and 77 percent.

The differences in accident frequency for each site can be accounted for in part by the differences in traffic volumes and lengths of the study segments. The F.M. 1960 study site had the highest volumes and the longest length of the three sites. Therefore, it is expected to have the highest number of accidents in a given year. The Abrams Road site had volumes that were two-thirds and a length that was one-fourth of the F.M. 1960 site.

Accidents are random events and an increase or decrease in the number of accidents does not always indicate a trend or change in conditions. Statistical analysis is necessary to determine if a change in accident frequency can be attributed to a change in conditions or an improvement. Equation 4-1 was used in the analysis to calculate the significance of the accident statistics (21). The level-of-significance of the comparison is determined by the K value, which is based on the upper-tail area for a normal curve. A K value of 2.33 is used to represent a 99 percent level-of-significance and a 1.28 is used for a 90 percent level-of-significance. If the calculated K value exceeds the target K value, then the change in accidents is statistically significant.

$$K = \frac{F_A - F_B + \frac{0.5}{m}}{\sqrt{\frac{F_B}{m}}} \qquad \text{Equation 4-1}$$

where K = Constant (determines level of significance)
F_A = Pre-construction accident frequency
F_B = During-construction accident frequency
m = Pre-construction exposure in million vehicle miles

The increase in accident frequency from average pre-construction to average during-construction accidents was significant at a level of greater than 99.9 percent for all three study sites. Post-construction accident data was available only for the F.M. 1960 site. The decrease in F.M. 1960 accident frequency from during-construction to post-construction was also significant at a level greater than 99.9 percent. The safety impacts of the reconstructed F.M. 1960 can also be evaluated by comparing the pre- and post-construction accident frequencies. The accident frequency decreased from pre- to post-construction and this decrease was significant at a level greater than 99.9 percent. This indicates that there is greater than 99.9 percent probability that the reconstructed roadway reduced the number of accidents per year.

Table 4-1. Accident Frequencies

Roadway	Total Accidents per Year					
	1985	1986	1987	1988	1989	1990
F.M. 1960	730	734	727	1055*	923*	667
S.H. 6	198	242	233	329*	523*	324*
Abrams Rd	N/A	N/A	43	30	42*	50*

Note: F.M. 1960 construction began January 1988 and ended December 1989
S.H. 6 construction began September 1988 and ended April 1991
Abrams Rd. construction began July 1989 and ended October 1991 (proposed)
* Indicates roadway under construction for part or all of year

Table 4-2. Average Accident Frequency for Construction Conditions

Roadway	Average Number of Accidents per Year		
	Pre-Construction	During-Construction	Post-Construction
F.M. 1960	730	989	667
S.H. 6	237	420	N/A
Abrams Rd	36	51	N/A

Table 4-3. Percent Change in Average Accident Frequency for Construction Conditions

Roadway	Percent Change in Average Number of Accidents per Year	
	Pre-Construction to During-Construction	Pre-Construction to Post-Construction
F.M. 1960	+35 %	-9 %
S.H. 6	+77 %	N/A
Abrams Rd	+42 %	N/A

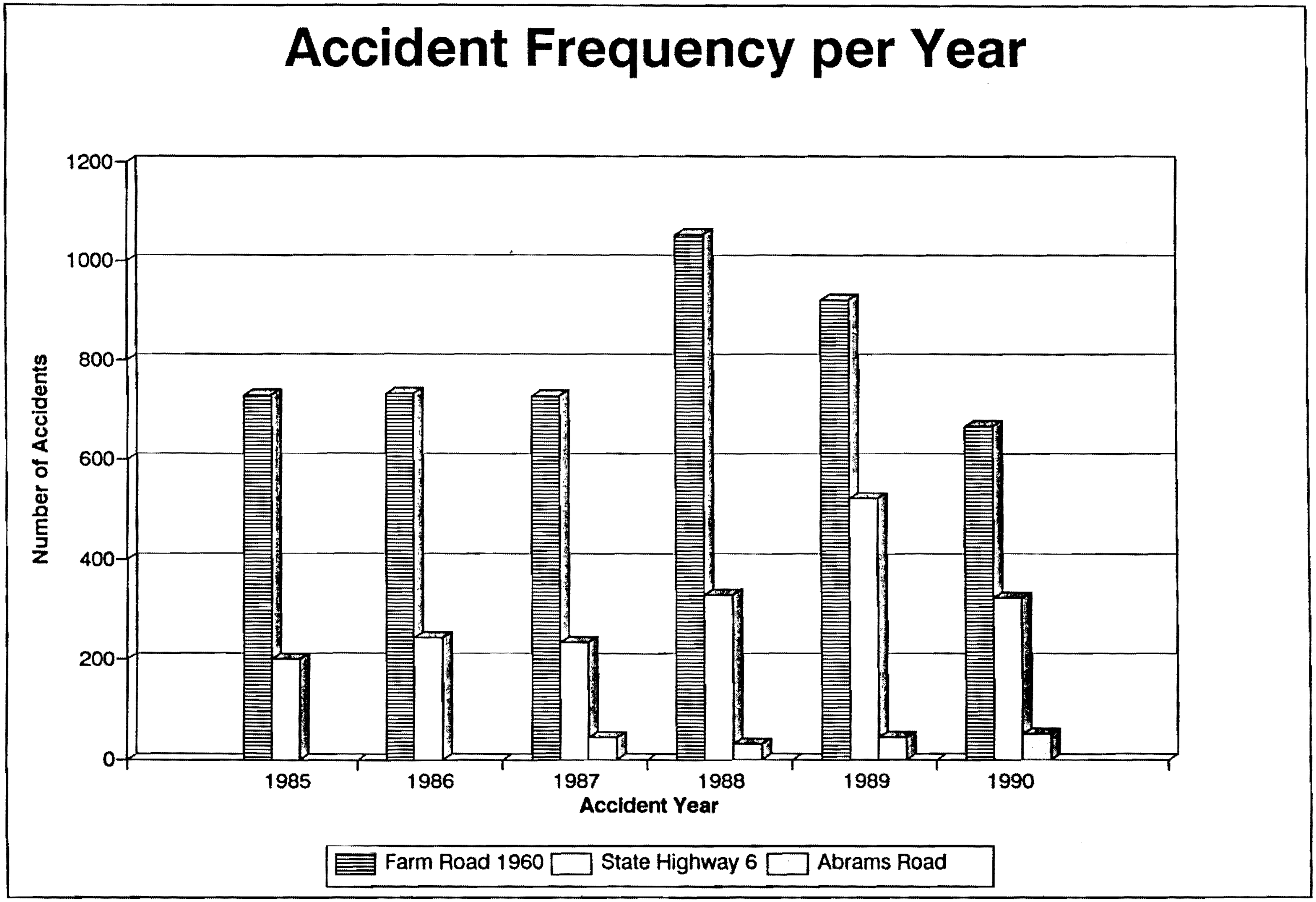


Figure 4-1. Accident Frequency per Year

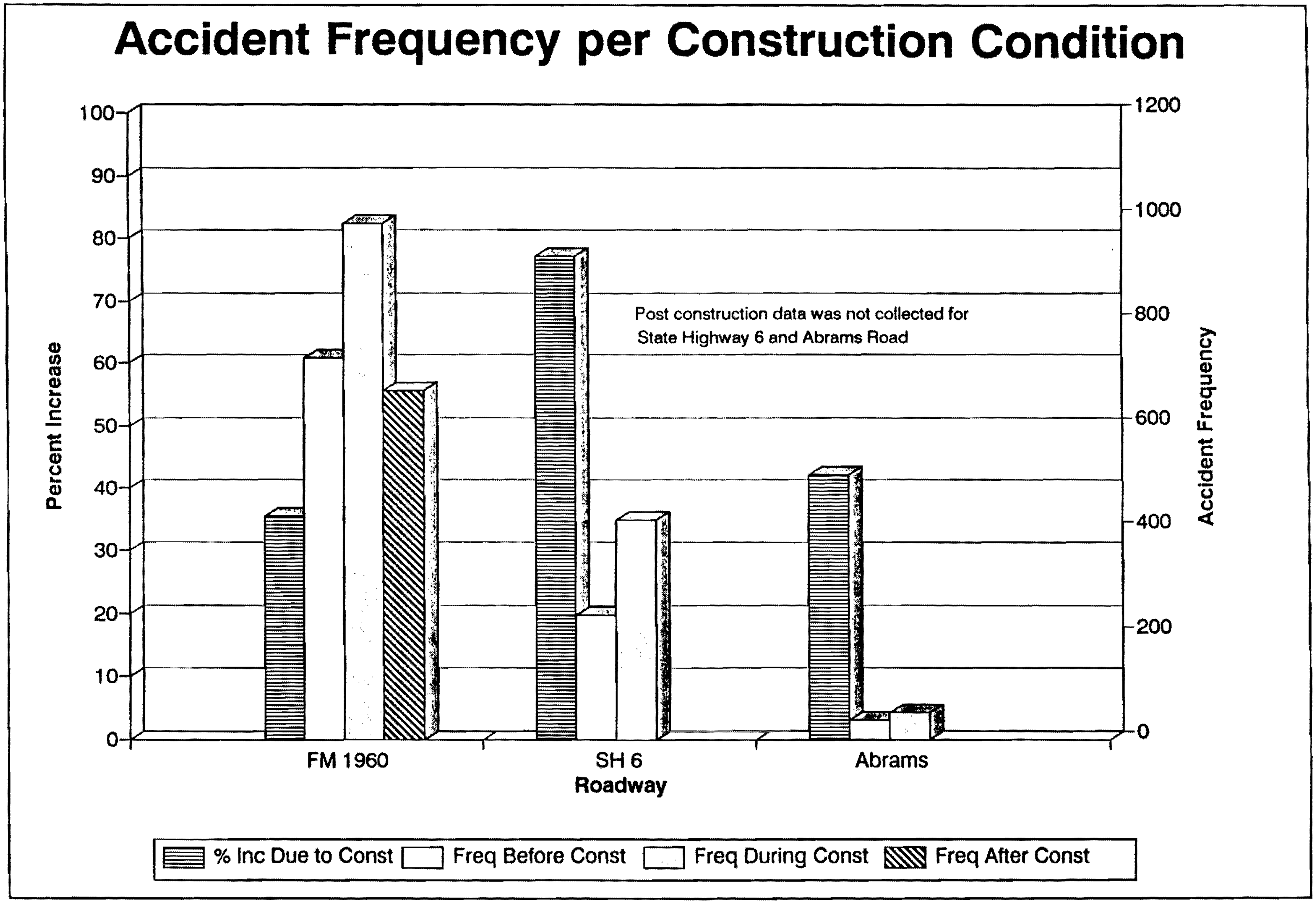


Figure 4-2. Average Accident Frequency for Construction Conditions

Accident Rate

Accident frequency may not accurately portray the relative number of accidents if traffic volumes and section lengths are not comparable, as is the case for the three sites in this study. Therefore, the accident frequency was normalized by dividing the number of accidents by the million vehicle miles of travel for the entire study site during a given year. This results is the accident rate per million vehicle miles (mvm). Table 4-4 shows the accident rates for the three study sites for each year that data is available. Figure 4-3 graphically illustrates this data. Table 4-5 and Figure 4-4 show the average accident rates for pre-, during-, and post-construction periods for the three study sites. Table 4-5 also shows the average accident rate for pre- and during-construction conditions. Table 4-6 shows the percent change in accident rate for the changes in construction conditions. The 59 to 106 percent increase in accident rate at the urban arterial work zone sites compares favorably to the results of a Virginia study (20), which found a 57 percent increase in accident rate at urban multilane highway work zones in Virginia. Figure 4-4 also illustrates the percent change in accident rate for pre- to during-construction conditions.

The statistical significance of changes in accident rates can also be analyzed using Equation 1. For accident rates, the F_A and F_B are changed to accident rates R_A and R_B. All of the changes in accident rates from pre- to during-construction and from during- to post-construction are significant at a level greater than 99.9 percent. The reduction in accident rate on F.M. 1960 from pre- to post-construction is also significant at a level greater than 99.9 percent.

There is considerable variation in the accident rates at the three sites for any given construction condition. Pre-construction rates vary between 2.0 and 6.5 accidents per mvm. The accident rate during construction varies between 3.4 and 10.3 accidents per mvm. Because accident rates normalize the effects of volume and section length, the differences in accident rates must be attributed to physical or operational differences in the sites, of which there were several. Although there are not sufficient data to statistically support any conclusions, it is not unreasonable to assume that F.M. 1960 had the highest accident rate because it had the highest number of intersections, signals, and driveways per mile.

Table 4-4. Accident Rates by Year

Roadway	Accidents per Million Vehicle Miles					
	1985	1986	1987	1988	1989	1990
F.M. 1960	6.12	6.41	6.92	11.09*	9.52*	5.43
S.H. 6	2.59	3.36	3.40	4.63*	8.51*	5.45*
Abrams Rd	N/A	N/A	2.03	1.81	2.79*	3.42*

Note: F.M. 1960 construction began January 1988 and ended December 1989
S.H. 6 construction began September 1988 and ended April 1991
Abrams Rd. construction began July 1989 and ended October 1991 (proposed)
* Indicates roadway under construction for part or all of year

Table 4-5. Average Accident Rate for Construction Conditions

Roadway	Average Accident Rate per Year		
	Pre-Construction	During Construction	Post-Construction
F.M. 1960	6.46	10.30	5.43
S.H. 6	3.29	6.78	N/A
Abrams Rd	1.97	3.43	N/A
Avg of 3 Sites	3.90	6.84	N/A

Table 4-6. Percent Change in Average Accident Rate for Construction Conditions

Roadway	Percent Change in Average Accident Rate per Year	
	Pre-Construction to During-Construction	Pre-Construction to Post-Construction
F.M. 1960	+59.3 %	-16.0 %
S.H. 6	+106.1 %	N/A
Abrams Rd	+74.1 %	N/A

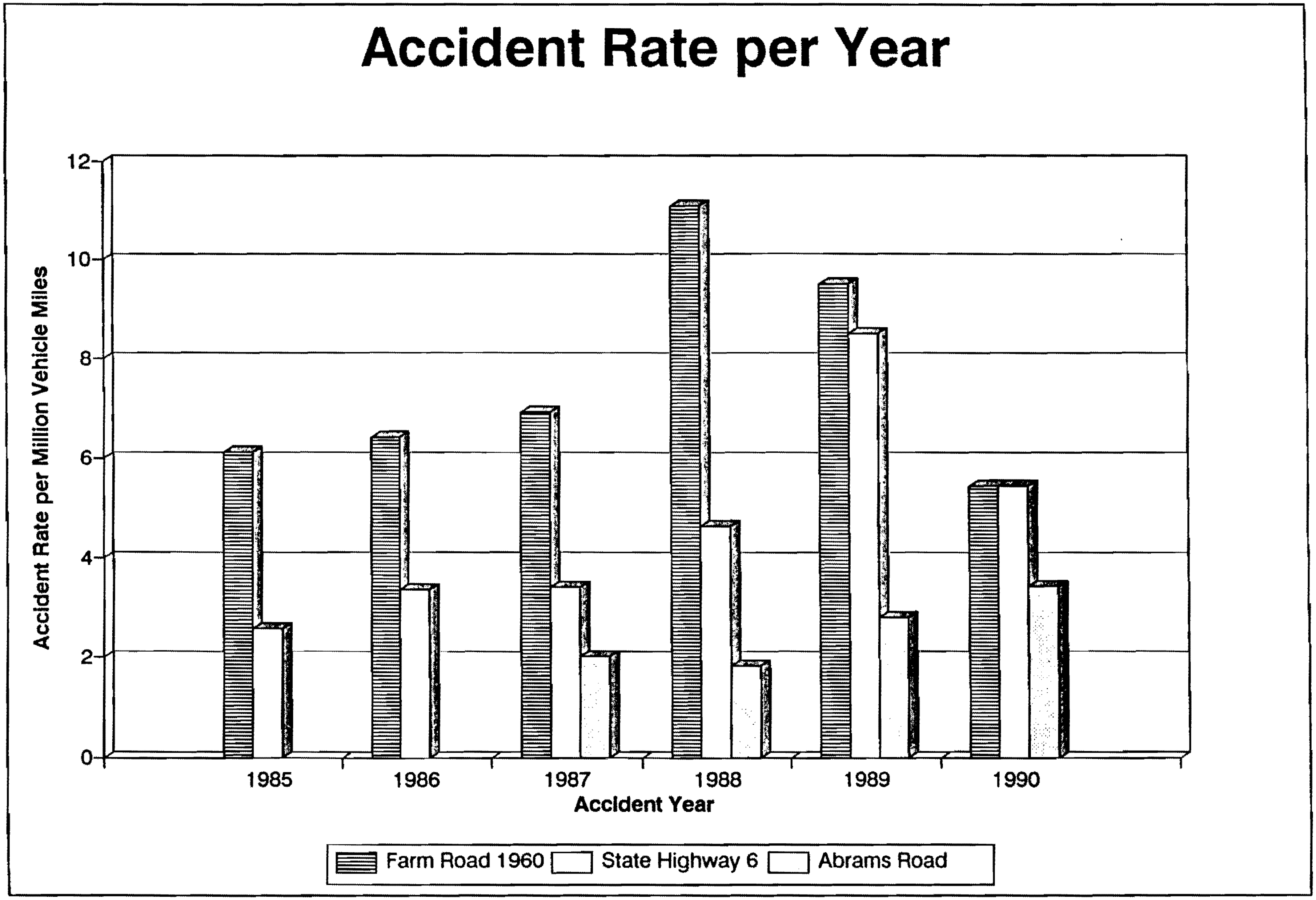


Figure 4-3. Accident Rate per Year

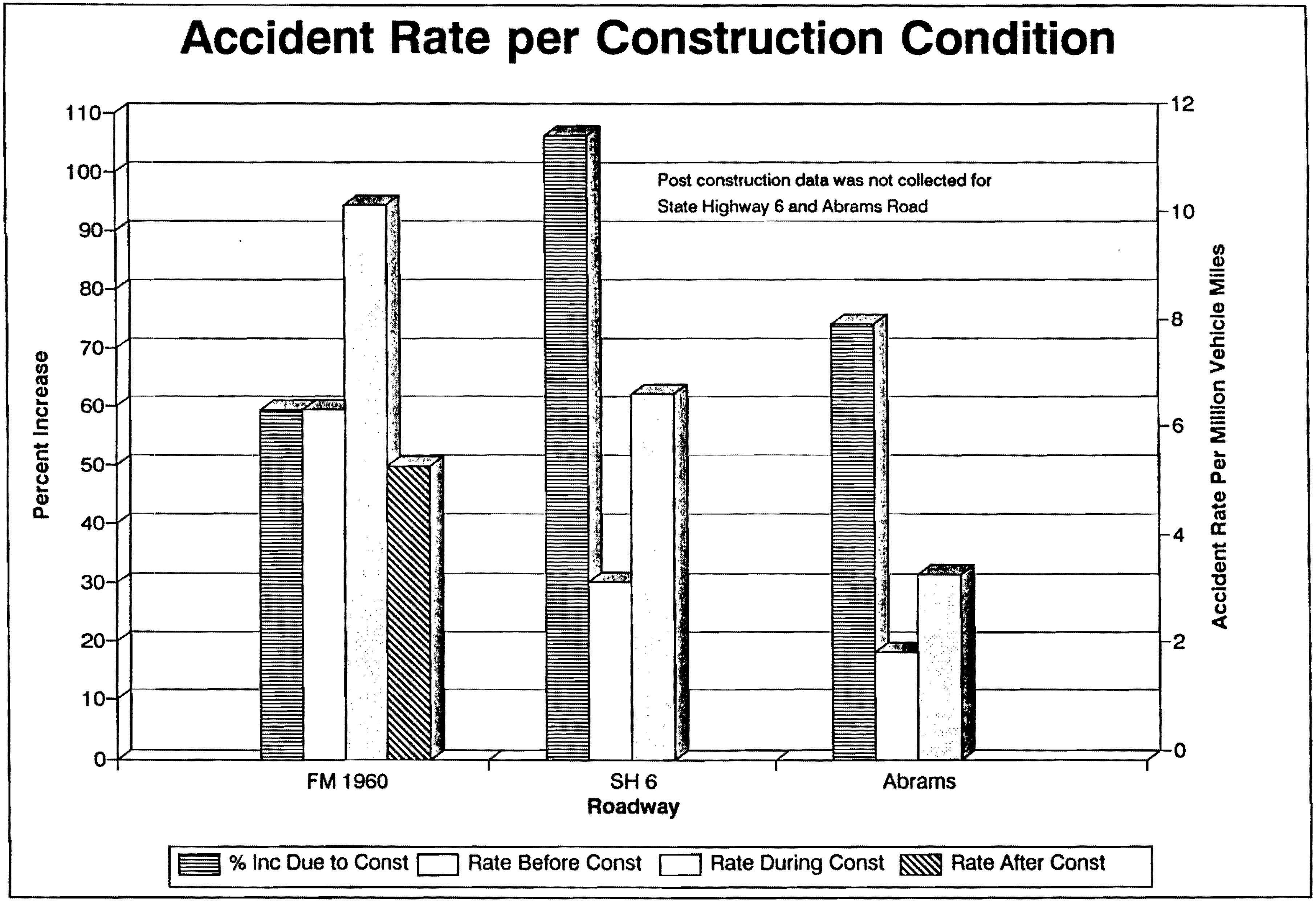


Figure 4-4. Average Accident Rate for Construction Conditions

Accident Type and Cause

The types of accidents occurring in a work zone provide some indication of the potential problem areas. Table 4-7 shows the number and proportion of accidents per year for angle, rear-end, sideswipe, and other types of accidents at each of the three sites. Table 4-8 shows the average number and proportion of accidents per year for each construction condition at each site. Figure 4-5 illustrates the percentages for each type of accident by construction condition at the three sites.

The types of accidents were statistically analyzed with a contingency table and Chi-square test to determine the relationship between accident type and the construction condition. The tests revealed that the type of accident is independent of the construction condition at all three sites, i.e. there is no significant relationship between construction condition and accident type.

Table 4-9 shows the first harmful event for each year of accident data. The information in this table indicates that the largest majority of accidents were collisions between two or more vehicles. The second highest percentage of accidents were collisions with fixed objects. Because of its format, the Abrams Road data does not include all of the harmful events used in the F.M. 1960 and S.H. 6 accident data.

Table 4-10 shows the first harmful event for each construction condition. These accidents were also statistically analyzed with a contingency table and Chi-square test to determine the relationship between the first harmful event and the construction condition. The tests indicated that the first harmful event was not dependent on the construction condition at all three sites. There is no statistically significant relationship between harmful events and construction conditions. However, the data shows that approximately 90 percent or more of the accidents involve two or more vehicles. Collisions with fixed objects were the next most common first harmful event.

Table 4-7. Accident Types by Year

Roadway	Accident Type	Number of Accidents per Year (Percent of Total Accidents)					
		1985	1986	1987	1988	1989	1990
F.M. 1960	Angle	230 (32)	253 (34)	262 (36)	357 (34)*	269 (29)*	199 (30)
	Rear End	271 (37)	227 (31)	260 (36)	332 (31)*	332 (36)*	259 (39)
	Sideswipe	37 (5)	44 (6)	32 (4)	82 (8)*	65 (7)*	41 (6)
	Other	192 (26)	210 (29)	173 (24)	284 (27)*	257 (28)*	168 (25)
S.H. 6	Angle	66 (33)	91 (38)	78 (33)	111 (34)*	200 (38)*	120 (37)*
	Rear End	62 (31)	85 (35)	88 (38)	118 (36)*	158 (30)*	122 (38)*
	Sideswipe	11 (6)	6 (2)	15 (6)	18 (5)*	35 (7)*	16 (5)*
	Other	59 (30)	60 (25)	52 (22)	82 (25)*	130 (25)*	66 (20)*
Abrams	Angle	N/A	N/A	30 (70)	21 (70)	22 (52)*	35 (70)*
	Rear End			8 (19)	7 (23)	12 (29)*	11 (22)*
	Sideswipe			1 (2)	1 (3)	4 (10)*	0 (0)*
	Other			4 (9)	1 (3)	4 (10)*	4 (8)*

Note: F.M. 1960 construction began January 1988 and ended December 1989
S.H. 6 construction began September 1988 and ended April 1991
Abrams Rd. construction began July 1989 and ended October 1991 (proposed)
* Indicates roadway under construction for part or all of year

Table 4-8. Accident Types for Construction Conditions

Roadway	Accident Type	Number of Accidents per Year (Percent of Total Accidents)		
		Pre-Construction	During-Construction	Post-Construction
F.M. 1960	Angle	248 (34)	313 (32)	199 (30)
	Rear End	256 (35)	333 (34)	259 (39)
	Sideswipe	38 (5)	73 (7)	41 (6)
	Other	192 (26)	270 (27)	168 (25)
S.H. 6	Angle	82 (35)	156 (37)	N/A
	Rear End	83 (35)	141 (34)	
	Sideswipe	12 (5)	25 (6)	
	Other	60 (25)	98 (23)	
Abrams	Angle	25 (69)	31 (62)	N/A
	Rear End	8 (22)	12 (24)	
	Sideswipe	1 (2)	3 (5)	
	Other	2 (7)	5 (9)	

Table 4-9. First Harmful Event of Accidents by Year

Roadway	First Harmful Event	Number of Accidents per Year (Percent of Total Accidents)					
		1985	1986	1987	1988	1989	1990
F.M. 1960	Other Non Collision	1 (0)	0 (0)	0 (0)	0 (0)*	1 (0)*	3 (0)
	Overturned	2 (0)	0 (0)	1 (0)	5 (0)*	5 (1)*	0 (0)
	Pedestrian	4 (1)	8 (1)	3 (0)	4 (0)*	3 (0)*	5 (1)
	Other Motor Vehicle	700 (96)	699 (95)	702 (97)	1004(95)*	876 (95)*	628 (94)
	Parked Car	2 (0)	1 (0)	1 (0)	1 (0)*	1 (0)*	2 (0)
	Pedal Cyclist	3 (0)	7 (1)	4 (1)	4 (0)*	2 (0)*	6 (1)
	Animal	0 (0)	0 (0)	0 (0)	1 (0)*	2 (0)*	1 (0)
	Fixed Object	18 (2)	18 (2)	15 (2)	34 (3)*	31 (3)*	21 (3)
	Other Object	0 (0)	1 (0)	1 (0)	2 (0)*	2 (0)*	1 (0)
S.H. 6	Other Non Collision	1 (1)	0 (0)	0 (0)	0 (0)*	2 (0)*	0 (0)*
	Overturned	1 (1)	0 (0)	3 (1)	1 (0)*	3 (1)*	3 (1)*
	Pedestrian	0 (0)	3 (1)	1 (0)	0 (0)*	1 (0)*	0 (0)*
	Other Motor Vehicle	186 (94)	227 (94)	216 (93)	312 (95)*	487 (93)*	302(93)*
	Parked Car	1 (1)	2 (1)	0 (0)	1 (0)*	0 (0)*	0 (0)*
	Pedal Cyclist	1 (1)	6 (2)	3 (1)	2 (1)*	2 (0)*	1 (0)*
	Animal	0 (0)	1 (0)	0 (0)	1 (0)*	0 (0)*	0 (0)*
	Fixed Object	6 (3)	3 (1)	10 (4)	12 (4)*	25 (5)*	17 (5)*
	Other Object	2 (1)	0 (0)	0 (0)	0 (0)*	3 (1)*	1 (0)*
Abrams	Other Non Collision	N/A	N/A	1 (2)	0 (0)	0 (0)*	0 (0)*
	Overturned			0 (0)	1 (3)	0 (0)*	1 (2)*
	Pedestrian			--	--	--	--
	Other Motor Vehicle			39 (91)	25 (83)	38 (90)*	49 (98)*
	Parked Car			--	--	--	--
	Pedal Cyclist			--	--	--	--
	Animal			--	--	--	--
	Fixed Object			3 (7)	3 (10)	2 (5)*	0 (0)*
	Other Object			0 (0)	1 (3)	2 (5)*	0 (0)*

Note: F.M. 1960 construction began January 1988 and ended December 1989
S.H. 6 construction began September 1988 and ended April 1991
Abrams Rd. construction began July 1989 and ended October 1991 (proposed)
* Indicates roadway under construction for part or all of year

Table 4-10. First Harmful Event of Accidents by Construction Condition

Roadway	First Harmful Event	Number of Accidents per Year (Percent of Total Accidents)		
		Pre-Construction	During-Construction	Post-Construction
F.M. 1960	Other Non Collision	0 (0)	1 (0)	3 (0)
	Overturned	1 (0)	5 (1)	0 (0)
	Pedestrian	5 (1)	4 (0)	5 (1)
	Other Motor Vehicle	700 (96)	938 (95)	628 (94)
	Parked Car	1 (0)	1 (0)	2 (0)
	Pedal Cyclist	5 (1)	3 (1)	6 (1)
	Animal	0 (0)	2 (0)	1 (0)
	Fixed Object	17 (2)	33 (3)	21 (3)
	Other Object	1 (0)	2 (0)	1 (0)
S.H. 6	Other Non Collision	0 (0)	1 (0)	N/A
	Overturned	1 (1)	3 (1)	
	Pedestrian	1 (0)	0 (0)	
	Other Motor Vehicle	222 (94)	393 (94)	
	Parked Car	1 (0)	0 (0)	
	Pedal Cyclist	3 (1)	1 (0)	
	Animal	1 (0)	0 (0)	
	Fixed Object	7 (3)	20 (5)	
	Other Object	1 (0)	2 (0)	
Abrams	Other Non Collision	0 (1)	0 (0)	N/A
	Overturned	0 (1)	1 (1)	
	Pedestrian	0 (0)	0 (0)	
	Other Motor Vehicle	33 (89)	48 (95)	
	Parked Car	0 (0)	0 (0)	
	Pedal Cyclist	0 (0)	0 (0)	
	Animal	0 (0)	0 (0)	
	Fixed Object	3 (8)	1 (1)	
	Other Object	0 (1)	1 (3)	

Note: F.M. 1960 construction began January 1988 and ended December 1989
S.H. 6 construction began September 1988 and ended April 1991
Abrams Rd. construction began July 1989 and ended October 1991 (proposed)
* Indicates roadway under construction for part or all of year

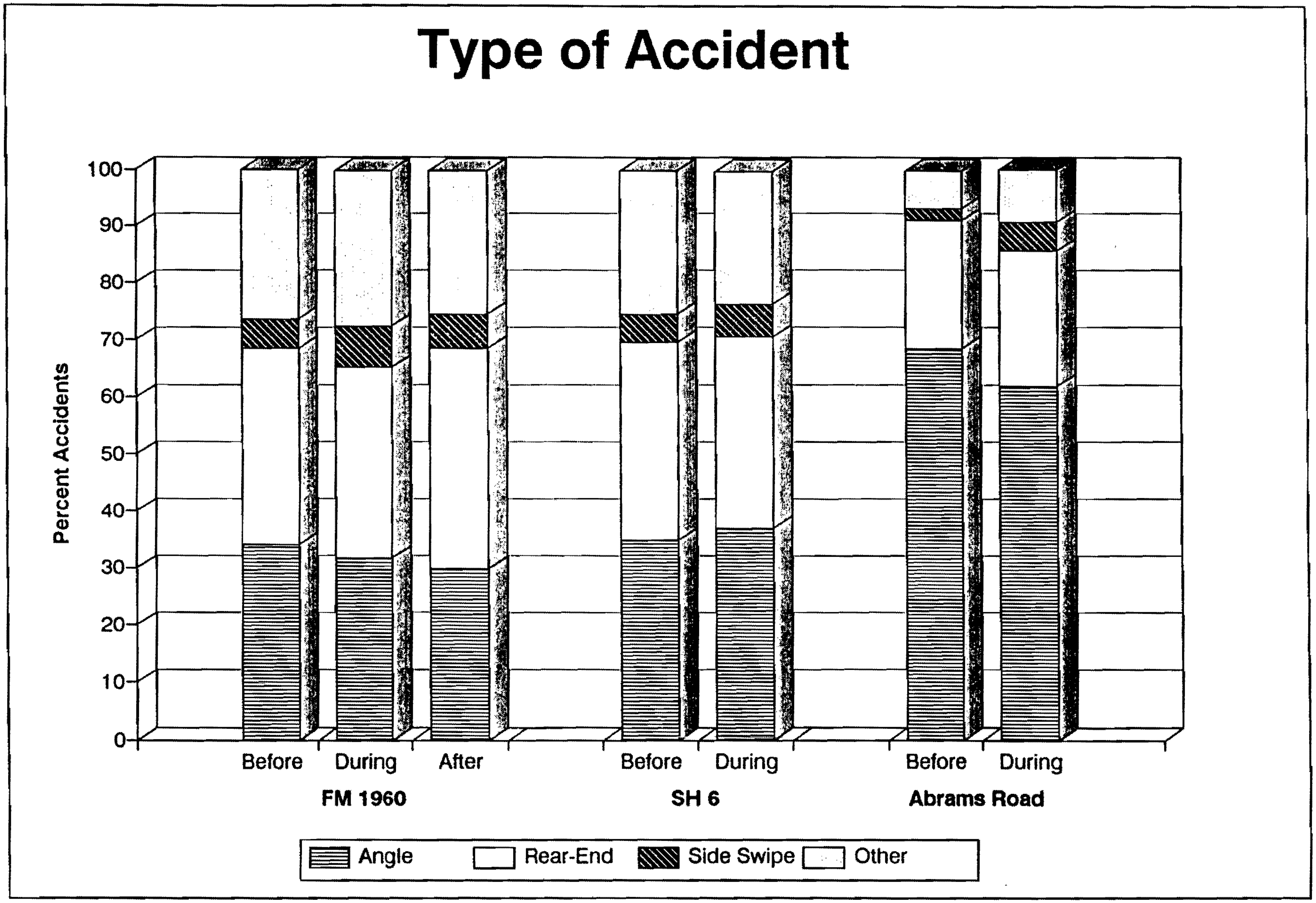


Figure 4-5. Types of Accidents for Construction Conditions

Accident Location

The locations of accidents were analyzed to identify locations with a higher incidence of accidents during periods of construction. Table 4-11 shows the number and percentage of accidents occurring during each year for four different location classifications. Table 4-12 provides the number and percentage of accidents by location for the different construction conditions. The data in these two tables indicate that approximately half of all accidents occur at or near intersections. If driveways are considered at intersections (in effect they are), then approximately three-fourths of all accidents are intersection related. Figure 4-6 illustrates the percentage of accidents occurring at each location for the different construction conditions.

Figure 4-7, 4-8, and 4-9 plot the accident rate for each milepoint of the work zone for each construction condition at the F.M. 1960, S.H. 6, and Abrams Road study sites, respectively. These three figures indicate several trends in accidents. The most obvious are the peaks occurring near intersections for both pre- and during-construction conditions. Also obvious is the fact that the during-construction accident rates are higher than the pre-construction (and post-construction for F.M. 1960) accident rates. The plot for F.M. 1960 illustrates a higher peak at the major intersections, while the plot for S.H. 6 shows several peaks which do not correspond to intersections. These locations represent driveway access points where the accident rate increased while the roadway was under construction.

The accident locations were statistically analyzed with a contingency table and a Chi-square test to determine the relationship between accident location and the construction condition. The tests revealed that the location of accidents is dependent on the construction condition, with a level of significance greater than 99 percent. Inspection of the data indicates that the difference can be attributed to an increase in the number of intersection accidents during construction.

Table 4-11. Accident Locations

Roadway	Accident Location	Number of Accidents per Year (Percent of Total Accidents)					
		1985	1986	1987	1988	1989	1990
F.M. 1960	At Intersection	146 (20)	169 (23)	203 (28)	338 (32)*	288 (31)*	164 (25)
	Intersection Related	158 (22)	124 (17)	124 (17)	138 (13)*	141 (15)*	119 (18)
	Driveway Access	263 (36)	281 (38)	224 (31)	304 (29)*	254 (28)*	216 (32)
	Non-Intersection	163 (22)	160 (22)	176 (24)	275 (26)*	240 (26)*	168 (25)
S.H. 6	At Intersection	52 (26)	69 (29)	54 (23)	72 (22)*	184 (35)*	142 (44)*
	Intersection Related	32 (16)	55 (23)	45 (19)	72 (22)*	77 (15)*	63 (19)*
	Driveway Access	65 (33)	81 (33)	77 (33)	111 (34)*	151 (29)*	44 (14)*
	Non-Intersection	49 (25)	37 (15)	57 (24)	74 (22)*	111 (21)*	75 (23)*
Abrams Rd.	At Intersection	N/A	N/A	24 (56)	17 (57)	25 (60)*	38 (76)*
	Intersection Related			5 (12)	5 (17)	3 (7)*	4 (8)*
	Driveway Access			3 (7)	3 (10)	3 (7)*	2 (4)*
	Non-Intersection			11 (26)	5 (17)	11 (26)*	6 (12)*

Note: F.M. 1960 construction began January 1988 and ended December 1989
S.H. 6 construction began September 1988 and ended April 1991
Abrams Rd. construction began July 1989 and ended October 1991 (proposed)
* Indicates roadway under construction for part or all of year

Table 4-12. Accident Locations for Construction Conditions

Roadway	Accident Type	Number of Accidents per Year (Percent of Total Accidents)		
		Pre-Construction	During-Construction	Post-Construction
F.M. 1960	At Intersection	173 (24)	313 (32)	164 (25)
	Intersection Related	135 (19)	140 (14)	119 (18)
	Driveway Access	256 (35)	278 (28)	216 (32)
	Non-Intersection	166 (23)	258 (26)	168 (25)
S.H. 6	At Intersection	59 (25)	154 (37)	N/A
	Intersection Related	49 (21)	70 (17)	
	Driveway Access	79 (33)	102 (24)	
	Non-Intersection	50 (21)	94 (22)	
Abrams	At Intersection	19 (54)	38 (74)	N/A
	Intersection Related	4 (11)	5 (9)	
	Driveway Access	4 (10)	1 (2)	
	Non-Intersection	9 (25)	7 (15)	

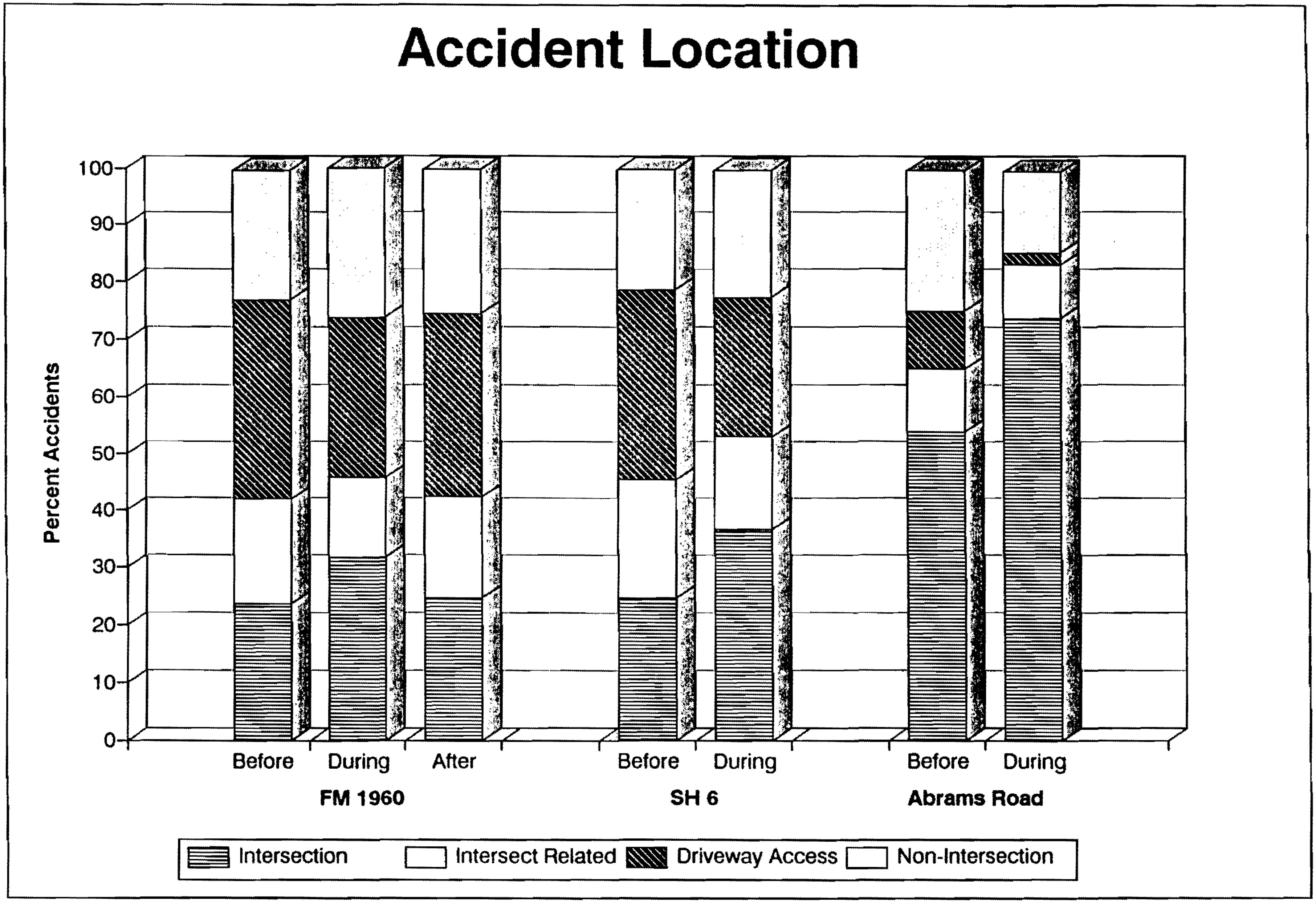


Figure 4-6. Location of Accidents for Construction Conditions

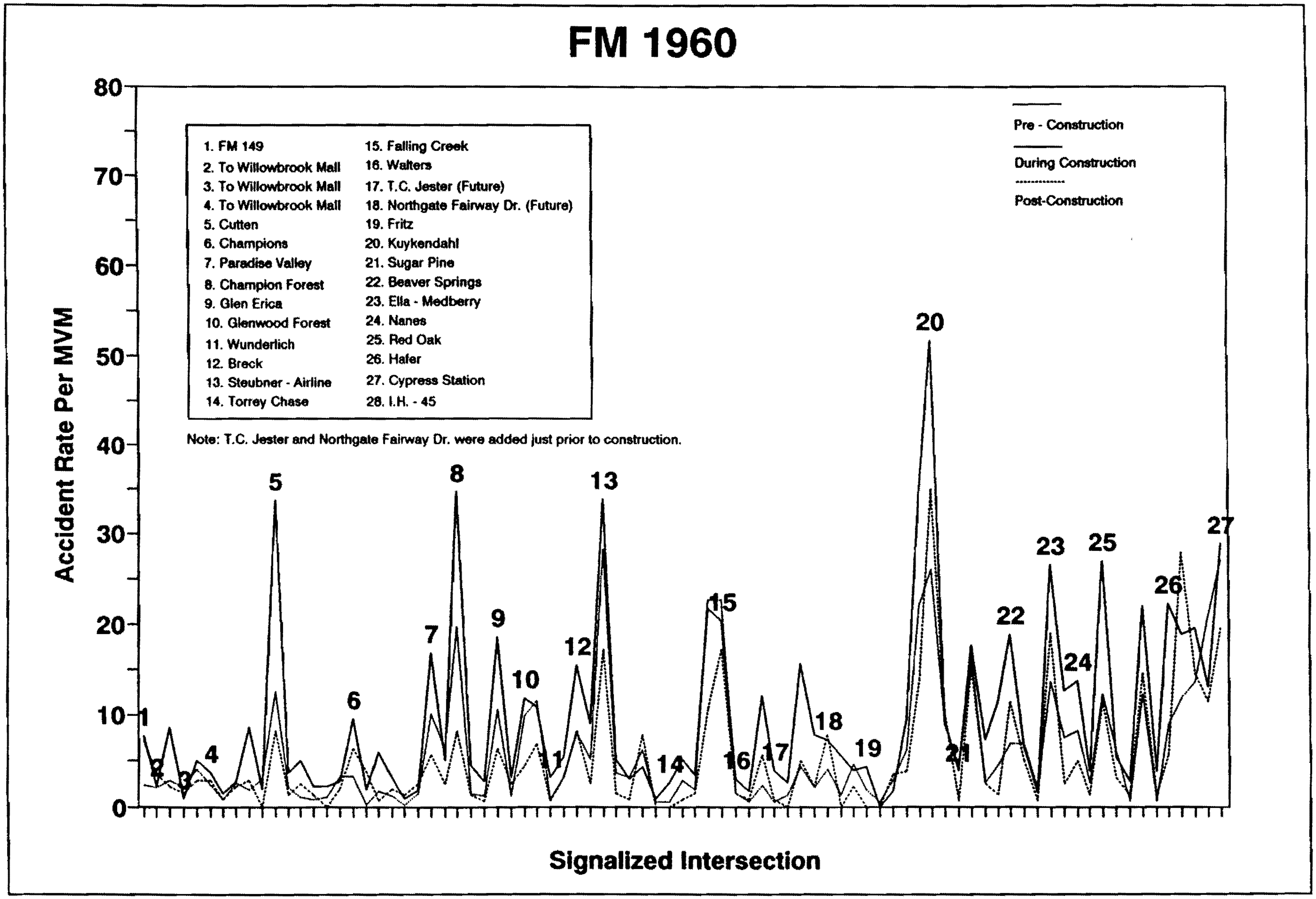


Figure 4-7. F.M. 1960 Accident Rate by Milepost

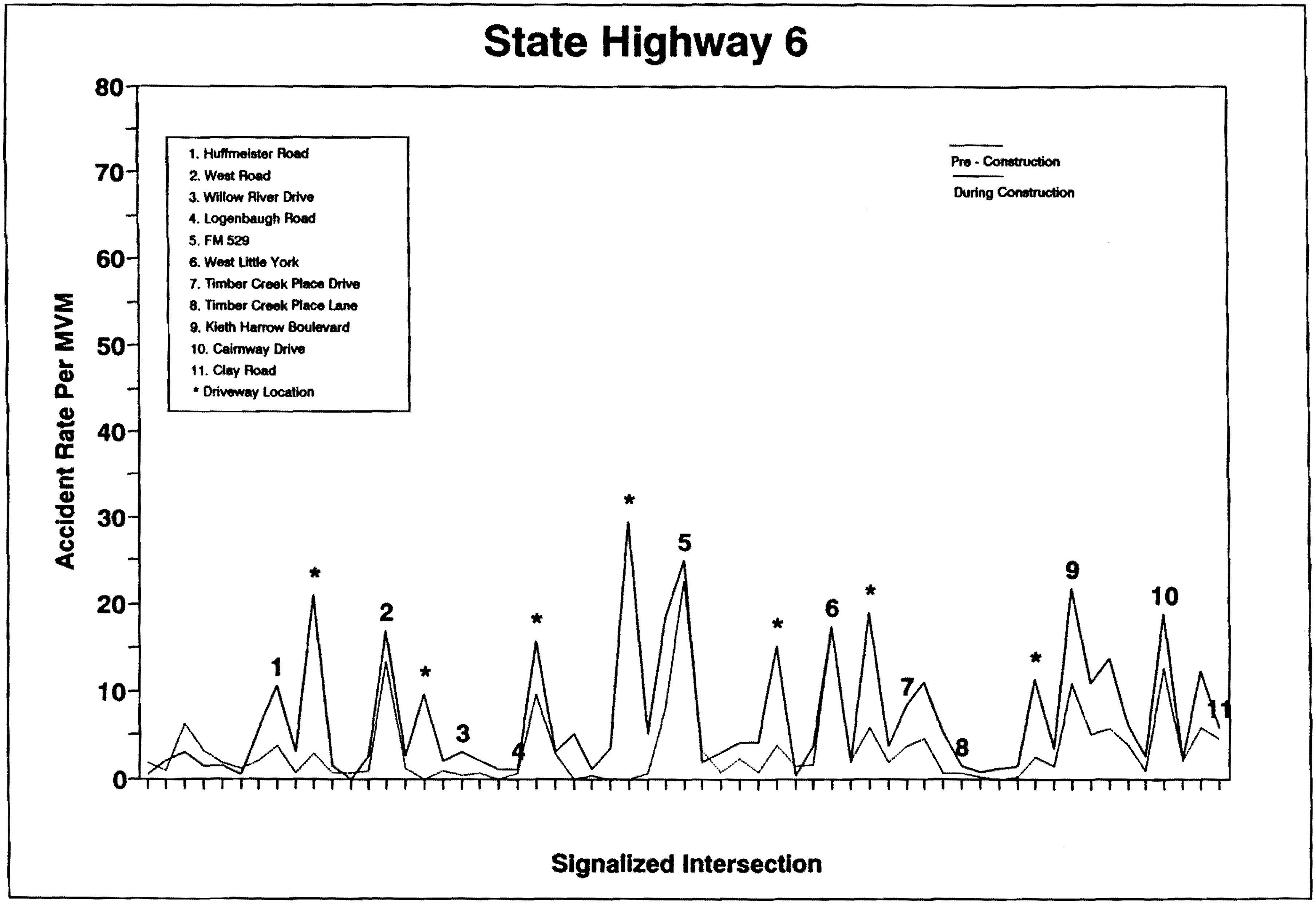


Figure 4-8. S.H. 6 Accident Rate by Milepost

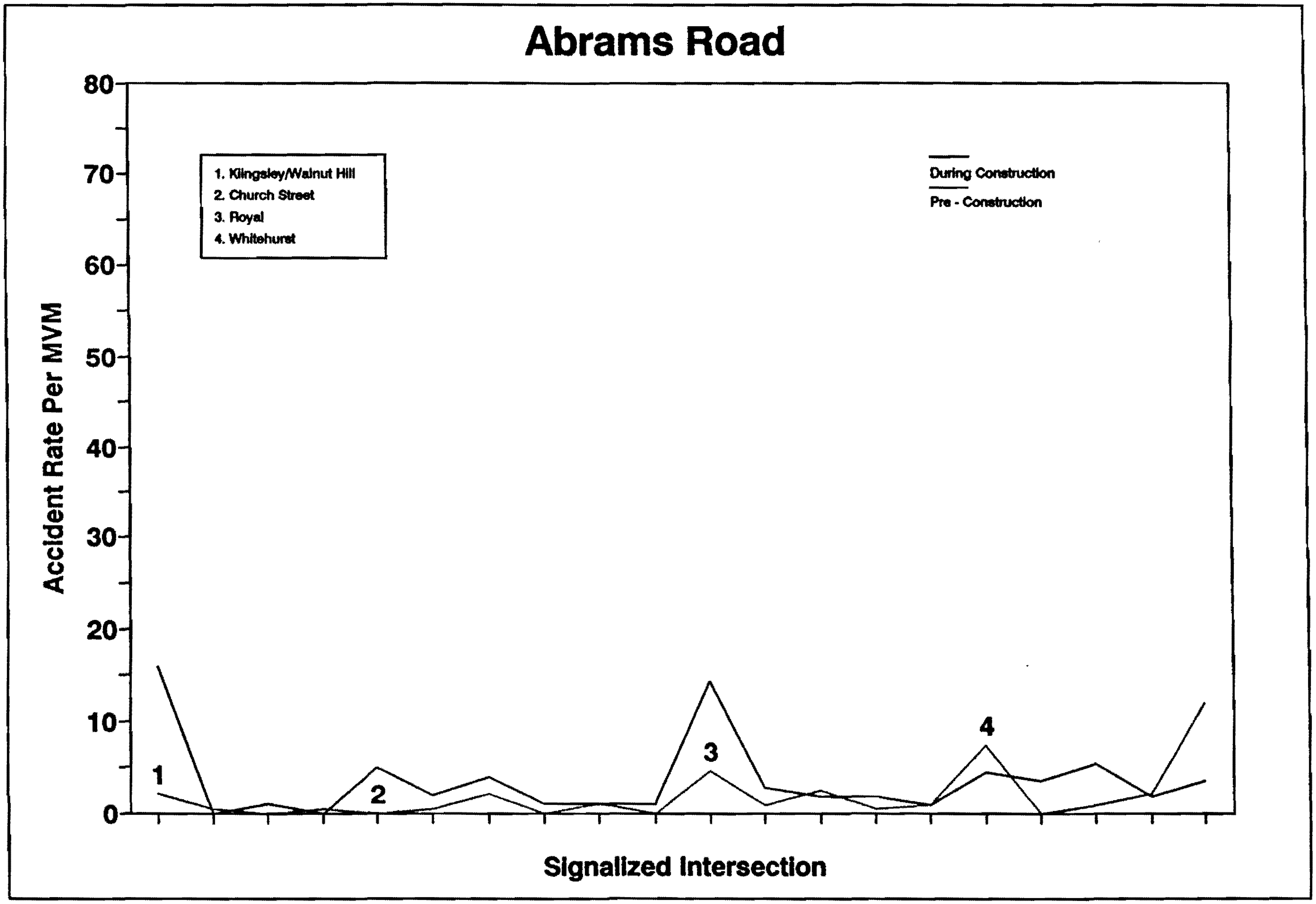


Figure 4-9. Abrams Road Accident Rate by Milepost

Accident Period

The period during which the accident occurred was also analyzed to determine if there was a relationship between accident period and construction conditions. The accident period is defined in three manners: weekday/weekend, time of day, and the lighting condition. Table 4-13 shows the number of accidents occurring during each year for weekday/weekend classifications, and Table 4-14 shows the average number and percentage of weekday/weekend accidents occurring for the different construction conditions. Figure 4-10 illustrates the percentage of accidents occurring for each weekday/weekend classification for the different construction conditions.

The time of day of the accident was split into four distinct periods: 6 am to 10 am, 10 am to 4 pm, 4 pm to 8 pm, and 8 pm to 6 am. Table 4-15 presents the number and percentage of accidents occurring during each year for the four different time periods. Table 4-16 shows the average number and percentage of accidents by time of day for the different construction conditions. Figure 4-11 illustrates the percentage of accidents by time of day for the different construction conditions.

Table 4-17 shows the number and percentage of accidents occurring each year for several lighting conditions: dawn, daylight, dusk, dark-lighted, and dark-not lighted. Table 4-18 shows the average and percentage of accidents that occur during each lighting condition for the different construction conditions. Figure 4-12 illustrates the percentage of accidents occurring during each lighting condition for the different construction conditions.

Each of the variables used in defining the accident period was statistically analyzed with a contingency table and a Chi-square test to determine the relationship between the time when the accident occurred and the construction condition. For the most part, the test results indicated that the construction condition was independent of the accident period. There are two instances where the results of the tests pointed towards dependency.

Dependency was found in the testing of lighting conditions for the different construction conditions on F.M. 1960 only. The results show an increase in the number of accidents for the dark-lighted condition with a 91 percent level of significance.

Dependency was also found in comparing the construction conditions of Abrams Road to the weekday/weekend time of accident. The results indicated more weekday accidents than would be expected for the construction conditions, but this result could be misleading due to the small sample size available for the roadway.

Table 4-13. Time of Week of Accidents by Year

Roadway	Time of Week	Number of Accidents per Year (Percent of Total Accidents)					
		1985	1986	1987	1988	1989	1990
F.M. 1960	Weekend Weekday	196 (27) 534 (73)	176 (24) 558 (76)	182 (25) 545 (75)	272 (26)* 783 (74)*	232 (25)* 691 (75)*	164 (25) 503 (75)
S.H. 6	Weekend Weekday	50 (25) 148 (75)	73 (30) 169 (70)	61 (26) 172 (74)	90 (27)* 239 (73)*	136 (26)* 387 (74)*	86 (27)* 238 (73)*
Abrams Rd.	Weekend Weekday	N/A	N/A	19 (44) 24 (56)	7 (23) 23 (77)	12 (29)* 30 (71)*	7 (14)* 43 (86)*

Note: F.M. 1960 construction began January 1988 and ended December 1989
S.H. 6 construction began September 1988 and ended April 1991
Abrams Rd. construction began July 1989 and ended October 1991 (proposed)
* Indicates roadway under construction for part or all of year

Table 4-14. Time of Week for Construction Conditions

Roadway	Accident Type	Number of Accidents per Year (Percent of Total Accidents)		
		Pre-Construction	During-Construction	Post-Construction
F.M. 1960	Weekend Weekday	185 (25) 545 (75)	252 (25) 737 (75)	164 (25) 503 (75)
S.H. 6	Weekend Weekday	63 (27) 174 (73)	113 (27) 307 (73)	N/A
Abrams	Weekend Weekday	13 (36) 23 (64)	9 (17) 42 (83)	N/A

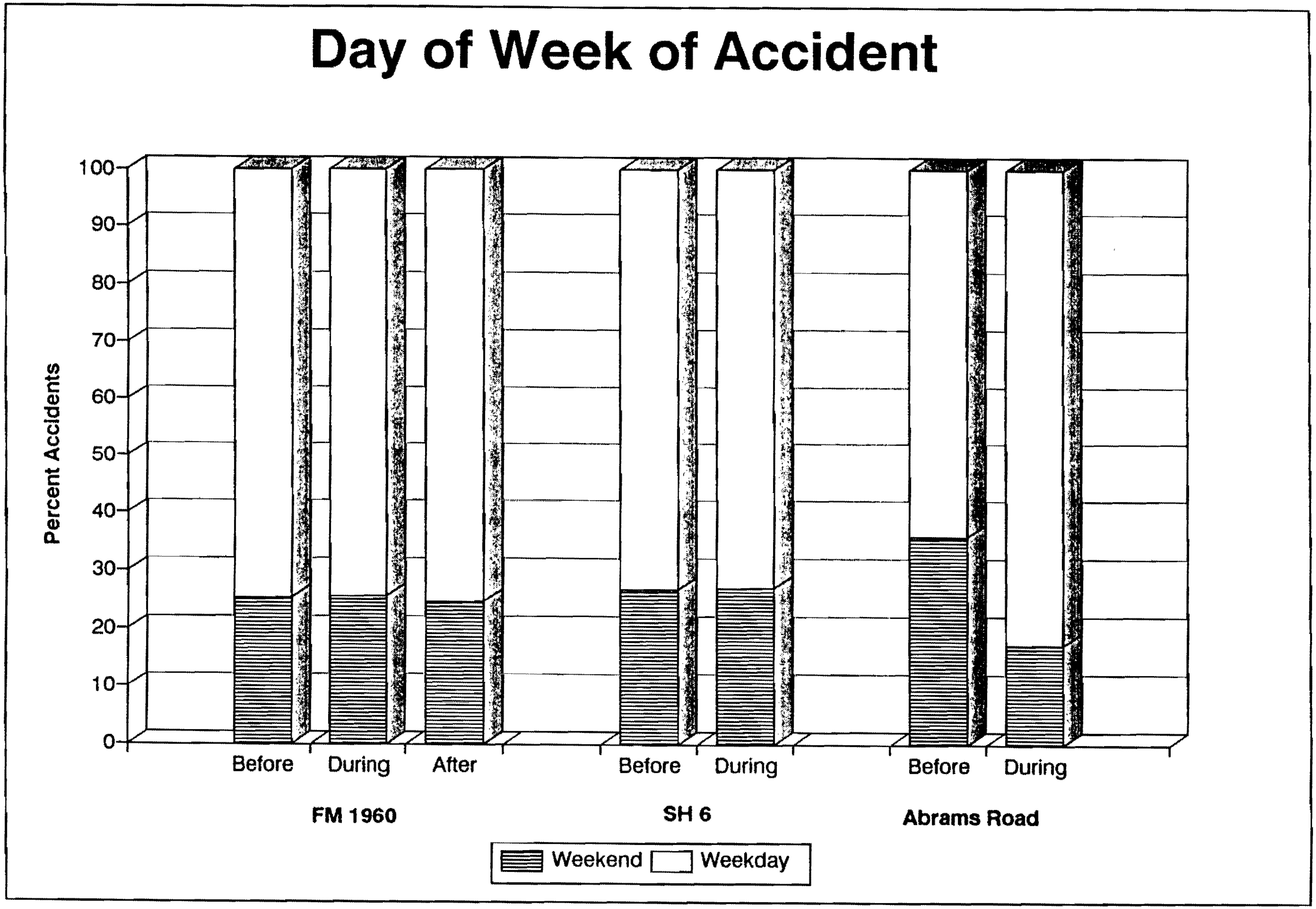


Figure 4-10 Percentage of Accidents by Weekday/Weekend

Table 4-15. Time of Day of Accidents by Year

Roadway	Time of Week	Number of Accidents per Year (Percent of Total Accidents)					
		1985	1986	1987	1988	1989	1990
F.M. 1960	6 am - 10 am	62 (9)	89 (12)	72 (10)	128 (12)*	117 (13)*	76 (11)*
	10 am - 4 pm	320 (44)	358 (49)	333 (45)	471 (45)*	358 (39)*	277 (42)*
	4 pm - 8 pm	185 (25)	155 (21)	192 (27)	258 (24)*	220 (24)*	173 (26)*
	8 pm - 6 am	163 (22)	132 (18)	130 (18)	198 (19)*	228 (25)*	141 (21)*
S.H 6	6 am - 10 am	34 (17)	36 (15)	24 (10)	43 (13)*	71 (14)*	39 (12)*
	10 am - 4 pm	59 (30)	83 (34)	81 (35)	125 (38)*	154 (29)*	111 (34)*
	4 pm - 8 pm	66 (33)	56 (23)	73 (31)	102 (31)*	160 (31)*	108 (33)*
	8 pm - 6 am	39 (20)	67 (28)	55 (24)	59 (18)*	138 (26)*	66 (20)*
Abrams Rd.	6 am - 10 am	N/A	N/A	9 (21)	7 (23)	7 (17)*	9 (18)*
	10 am - 4 pm			7 (16)	8 (27)	16 (37)*	7 (14)*
	4 pm - 8 pm			16 (37)	7 (23)	7 (17)*	17 (34)*
	8 pm - 6 am			11 (26)	8 (27)	12 (29)*	17 (34)*

Note: F.M. 1960 construction began January 1988 and ended December 1989
S.H. 6 construction began September 1988 and ended April 1991
Abrams Rd. construction began July 1989 and ended October 1991 (proposed)
* Indicates roadway under construction for part or all of year

Table 4-16. Time of Day of Accident for Construction Conditions

Roadway	Time of Day	Number of Accidents per Year (Percent of Total Accidents)		
		Pre-Construction	During-Construction	Post-Construction
F.M. 1960	6 am - 10 am	74 (10)	123 (12)	76 (11)
	10 am - 4 pm	337 (46)	414 (42)	277 (42)
	4 pm - 8 pm	177 (24)	239 (24)	173 (26)
	8 pm - 6 am	142 (19)	213 (22)	141 (21)
S.H. 6	6 am - 10 am	31 (13)	57 (13)	N/A
	10 am - 4 pm	83 (35)	136 (32)	
	4 pm - 8 pm	71 (30)	129 (31)	
	8 pm - 6 am	52 (22)	98 (23)	
Abrams Rd.	6 am - 10 am	8 (22)	8 (16)	N/A
	10 am - 4 pm	9 (26)	11 (21)	
	4 pm - 8 pm	10 (27)	15 (29)	
	8 pm - 6 am	9 (25)	17 (34)	

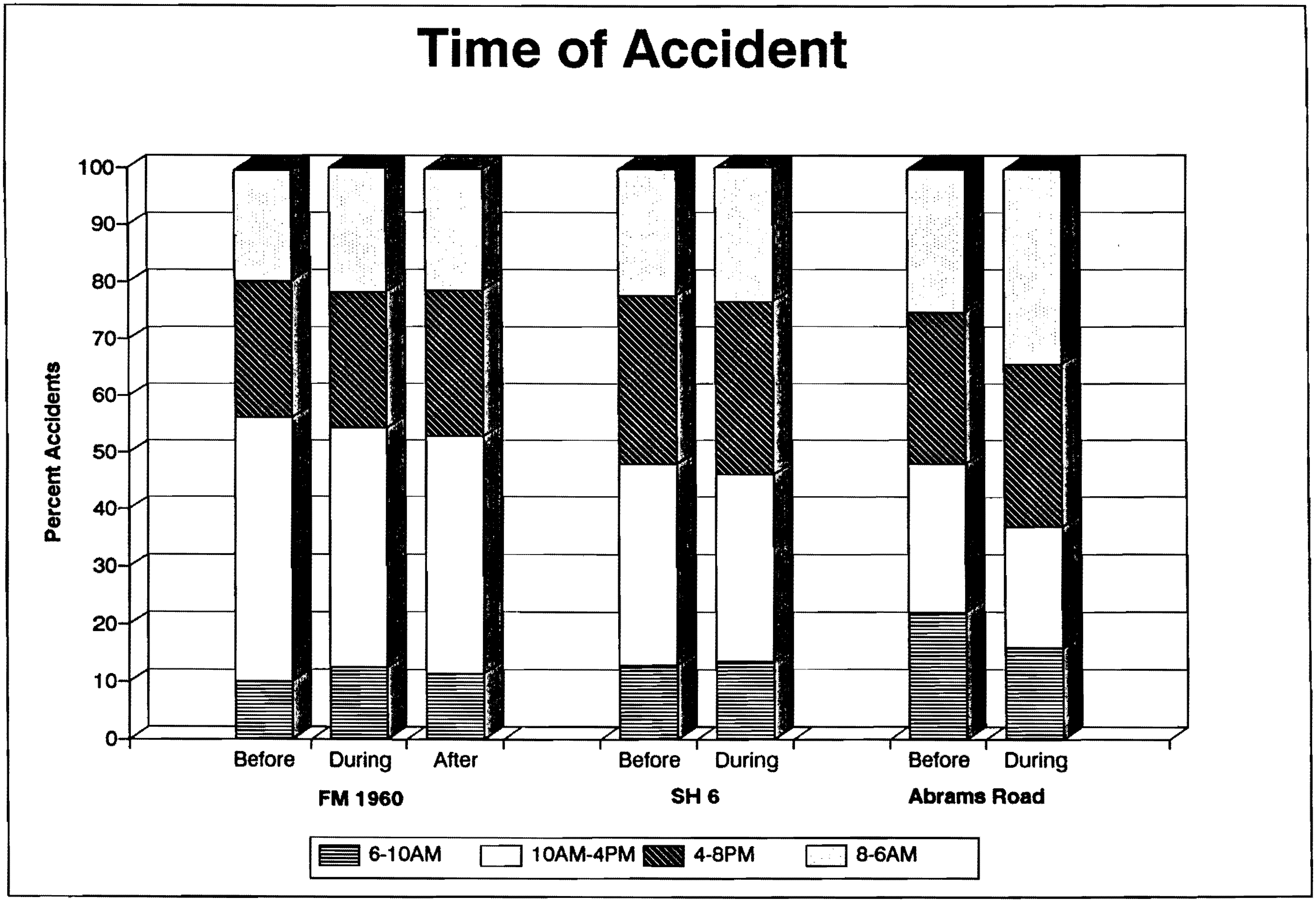


Figure 4-11. Percentage of Accidents by Time of Day

Table 4-17. Accidents by Light Condition by Year

Roadway	Lighting Condition	Number of Accidents per Year (Percent of Total Accidents)					
		1985	1986	1987	1988	1989	1990
F.M. 1960	Dawn	2 (0)	3 (0)	4 (1)	6 (1)*	5 (1)*	3 (0)
	Daylight	493 (68)	548 (75)	523 (72)	738 (70)*	586 (63)*	454 (68)
	Dusk	7 (1)	10 (1)	17 (2)	16 (2)*	25 (3)*	17 (3)
	Dark - Lighted	67 (9)	96 (13)	112 (15)	157 (15)*	190 (21)*	145 (22)
	Dark - Not Lighted	161 (22)	77 (10)	71 (10)	138 (13)*	117 (13)*	48 (7)
S.H. 6	Dawn	1 (1)	2 (1)	4 (2)	3 (1)*	17 (3)*	2 (1)*
	Daylight	130 (66)	158 (65)	145 (62)	233 (68)*	298 (57)*	193 (60)*
	Dusk	1 (1)	0 (0)	7 (3)	6 (2)*	8 (2)*	10 (3)*
	Dark - Lighted	18 (9)	46 (19)	38 (16)	39 (12)*	65 (12)*	41 (13)*
	Dark - Not Lighted	48 (24)	36 (15)	39 (17)	58 (18)*	135 (26)*	78 (24)*
Abrams Rd.	Dawn	N/A	N/A	0 (0)	2 (7)	1 (2)*	2 (4)*
	Daylight			28 (65)	20 (67)	29 (69)*	27 (54)*
	Dusk			1 (2)	1 (3)	0 (0)*	0 (0)*
	Dark - Lighted			11 (26)	5 (17)	10 (24)*	19 (38)*
	Dark - Not Lighted			3 (7)	2 (7)	2 (5)*	2 (4)*

Note: F.M. 1960 construction began January 1988 and ended December 1989
S.H. 6 construction began September 1988 and ended April 1991
Abrams Rd. construction began July 1989 and ended October 1991 (proposed)
* Indicates roadway under construction for part or all of year

Table 4-18. Accidents by Light Condition for Construction Conditions

Roadway	Accident Type	Number of Accidents per Year (Percent of Total Accidents)		
		Pre-Construction	During-Construction	Post-Construction
F.M. 1960	Dawn	4 (1)	5 (1)	3 (0)
	Daylight	521 (71)	664 (67)	454 (68)
	Dusk	11 (2)	20 (2)	17 (3)
	Dark - Lighted	91 (13)	173 (18)	145 (22)
	Dark - Not Lighted	103 (14)	127 (13)	48 (7)
S.H. 6	Dawn	2 (1)	9 (2)	N/A
	Daylight	155 (65)	248 (59)	
	Dusk	3 (1)	9 (2)	
	Dark - Lighted	34 (14)	53 (13)	
	Dark - Not Lighted	43 (18)	101 (24)	
Abrams	Dawn	1 (3)	1 (3)	N/A
	Daylight	25 (69)	29 (57)	
	Dusk	1 (2)	0 (0)	
	Dark - Lighted	7 (20)	18 (36)	
	Dark - Not Lighted	2 (6)	3 (5)	

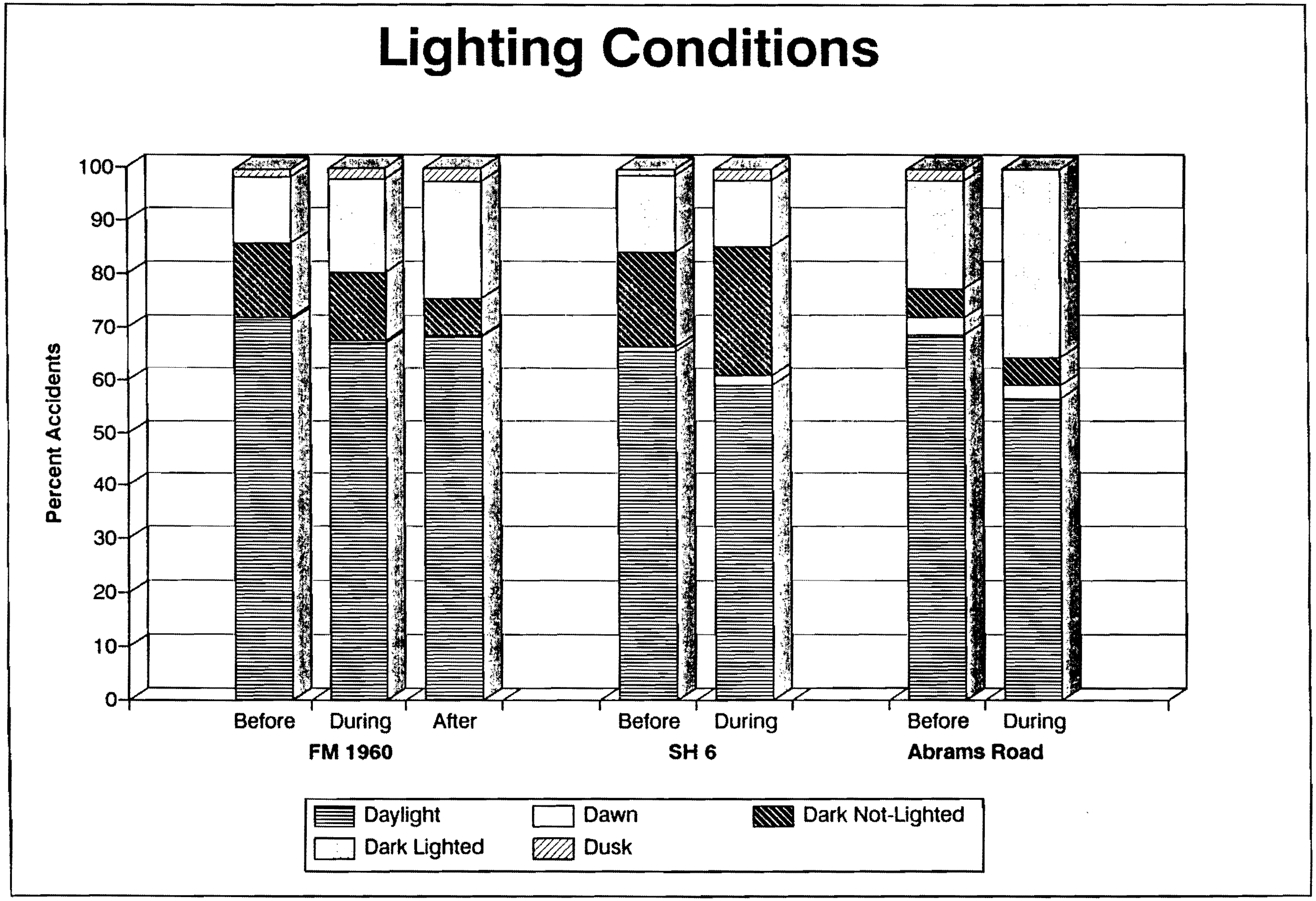


Figure 4-12. Light Condition of Accidents for Construction Conditions

Conclusions from Accident Analysis

Although the analysis of accident data did not provide an indication of the effectiveness of specific traffic control devices, it did provide useful information about the expected increases in accidents, the locations of accidents, and the time period of accidents for urban arterial work zones. This information can be used with the other information obtained in this study to develop guidelines for traffic control in urban arterial work zones.

Several statistically significant conclusions can be drawn from the accident analysis. First is that urban arterial construction will result in an increase in accident frequency and accident rate. Accident frequency may increase from 35 to 77 percent, and the accident rate may increase from 59 to 106 percent. Construction will also cause an increase in the number of accidents occurring near intersections and driveways. Urban arterial construction also results in an increase in the number of accidents occurring during dark conditions, even though construction activities are not taking place during these hours. Over 90 percent of accidents in the work zones take place between two or more vehicles. Collisions with a fixed object were the next most common type of accident. However, construction activities do not seem to have an impact on the type of accident.

The increase in intersection and driveway related accidents indicates a need to better address work zone traffic control at intersections and driveways. The accident analysis was not able to determine specific features of intersections and driveways which impacted accidents. However, some features which should be considered include traffic signals, left-turn lanes, street signing, turning radii at intersections and driveways, and the reduced width of travel lanes. If lanes of unequal width are used, it may be appropriate to locate the wider lane on the outside if there are a large number of driveways or intersections. This provides slightly more room for vehicles to turn onto the roadway.

The increase in accidents occurring during nighttime indicates a need to provide a higher level of reflectorization or illumination for traffic control devices. Greater illumination or use of higher grade reflective sheeting may improve driver visibility of these devices.

CHAPTER 5

TRAFFIC VOLUME AND TRAVEL TIME ANALYSIS

Traffic volume and travel time data were collected at each of the study sites in order to evaluate the impact of construction on traffic flow and operations. Both types of data were collected while construction activities were underway. Pre-construction and post-construction data were not obtained at all three sites because of scheduling conflicts between the research study and construction at the sites. Pre-construction data are available for S.H. 6 and post-construction data are available for F.M. 1960. Pre-construction data is not available for Abrams Road because of a change in study site locations.

Traffic Volume Data

Average weekday traffic volumes for each phase of construction were obtained by with automatic traffic counters. Twenty-four hour volumes were collected from Monday afternoon to Friday morning at all three study sites. Two counters were used at each location to insure the accuracy of the traffic volumes. Daily traffic volumes were obtained for each roadway segment during each construction phase. Roadway segments were defined by major signalized intersections on the arterial street. The volumes were converted to average daily volume and peak-period volumes. Morning peak-period volumes represent time between 6 and 9 am, and evening peak-period volumes represent the time between 3 and 7 pm.

F.M. 1960

Traffic volumes were collected on four segments of F.M. 1960 and on the approaches of intersecting streets. Average weekday two-way traffic volumes for the F.M. 1960 study site are illustrated in Figure 5-1. Pre-construction daily traffic volume data for 1986 and 1987 were obtained from other data sources not related to this study.

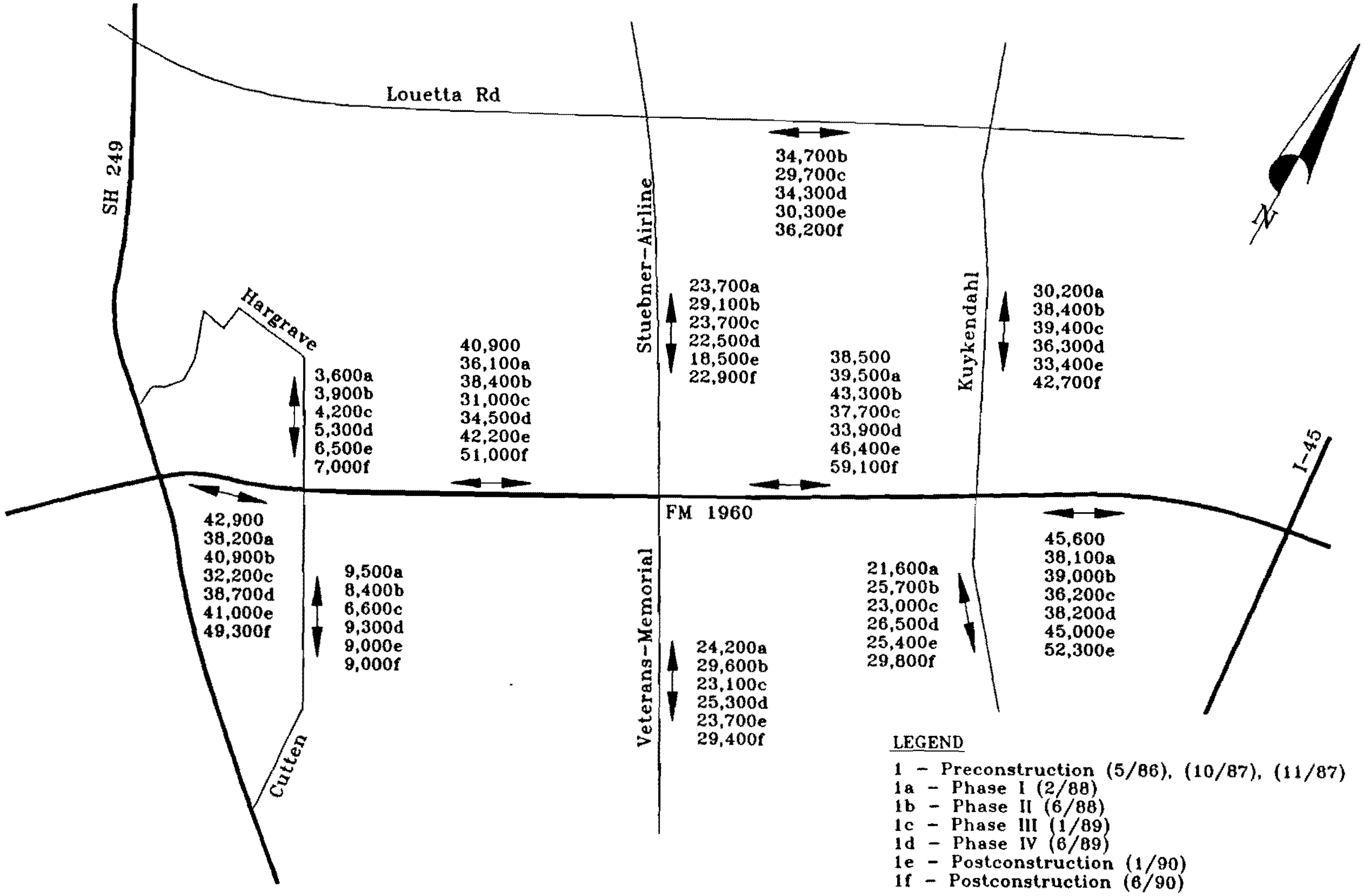


Figure 5-1. F.M. 1960 Average Weekday Traffic Volumes

The general trend for traffic along F.M. 1960 shows that the volumes initially decreased at the beginning of construction and fluctuated up and down throughout the construction period without returning to pre-construction levels. The post-construction data collected in January 1990 indicates that the volumes returned to pre-construction levels and post-construction data collected in June and July 1990 show that traffic volumes increased above pre-construction levels. Figures 5-2 and 5-3 are graphical representations of the morning and evening peak-hour traffic volumes in the eastbound and westbound direction for the segments of Cutten Road to Veterans Memorial, and Veterans Memorial to Kuykendahl.

The initial decrease in traffic volumes may be the result of driver diversion from the construction area. Traffic volumes increased as construction entered Phase II of the contract. The reason for the increase in traffic volumes is unknown, however, the following conditions are offered as possible reasons for the increase in traffic volumes: 1) motorists determined that the construction delay was not as significant as originally perceived, 2) motorists found that there was no real travel time savings on alternate routes when compared to F.M. 1960, or 3) construction activity inhibiting traffic flow decreased, thereby reducing travel delay through the work zone.

During Phase III construction activity was in the center of the roadway. This forced left turns from both directions to cross the work zone at intersections or median crossovers, concentrating left-turns at fewer locations. The delays associated with these maneuvers and others actions (such as construction equipment moving across the roadway to enter the work zone) may have enticed motorists to choose alternate routes, thus avoiding the F.M. 1960 construction area. Figure 5-1 shows that, for most segments, during Phase III traffic volumes were the lowest of all during-construction volumes. The general trend shows a decrease in traffic volumes ranging from 2 to 25 percent.

During Phase IV construction activity was nearing completion with motorists traveling on newly constructed pavement. This improved condition may have increased traffic volumes. Figures 5-2 and 5-3 show most traffic volumes increasing to pre-construction levels.

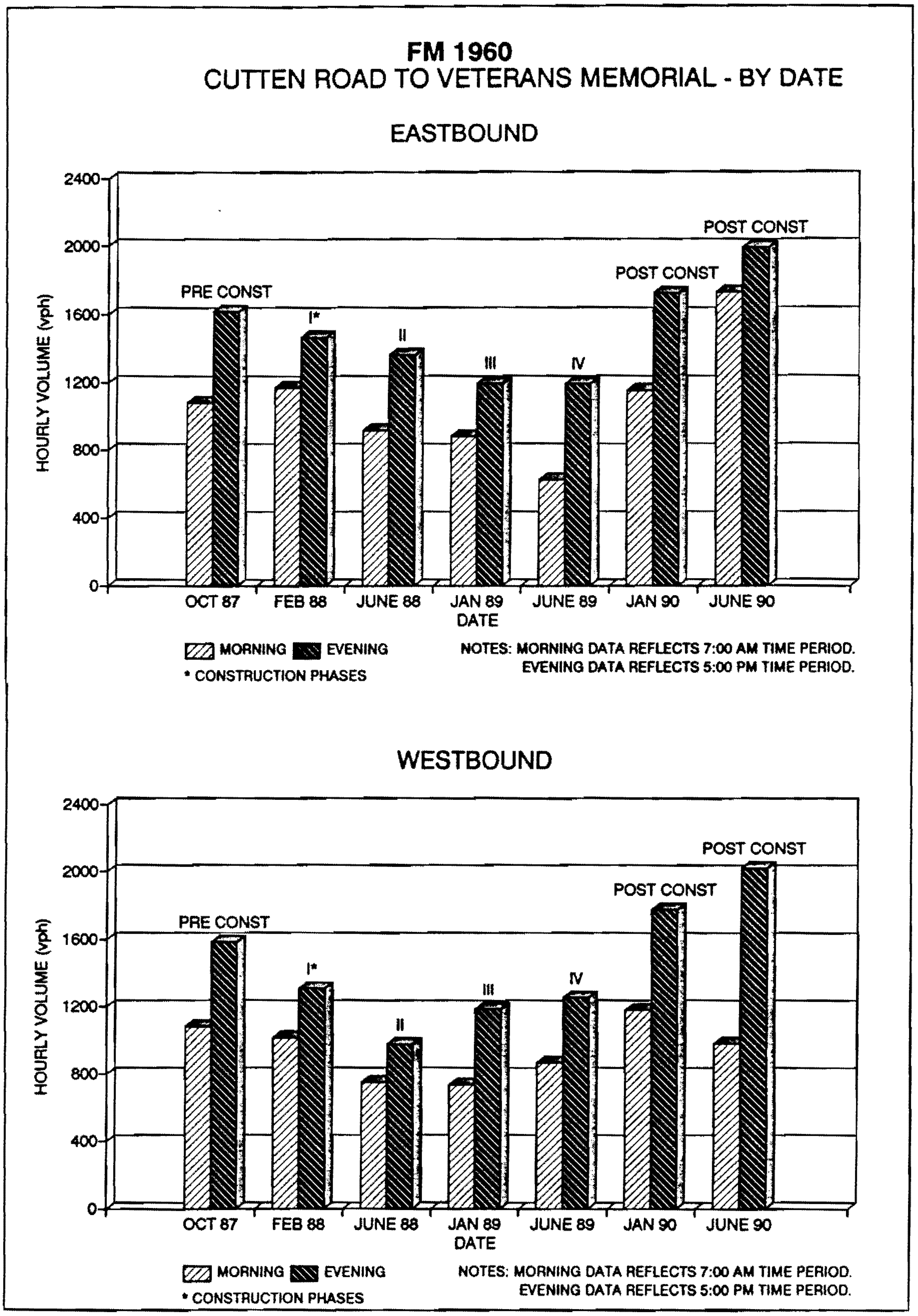


Figure 5-2. F.M. 1960 Traffic Volumes, Cutten Road to Veterans Memorial

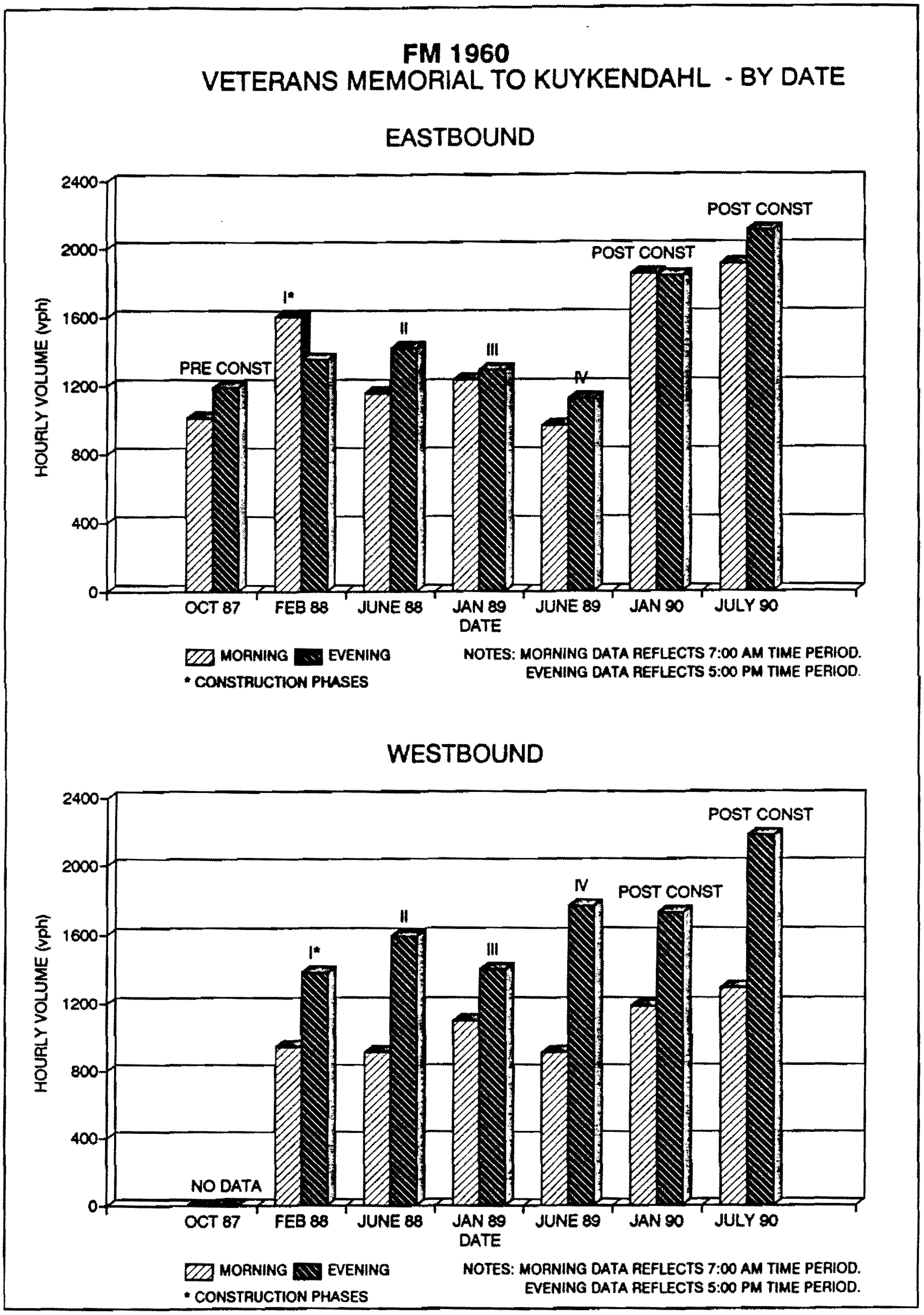


Figure 5-3. F.M. 1960 Traffic Volumes, Veterans Memorial to Kuykendahl

Final construction activity involved the application of permanent pavement markings and general clean-up activities. Traffic volumes increased above pre-construction levels in almost every segment along F.M. 1960.

Traffic volumes were also collected along alternate routes and on approaches to F.M. 1960. Figure 5-1 indicates that traffic volumes along Louetta fluctuated similarly to F.M. 1960. Pre-construction data was not available for Louetta for comparison purposes. Traffic volumes on Louetta were at their lowest during Phase III construction, paralleling the trend on F.M. 1960 during the same phase.

Traffic volumes on approaches to F.M. 1960 show unpredictable results. Figure 5-1 shows approach street traffic volumes increasing and/or decreasing in a manner inconsistent with traffic volumes along F.M. 1960.

Turning movement counts were also obtained on F.M. 1960 during the morning, off, and evening peak-periods. Turning movement counts at the intersections with Kuykendahl, Veterans Memorial and Cutten show a consistent pattern throughout all phases of construction. Although slight fluctuations of 5 percent occurred between phases, through movements were approximately 80 percent of the total volume.

State Highway 6

Traffic volumes were collected on three segments of S.H. 6. Because construction began prior to the research study, pre-construction data was limited. However, Phase I through IV traffic volumes were collected and analyzed. Average daily traffic volumes are shown in Figure 5-4.

The general trend in traffic volumes was very similar to the traffic volumes of F.M. 1960. This especially true for the two segments south of West Little York. These two segments tend to change relative to one another. The remaining segment between West Road and F.M. 529 tend to change with unpredictable behavior inconsistent with the other segments.

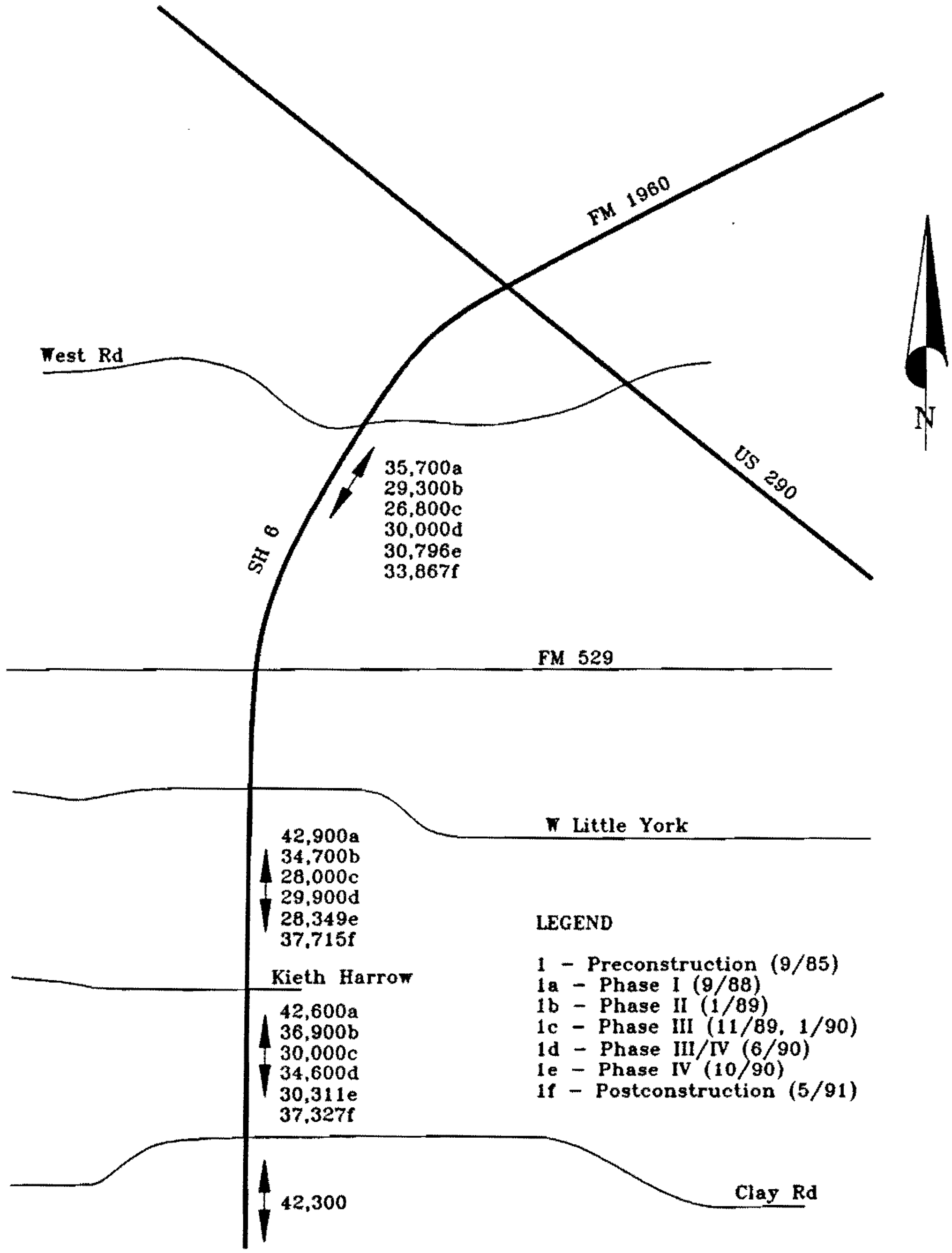


Figure 5-4. S.H. 6 Average Weekday Traffic Volumes

Phase I traffic volumes do not represent a significant change compared to the pre-construction volume south of Clay Road. Phase I traffic volumes were compared to subsequent construction phase volumes. During Phase II traffic volumes ranged from 13 to 19 percent of Phase I volumes. Similar to F.M. 1960, the lowest traffic volume occurred during Phase III of the construction contract; the decrease ranged from 25 to 35 percent of Phase I volumes. During the last phase of the contract, Phase IV, traffic volumes ranged from 14 to 34 percent of Phase I volumes. Traffic volumes in post-construction conditions were shown to range from 5 to 13 percent of Phase I volumes.

Figures 5-5, 5-6 and 5-7 are graphical representation of the morning and evening peak-hour traffic volumes in the southbound and northbound direction for the segments of Clay Road to Kieth Harrow, Kieth Harrow to West Little York, and F.M. 529 to West Road. These figures reflect the travel conditions described above.

Abrams Road

Average weekday traffic volumes were collected on three segments of Abrams Road and on cross-street approaches of three major intersections on Abrams Road. However, as described in Chapter 3, construction began before the site was selected for study, therefore, pre-construction and Phase I traffic volumes were not collected. Phase II through IV traffic volumes were collected and analyzed. The Abrams Road construction project is currently in the final stage of completion, therefore, post construction data was not collected. Phase II through three traffic volume data is shown in Figure 5-8.

The general trend in traffic volumes is similar to the traffic volumes on F.M. 1960 and S.H. 6. Traffic volumes during Phase III are lower than volumes during Phase II. Traffic volumes were generally lowest during Phase III of construction. Phase IV resulted in an increase in traffic volumes.

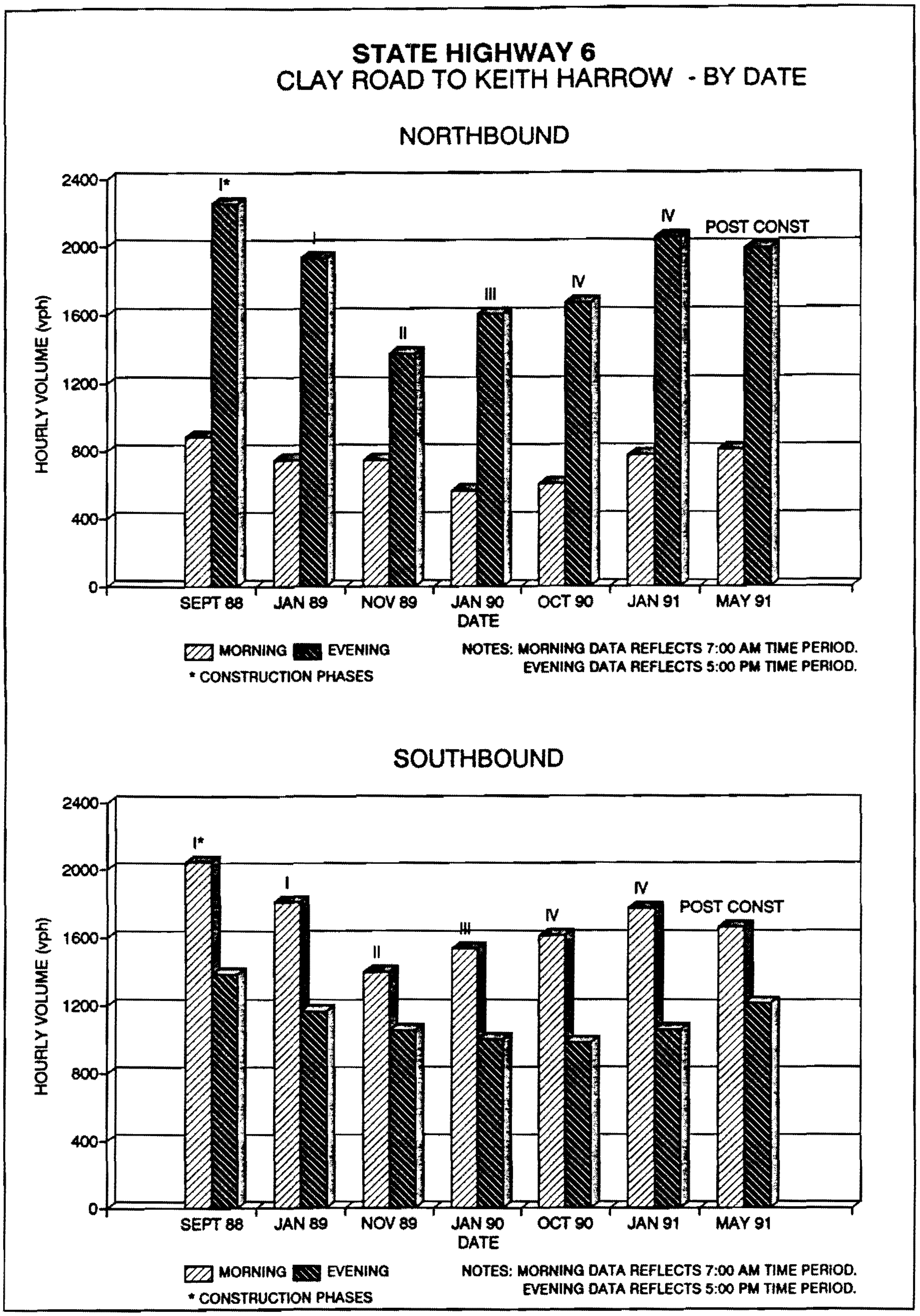


Figure 5-5. S.H. 6 Traffic Volumes, Clay Road to Kieth Harrow

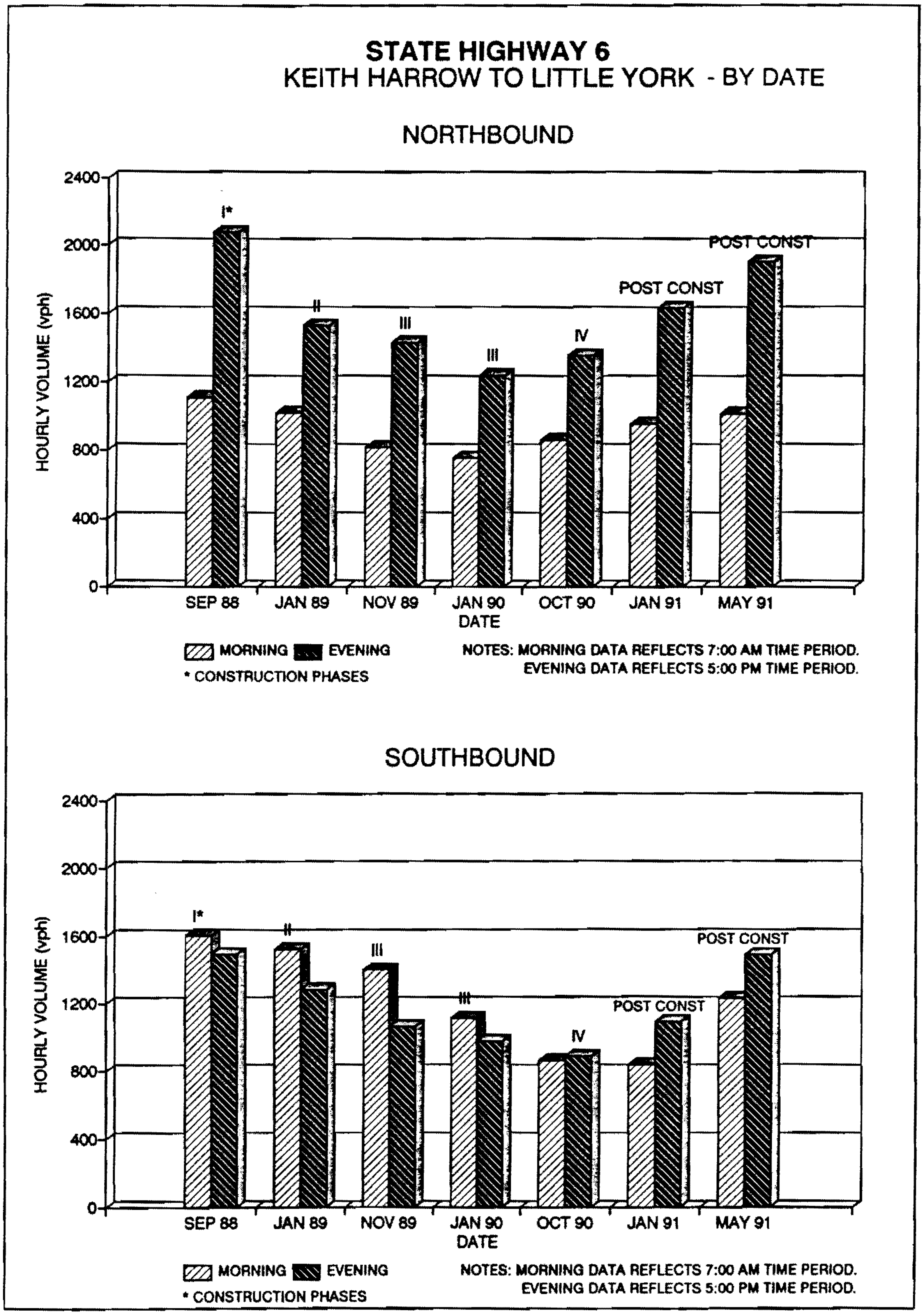


Figure 5-6. S.H. 6 Traffic Volumes, Kieth Harrow to West Little York

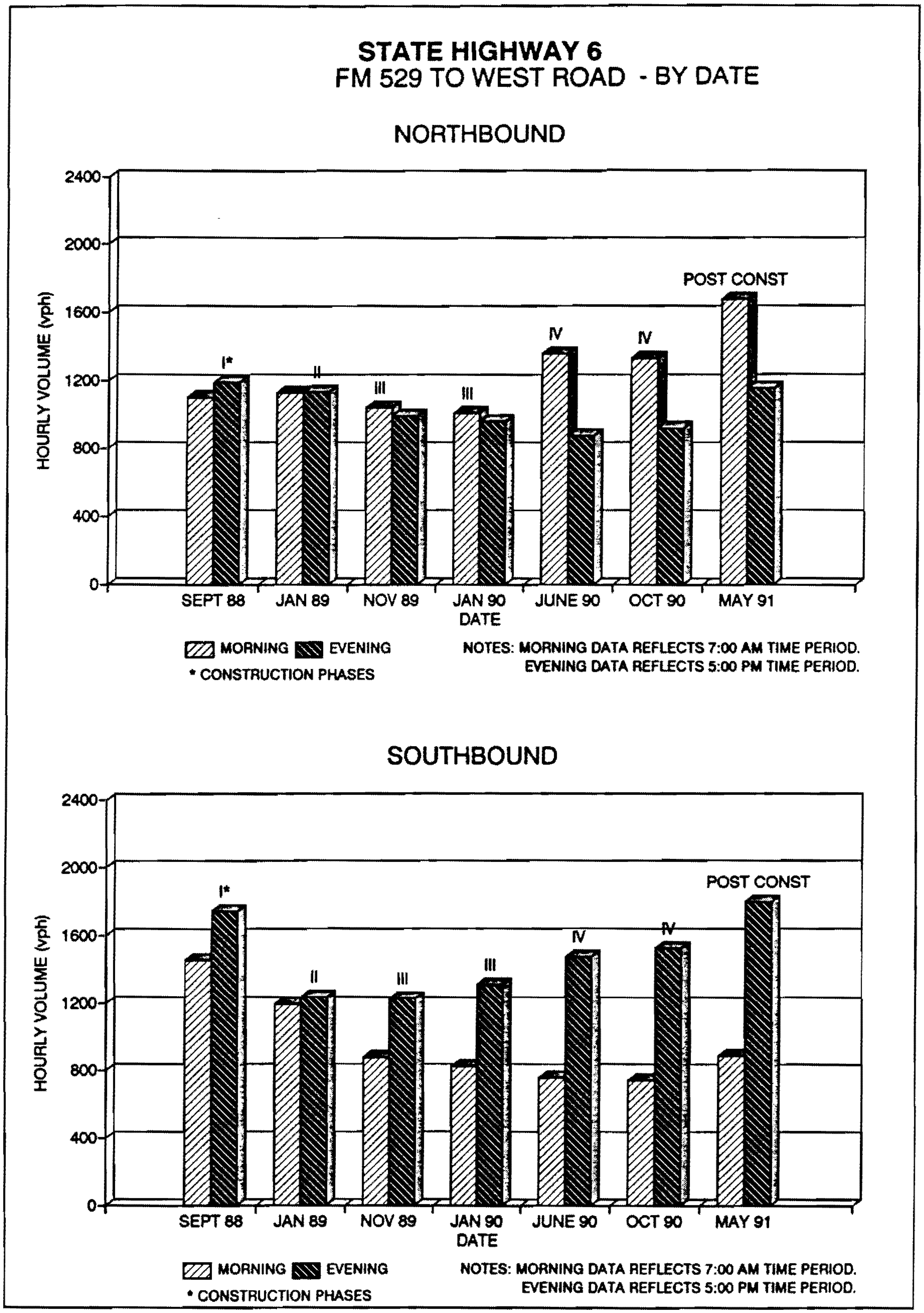


Figure 5-7. S.H. 6 Traffic Volumes, F.M. 529 to West Road

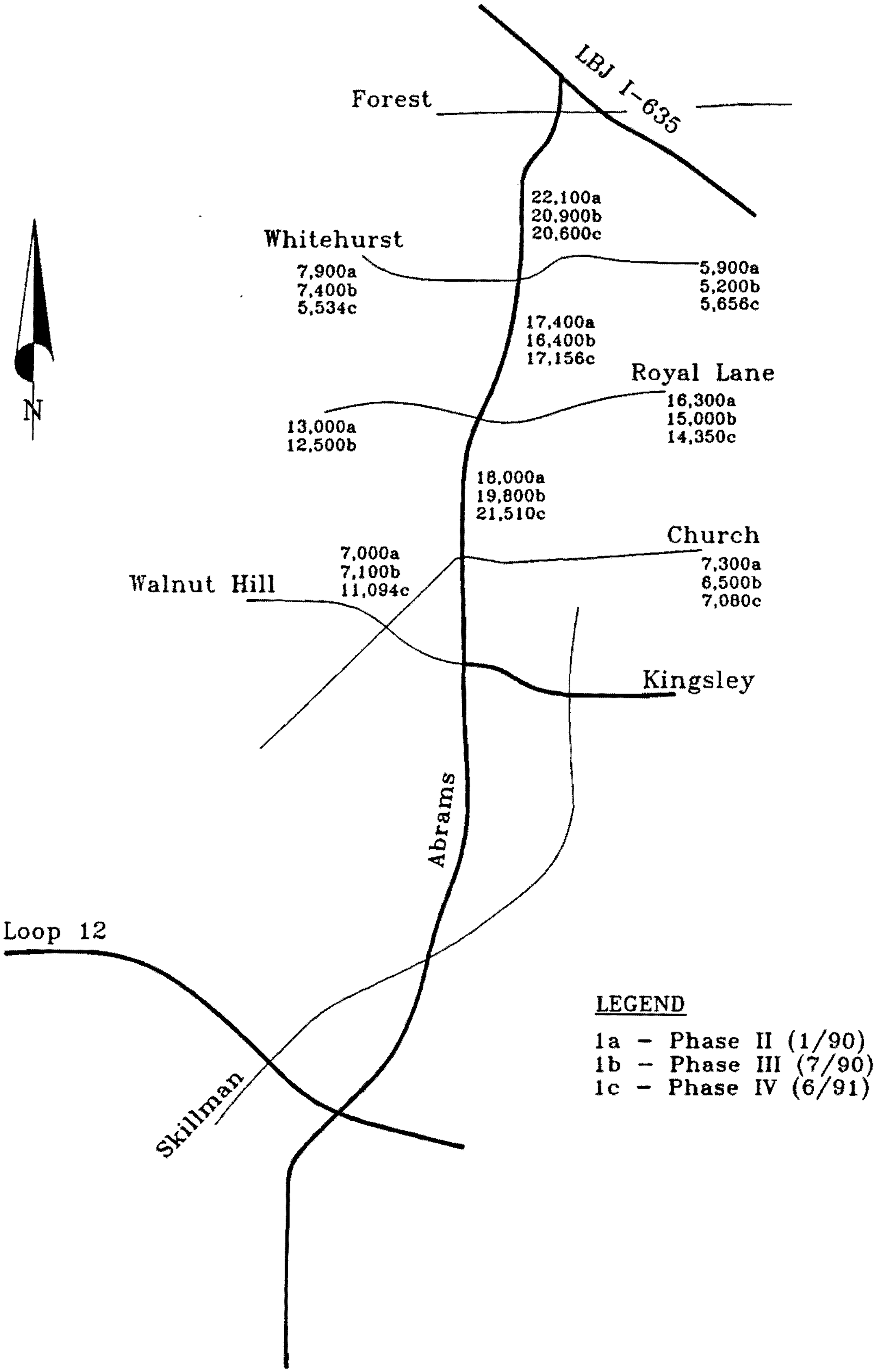


Figure 5-8. Abrams Road Average Weekday Traffic Volumes

Figures 5-9, 5-10 and 5-11 are graphical representations of the traffic volumes in the southbound and northbound direction for the segments Church to Royal Lane, Royal Lane to Whitehurst, and Whitehurst to Forest. These figures show morning and evening peak-hour traffic volumes and indicate a substantial difference between morning and evening travel conditions. The evening traffic volumes are higher than the morning volumes by as much as 50 percent. This may indicate that this roadway is used primarily by commuters during the homebound trip.

Traffic volumes on the cross-street approaches of Whitehurst, Royal, and Church showed similar patterns. Whitehurst reflected higher evening volumes, most significantly in the eastbound direction. The eastbound morning peak-period volumes were approximately 10 to 30 percent of the evening peak-period volume. Royal Lane showed a strong eastbound movement in the evening peak-period, ranging from 10 to 40 percent of the morning peak-period volume. The westbound travel pattern reflected a higher morning volume (10 to 60 percent of the evening peak-period volume). Church Street reflected the same pattern as Royal Lane, high evening volumes in the eastbound direction and high volumes in the westbound direction during the morning peak.

Travel Time Data

Travel time data were collected on each of the three study sites during each phase of construction (and after construction on F.M. 1960). The average-car technique was used for the travel time runs. The time at which the test vehicle passed each intersection was recorded along with any travel delays.

Multiple runs were made for the morning, off, and evening peak-periods for each individual day of data collection. From this data, an average travel time was calculated for each day and each peak-period. An overall average for the peak-period was then computed. It should be noted that travel times include delays incurred at signalized intersections.

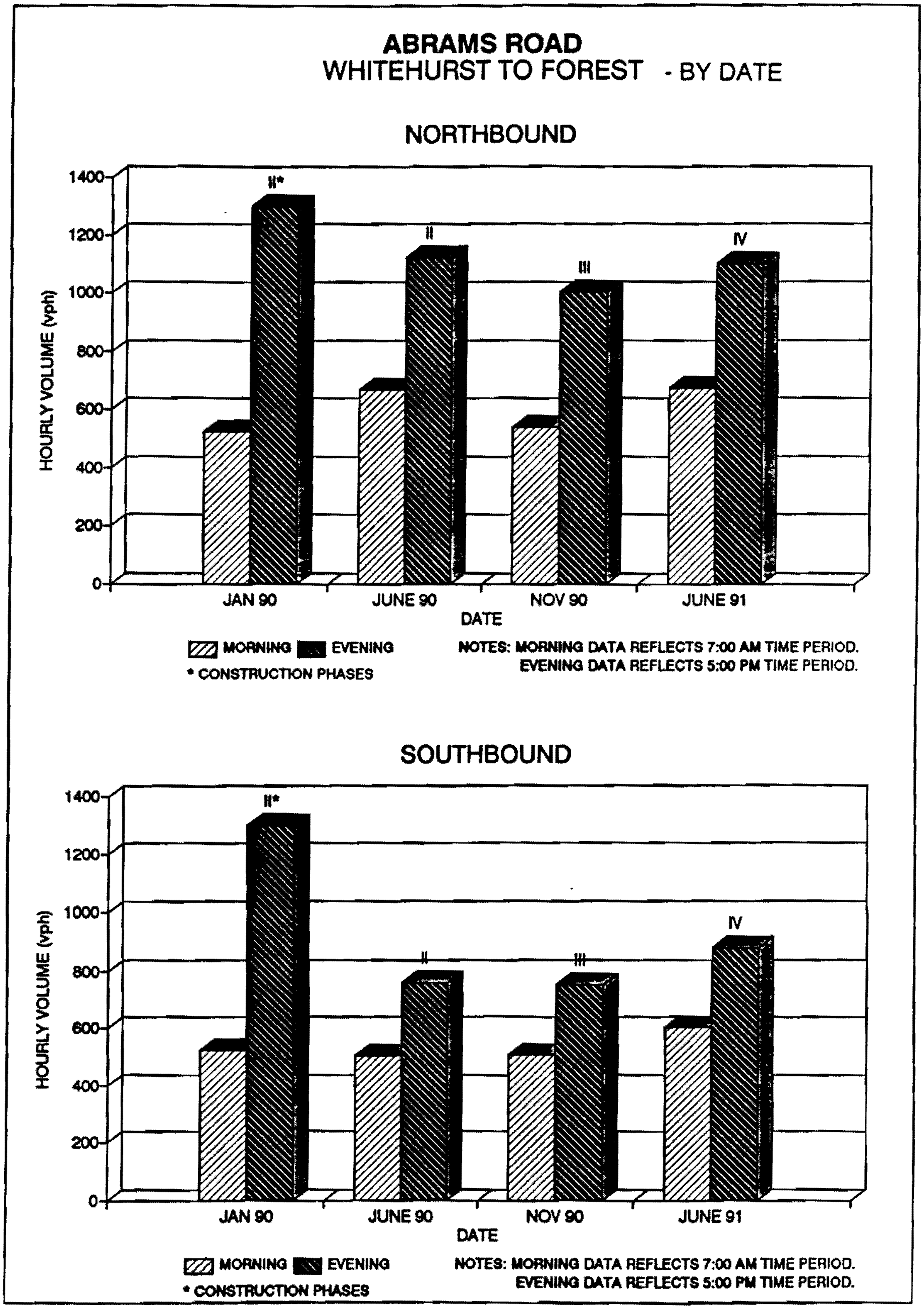


Figure 5-9. Abrams Road Traffic Volumes, Whitehurst to Forest Lane

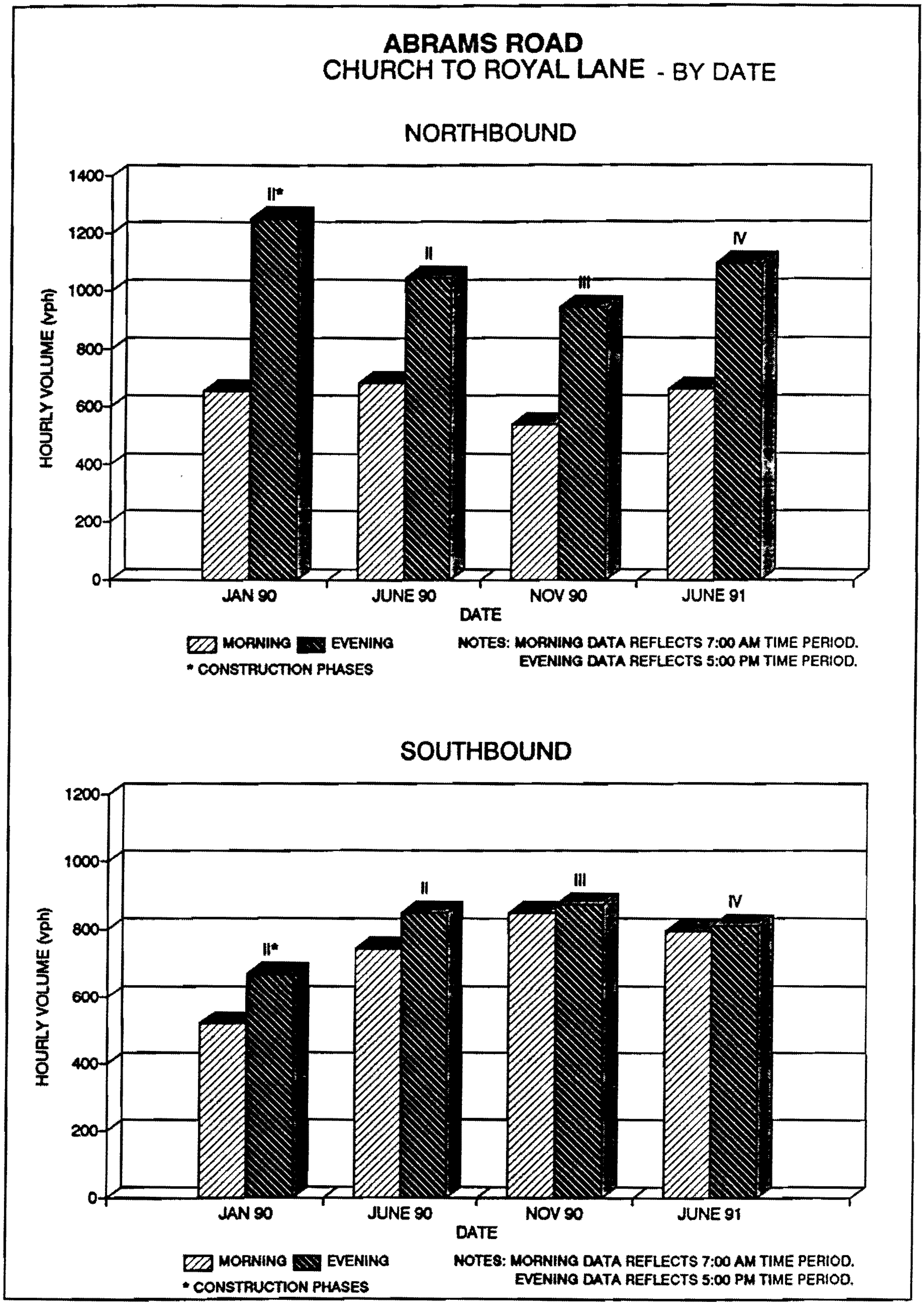


Figure 5-10. Abrams Road Traffic Volumes, Church to Royal Lane

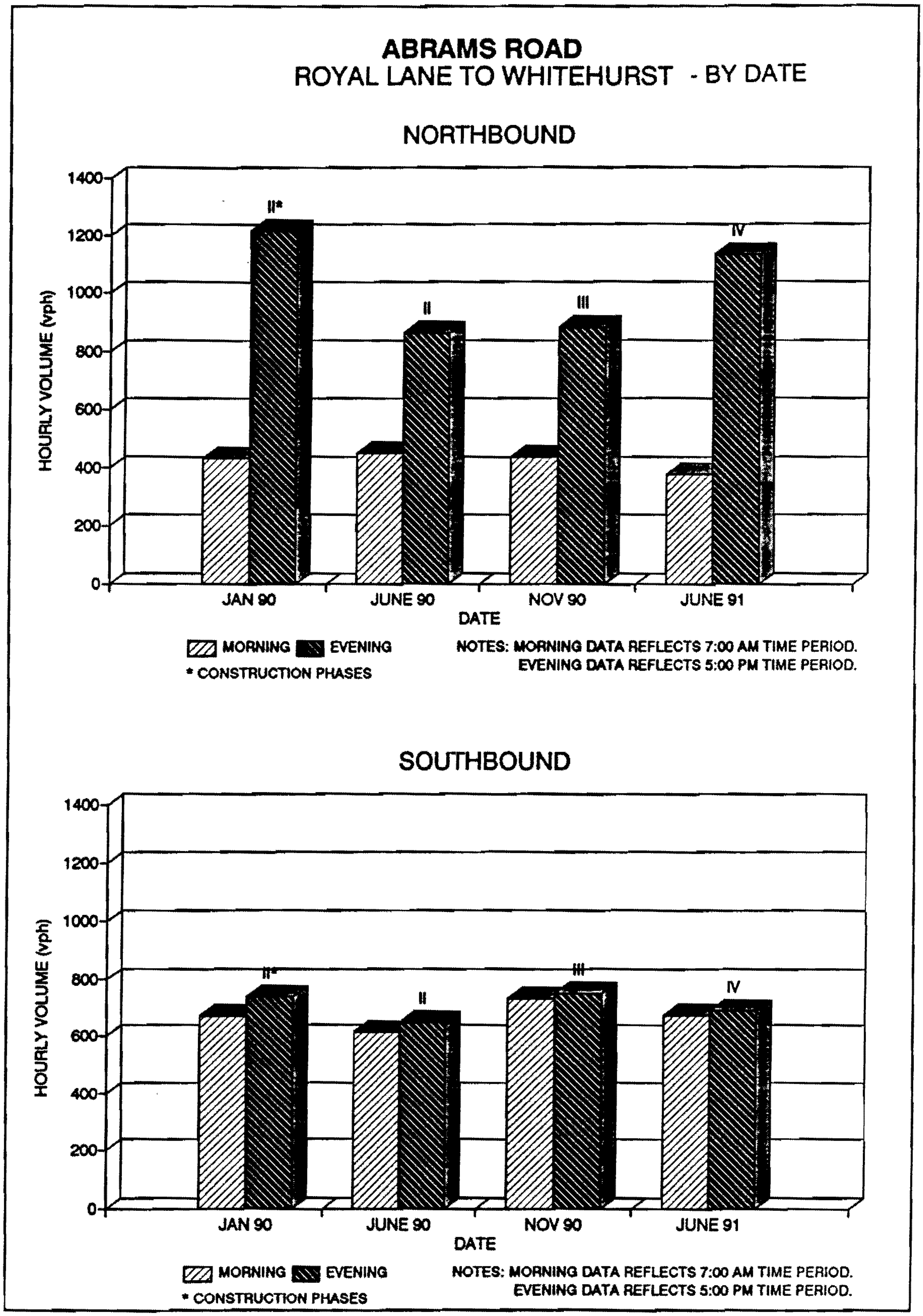


Figure 5-11. Abrams Road Traffic Volumes, Royal Lane to Whitehurst

F.M. 1960

The travel time data for F.M. 1960 is summarized in Table 5-1. The average speeds resulting from these travel times are shown in Table 5-2. As previously noted, pre-construction data is limited. Phase I travel times are limited, and therefore, travel time comparisons are based on data from the Phase II through post-construction.

Table 5-1 indicates that, as construction progressed, average travel times increased for the eastbound direction during the morning and evening peak-periods. The average travel time for the westbound direction remained relatively constant from Phase II to Phase III. However, an increase is noted in Phase IV for both peak-periods. Post-construction data illustrate significantly lower travel times in both directions for all time periods.

Table 5-1. F.M. 1960 Travel Time Comparison
(Limits: S.H. 249 to Hafer Road)

Direction	Phase	Average Travel Time During Peak-Period, Minutes		
		Morning Peak	Off Peak	Evening Peak
Eastbound	II	15.3	20.6	18.7
	III	17.1	19.5	20.4
	IV	18.2	22.7	23.1
	PC[1]	14.3	15.5	16.5
	PC[2]	14.1	15.5	15.6
Westbound	II	16.1	22.8	21.3
	III	16.0	19.7	21.8
	IV	18.1	23.8	24.7
	PC[1]	15.5	15.9	19.0
	PC[2]	14.9	16.1	17.1

Note: PC[1] - Post-Construction (upon completion)
PC[2] - Post-Construction (6 months after completion)

Delays experienced within the F.M. 1960 corridor may be attributed to construction conditions. The absence of the continuous left-turn lane have appeared to be the major contributor to the delays. The narrower traffic lanes and presence of construction drums also seemed to affect the driver's speed. The motorists' survey included in Chapter 6 explains drivers' perceptions of the F.M. 1960 construction conditions.

Table 5-2. F.M. 1960 Travel Speed Comparison
(Limits: S.H. 249 to Hafer Road)

Direction	Phase	Average Travel Speed During Peak-Period, mph		
		Morning Peak	Off Peak	Evening Peak
Eastbound	II	30	22	25
	III	27	24	23
	IV	25	20	20
	PC[1]	32	30	28
	PC[2]	33	30	30
Westbound	II	29	20	22
	III	29	23	21
	IV	26	19	19
	PC[1]	30	29	24
	PC[2]	31	29	27

Note: PC[1] - Post-Construction (upon completion)
PC[2] - Post-Construction (6 months after completion)

Table 5-1 shows that travel times for the evening peak-period are higher than those during the morning peak-period. Taking into consideration that evening peak-period roadway volumes are typically higher than those during the morning peak-period, the longer travel times are expected.

The off peak-period travel times show equal or longer travel times than the evening peak-period during construction. The off peak travel times are lower than the evening peak-period travel times after construction was completed. The higher travel times experienced during the off peak-period may be due to the many motorists turning in and out of the retail and commercial establishments located along F.M. 1960.

State Highway 6

The summary of travel time data collected on S.H. 6 is shown in Table 5-3, and the speeds resulting from these travel times are shown in Table 5-4. As previously indicated, the S.H. 6 project has three roadway segments which are not always in the same phase of construction. Table 5-3 shows that two different phases of construction were represented for some sets of collected data.

As previously noted in the study site description, S.H. 6 is a north/south roadway between U.S. 290 and I.H. 10, both which are major radial freeways. The data shown in Table 5-3 illustrates how the southbound average travel times for the morning peak are significantly higher than those for the northbound direction. Heavier southbound commuter traffic supports the longer travel times. The average travel time runs for the off peak-period show similar values as those for the evening peak-period in both directions. The interaction of lunch time traffic in and out of driveways may contribute to these lowered travel times.

Table 5-3. State Highway 6 Travel Time Comparison
(Limits: U.S. 290 to Clay Road)

Direction	Phase (Segment)	Average Travel Time During Peak-Period, Minutes		
		Morning Peak	Off Peak	Evening Peak
Northbound	I (1,2,3)	10.7	12.7	13.2
	I (3), II (1,2)	12.9	12.4	12.5
	II (2,3), III (1)	13.2	12.1	13.5
	III (1,2,3)	12.9	14.1	14.5
	III (2,3), IV (1)	12.6	13.8	13.1
	III (3), IV (1,2)	13.2	15.8	14.1
	IV (1,2,3)	12.8	13.3	13.7
	IV (3), PC (1,2)	11.6	12.7	13.7
	PC (1,2,3)	10.7	10.7	11.2
Southbound	I (1,2,3)	13.2	11.1	12.2
	I (3), II (1,2)	15.8	13.3	13.9
	II (2,3), III (1)	12.6	13.0	13.2
	III (1,2,3)	13.7	11.8	12.9
	III (2,3), IV (1)	13.5	12.9	14.0
	III (3), IV (1,2)	13.4	14.7	14.9
	IV (1,2,3)	14.4	15.5	15.6
	IV (3), PC (1,2)	12.7	12.6	13.2
	PC (1,2,3)	10.2	10.7	11.0

Note: Phases are shown by segment.
Example: I(3), II(1,2) shows that Segment 3 was in the first phase and Segments 1 and 2 were in the second phase.
PC - Post-Construction

Table 5-4. State Highway 6 Travel Speed Comparison
(Limits: U.S. 290 to Clay Road)

Direction	Phase (Segment)	Average Travel Speed During Peak-Period, mph		
		Morning Peak	Off Peak	Evening Peak
Northbound	I (1,2,3)	36	30	29
	I (3), II (1,2)	30	31	30
	II (2,3), III (1)	29	31	28
	III (1,2,3)	30	27	26
	III (2,3), IV (1)	30	28	29
	III (3), IV (1,2)	29	24	27
	IV (1,2,3)	30	29	28
	IV (3), PC (1,2)	33	30	28
	PC (1,2,3)	36	36	34
Southbound	I (1,2,3)	29	34	31
	I (3), II (1,2)	24	29	27
	II (2,3), III (1)	30	29	29
	III (1,2,3)	28	32	30
	III (2,3), IV (1)	28	30	27
	III (3), IV (1,2)	28	26	26
	IV (1,2,3)	26	25	24
	IV (3), PC (1,2)	30	30	29
	PC (1,2,3)	37	36	35

Note: Phases are shown by segment.
Example: I(3), II(1,2) shows that Segment 3 was in the first phase and Segments 1 and 2 were in the second phase.
PC - Post-Construction

Abrams Road

The summary of travel time data collected on Abrams Road is shown in Table 5-5 and the resulting average travel speeds are shown in Table 5-6. Data collection began starting with Phase II of the construction contract. The earlier phases were in operation before this study site was selected.

The Abrams Road travel time data does not indicate a large variance between construction phases. The Abrams Road site is approximately 2 miles in length, therefore, it may not possess the distance required for large variances to occur. The most noticeable difference is the northbound evening peak travel time larger than the morning peak-period. This would be expected because the traffic volumes are at their highest at this time.

Table 5-5. Abrams Road Travel Time Comparison
(Limits: Forest to Kingsley)

Direction	Phase	Average Travel Time During Peak-Period, Minutes		
		Morning Peak	Off Peak	Evening Peak
Northbound	II	4.9	3.7	4.9
	II	4.4	4.3	4.8
	III	5.4	5.4	5.7
Southbound	II	4.5	4.4	5.0
	II	4.4	4.9	4.4
	III	4.9	4.0	5.4

Table 5-6. Abrams Road Travel Speed Comparison
(Limits: Forest to Kingsley)

Direction	Phase	Average Travel Speed During Peak-Period, mph		
		Morning Peak	Off Peak	Evening Peak
Northbound	II	26	34	26
	II	29	29	26
	III	23	23	22
Southbound	II	28	29	25
	II	29	26	29
	III	26	32	23

Conclusions from Traffic Volume and Travel Time Analysis

The traffic volume and travel time data did not indicate any specific trends in traffic flow which would lead to the development of guidelines for urban arterial work zones. It does appear that the traffic volumes are lower when the area of construction is located in the middle of the roadway between traffic flowing in opposite directions. In general, traffic volumes during construction were about 85 percent of the pre-construction traffic volume. However, there is wide variation in the traffic volumes, and therefore, the traffic control plan should be prepared to accommodate traffic volumes which are comparable to pre-construction volumes.

CHAPTER 6
MOTORIST SURVEYS

Two motorist surveys were conducted in conjunction with this project. They were administered at the F.M. 1960 and Abrams Road study sites in Houston and Dallas. These surveys evaluated motorist understanding of selected work zone traffic control devices and also identified motorist concerns related to construction activities at the study sites.

The surveys were conducted by personal interview at retail centers and drivers license offices in the areas adjacent to the work zones. Participants were asked to respond to pictures of signs and work zone scenes and were also asked for their opinion on various aspects of the local arterial work zone. These surveys had the following objectives and concerns:

Objectives

- Ascertain knowledge about work zone traffic control in general.
- Determine confusing or problematic areas of the traffic control devices.
- Elicit information concerning problems with the construction projects that may not be related to traffic control devices.

Concerns

- Are motorists having difficulties with the construction area due to confusion and/or the number of signs and traffic control devices?
- Are motorists having trouble finding destinations within the construction area due to problems with signing?
- Are primary concerns on the part of users related to traffic control and signing, or are other factors more important?

The Houston survey was conducted in February 1989 at Willowbrook Mall and the Grant Road Driver License (DL) Station, both of which were affected by the F.M. 1960 reconstruction project. Response was strictly voluntary at the mall site (individuals at the mall were not asked to participate). However, individuals at the DL station were asked to participate in the survey. The result was that 90 individuals were interviewed at

Willowbrook Mall and 115 individuals were interviewed at the DL station, for a total of 205 survey participants.

The Dallas survey was conducted in May 1990 at three locations near the Abrams Road reconstruction project. Two of the locations were retail businesses adjacent to the project and the third location was a DL station near the study site. Respondents at all three locations were approached by the surveyors and asked if they would like to voluntarily participate in the survey. The result was that 198 respondents were interviewed at the two retail locations and 147 respondents were interviewed at the DL station.

The motorist surveys consisted of three parts. One part was a discussion with the survey participants on their opinions about various aspects of the reconstruction project. A second part contained multiple choice questions about specific traffic control devices used in the arterial work zones. The third part of these surveys was a brief set of biographical questions. The length of the Houston survey averaged about 10 minutes and the Dallas survey averaged about 6 minutes in length. The Dallas survey was shorter because there were fewer questions in the part on driver opinions of various reconstruction aspects and fewer questions about specific traffic control devices. The results of these surveys are described in detail in a previous research report (3). Another report (4) contains the portions of the survey instruments used in addressing motorist comprehension of selected traffic control devices.

The motorist surveys revealed that drivers are not primarily concerned with traffic control devices within the construction zone. More important issues involve the length of the project, duration of construction and travel delay. The surveys also indicated that motorists do have problems understanding arterial work zone signing. The Houston survey identified several problematic devices and the Dallas survey substantiated these findings. Problematic devices included the **NO CENTER LANE, NO CENTER TURN LANE, Lane Reduction Transition, Low Shoulder,** and **Advance Road Construction** signs, the **Vertical Panel**, and differences in sign color.

Survey Results - Motorists' Comments and Opinions

Both the Houston and Dallas motorist surveys included questions intended to determine motorists' opinions about the arterial construction activities taking place at the two study sites. In this part of the surveys, participants were asked to respond to several questions about delay due to construction, the impacts of construction on travel, the use of traffic control devices, the perceived problems of the construction, and the benefits of construction. Tables 6-1 through 6-5 show the questions and responses to this part of the survey.

Delay Due to Construction

In the first part of these questions, participants were asked to estimate the travel delay experienced the day of the survey (Houston) or on a usual basis (Dallas). They were also asked if this delay was reasonable. Table 6-1 summarizes the results of the delay questions.

The Houston survey revealed that motorist's perceptions of time delay varied. However, a majority of the perceptions in Dallas were 10 minutes or less. This discrepancy might be due to the fact that the Houston arterial construction site was approximately 3 times longer in length than the Dallas site. When asked, "is this delay was reasonable?," Houston motorists were much more tolerant of travel delay than those in Dallas. Interpreting this delay as a percentage of travel time, the Dallas construction had a greater impact on motorists.

Table 6-1. Comparison of Responses to Delay Questions

Question	Responses	Houston Survey	Dallas Survey
How much does construction delay you?	no delay	16%	19%
	< 5 minutes	22%	34%
	6-10 minutes	21%	29%
	11-15 minutes	22%	10%
	> 15 minutes	19%	8%
Is this delay reasonable?	yes	66%	52%
	no	33%	21%
	other	1%	27%

Impacts of Construction on Travel

Two questions addressed how the construction was impacting the ability of drivers to travel. Table 6-2 summarizes the answers to these questions.

Table 6-2. Comparison of Responses to Travel Impact Questions

Question	Responses	Houston Survey	Dallas Survey
Is the construction on F.M. 1960 [Abrams Road] causing you to use other routes to get where you want to go?	yes	86%	65%
	no	14%	35%
	other	1%	0%
Do you have trouble finding or getting to specific places because of the construction?	yes	50%	50%
	no	50%	50%

The Houston survey revealed that a large percentage of motorists used alternate routes to get around F.M. 1960 construction. A smaller percentage of motorists were using alternate routes in Dallas. Again, the differences in alternate route choice may be due to the length of construction on the facilities. When asked if they had difficulty finding or getting to specific places due to construction, half the motorists in both surveys said yes.

Use of Traffic Control Devices

Several questions addressed the use of traffic control devices in work zones. These questions were not intended to determine how well motorists understood the devices, instead, they were intended to determine if motorists thought that a particular type of device was being used in sufficient numbers. Table 6-3 summarizes the results of these questions.

Approximately half of the motorists in both surveys thought there were the right amount of signs giving directions to places along the construction area. However, some motorists in both surveys felt there were too few signs and some were not sure in the Dallas survey. When asked, "if there were too many, too few, or the right amount of signs that give warnings and information about how to drive through the construction area," a majority of motorists thought there was the right amount in Houston. A similar question was asked about the number of barrels through the construction area. Over half of the motorists in Houston thought there should be the same number of barrels on site. However, some motorists thought there should be less. The Dallas survey resulted in half of the motorists saying there should be the same number of barrels, but over a third stated there should be less or were not sure. It should be noted that barrel spacing along F.M. 1960 was smaller than that used on Abrams Road. In addition, the increased length of F.M. 1960 gave the appearance of possible over use of the barrels.

Table 6-3. Comparison of Responses to Traffic Control Device Questions

Question	Responses	Houston Survey	Dallas Survey
Are there too many, too few, or the right amount of signs that give directions to places along the construction area?	too many	18%	4%
	right amount	49%	54%
	too few	29%	21%
	not sure	4%	21%
Are there too many, two few, or the right number of signs that give warnings and information about how to drive through the construction area?	too many	9%	*
	right amount	73%	*
	too few	14%	*
	comments	4%	*
Should there be more, less, or about the same number of barrels through the construction area?	more	5%	11%
	same number	70%	50%
	less	22%	16%
	not sure	3%	23%

* - Question not asked in Dallas survey

Perceived Problems of Construction

One question asked the participants to identify problems at the F.M. 1960 and Abrams Road work zones from a list of possible responses. Individuals were allowed to identify as many problems from the list as they wished. The results are summarized in Table 6-4.

Table 6-4. Comparison of Responses to Perceived Problem Question

Question	Responses	Houston Survey	Dallas Survey
From the list, what would you say is the biggest problem in the F.M. 1960 [Abrams Road] construction area?	The construction length is too long	23%	5%
	Difficulty making turns due to congestion	18%	8%
	Construction has taken too long	14%	24%
	Travel delay caused by construction	13%	18%
	Potential road hazards	12%	25%
	General confusion	11%	--
	Too much traffic	9%	8%
	Difficult to find where you are going	1%	3%
	Signs are confusing	1%	3%
	Inadequate or confusing lane striping	--	5%
	Other	--	1%

When motorists were asked, "to select the biggest problem in the construction area," the Houston survey revealed that motorists thought that the length of construction was too long, it was difficult to make turns, and that the time of construction was too long. The Dallas survey revealed the motorists were concerned about potential road hazards, construction taking too long and travel delay. It should be noted that motorists concerns about confusing signs or traffic control devices were low on their list of priorities for both surveys.

Benefits of Construction.

The final question asked participants if they thought the problems associated with the construction could be endured knowing that a better arterial would result from the construction. Table 6-5 summarizes the responses to this question.

An overwhelming percentage of motorists in both surveys agreed that the inconveniences of present construction are worth the future benefits that will be gained once the facilities are reconstructed. This implies that even though motorists complain and do not understand construction practices and applications, they are willing to tolerate the inconvenience knowing that the new facility will be an operational improvement.

Table 6-5. Comparison of Responses to Benefit Question

Question	Responses	Houston Survey	Dallas Survey
Do the future benefits outweigh the present inconveniences associated with construction?	yes	91%	84%
	no	7%	5%
	not sure	2%	11%

Survey Results - Signing Comprehension

The second part of the motorist surveys exposed motorists to isolated pictures of construction traffic control devices and pictures of arterial work zone scenes showing field applications of construction traffic control devices. They were then asked to select the meaning of a given device from several possible choices. There were typically four choices for each question, with one of the four choices being "not sure." This response choice was used to hopefully eliminate any guessing from the participants. The question, pictures, possible responses, and response percentages for both the Houston and Dallas motorist surveys are given in Research Report 1161-3, Volume 3 (4).

Devices Included Only in Houston Survey

The Houston motorist survey was administered at the beginning of this study. As mentioned previously, the Houston survey averaged about 10 minutes in length. In order to shorten the length of the survey, some of the devices which appeared to be adequately understood were not included in the Dallas motorist survey. The results for those devices which were only in the Houston survey are discussed in this subsection. The next subsection addresses the results for devices which appeared in both the Houston and Dallas surveys. Table 6-6 summarizes those devices which were included only in the Houston survey.

Table 6-6. Summary of Results for Devices Included only in Houston Survey

Name of Traffic Control Device	Sign Designation	Exposure	Correct Response Rate
ROAD CLOSED	R11-2	field	84%
Divided Highway Ahead	W6-1	isolated	89%
		field	85%
NO CENTER LANE	Non-standard sign	isolated	46%
		field	56%
NO CENTER TURN LANE	Non-standard sign	isolated	79%
		field	73%

ROAD CLOSED sign (R11-2) - Participants viewed the field placement of the **ROAD CLOSED** sign shown in Figure 6-1A. Motorists were able to easily identify the correct meaning of this device.

Divided Highway sign (W6-1) - The isolated and field placement of this device are shown in Figures 6-1B and 6-1C. A majority of the motorists surveyed were able to identify the correct responses for this sign.

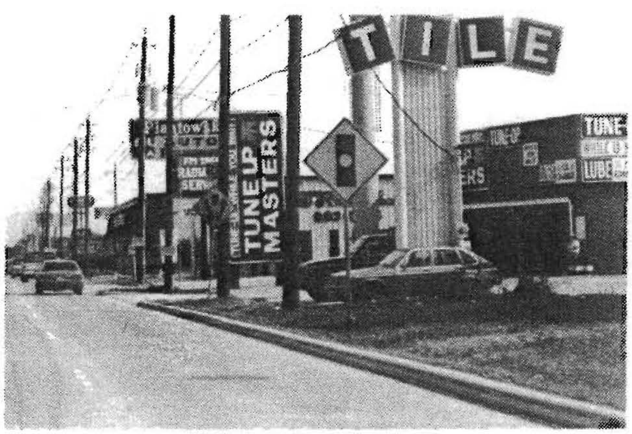
NO CENTER LANE and **NO CENTER TURN LANE** signs (Non-Standard) - These signs are used throughout F.M. 1960 and are shown in Figures 6-1D, 6-1E, 6-2A, and 6-2B. Motorists do not seem able to fully understand the meaning of the **NO CENTER LANE** sign. For both the isolated and field placement of the sign, approximately half of the respondents answered correctly. The expansion of this sign to **NO CENTER TURN LANE** facilitated a better response rate from the motorists. Approximately three-fourths of the participants were able to correctly identify the isolated and field placement of the sign.

Devices Included in Both the Houston and Dallas Surveys

Many traffic control devices were included in both the Houston and Dallas surveys. However, in the Houston survey, the exposure for many of these devices included both isolated and field conditions. Most of the devices included in the Dallas survey used only the field exposure. Table 6-7 summarizes the results for devices which were in both surveys.

A. Field Placement of ROAD CLOSED Sign

B. Divided Highway Ahead Sign



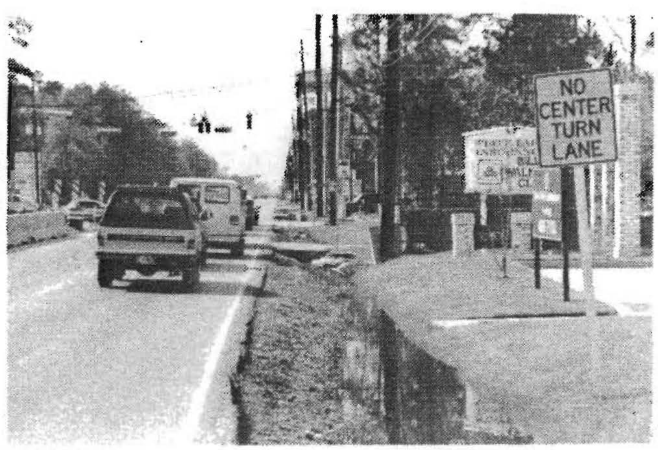
C. Field Placement of Divided Highway Ahead Sign

D. NO CENTER LANE Sign

E. Field Placement of NO CENTER LANE Sign

Figure 6-1. Devices Tested Only in Houston.

A. NO CENTER TURN LANE Sign



B. Field Placement of NO CENTER TURN LANE Sign

Figure 6-2. Devices Tested Only in Houston.

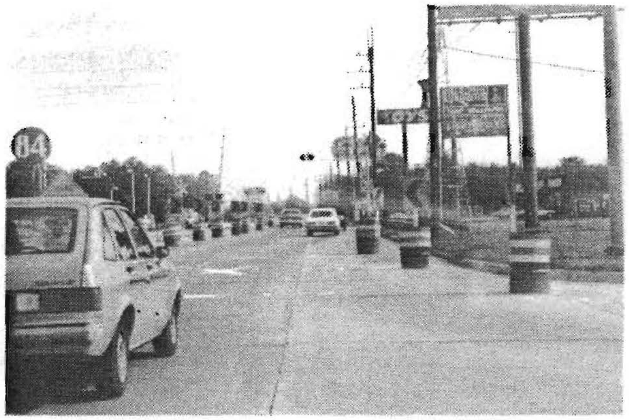
Table 6-7. Summary of Results for Devices in both Houston and Dallas Surveys

Name of Traffic Control Device	Sign Designation	Exposure	Correct Response Rate	
			Houston	Dallas
Chevron Panel	CW1-8	isolated	36%	*
		field	92%	85%
Lane Reduction Transition	CW4-2	isolated	78%	74%
		field	79%	*
Low Shoulder	CW8-9a	isolated	13%	18%
RIGHT LANE ENDS	CW9-1R	isolated	93%	74%
		field	81%	*
Advance Road Construction	CW20-1C	isolated	66%	69%
		field	58%	*
Flagger Ahead	CW20-7a	isolated	78%	79%
		field	85%	*
DO NOT BLOCK INTERSECTION	R10-7	isolated	74%	88%
		field	88%	*
Color Cues	W6-3 & CW6-3	isolated	44%	50%
CROSSOVER	D13-1	field	52%	53%
Vertical Panel	---	isolated	*	16%
		field	70%	*
White Delineator Post	---	field	58%	75%

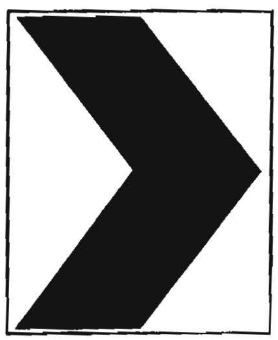
* - Question not asked in survey

Chevron Panel sign (CW1-8) - Participants in Houston viewed both the field placement and isolated versions of this sign (see Figures 6-3A and 6-3B). The field placement was easily recognized by a majority of the motorists. However, the isolated sign had a poor comprehension level. Motorists seem to be able to better identify signing if it is shown in the field placement. Therefore, only this version was tested in Dallas. A vast majority of the motorists were able to correctly identify the sign.

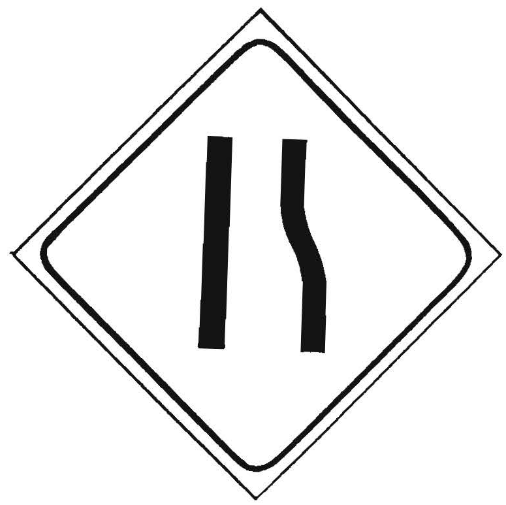
Lane Reduction Transition sign (CW4-2) - The isolated and field placement of this sign were tested in Houston (see Figures 6-3C and 6-3D). Both signs tested approximately the same with just over three-fourths of motorists correctly identifying the sign. The Dallas survey tested the isolated sign only. Approximately three-fourths of the participants chose the correct response to the question. There are some slight comprehension problems with this sign in both surveys.



A. Field Placement of Chevron Panel



B. Chevron Panel



D. Lane Reduction Transition Sign

C. Field Placement of Lane Reduction Transition Sign

Figure 6-3. Devices Tested in Houston and Dallas.

Low Shoulder sign (CW8-9a) - Only the isolated version of this sign was tested in both surveys (see Figure 6-4A). The results revealed a very poor comprehension level in Houston and Dallas. Motorists seem confused by this sign and interpret it to mean uneven pavement or pavement edge drop-off.

RIGHT LANE ENDS sign (CW9-1R) - The Houston survey results revealed a high comprehension level for both the isolated and field placement of this sign (see Figures 6-4B and 6-4C). The Dallas survey results were relatively similar with approximately three-fourths of the survey participants correctly identifying the sign.

Advance Road Construction sign (CW20-1C) - Both the isolated and field placement of this sign were tested in Houston (see Figure 6-4D and 6-4E). The results showed that motorists have some difficulty correctly identifying this sign. Only two-thirds of the respondents were able to answer correctly. The Dallas survey used only the isolated placement of the sign. Results were similar to those in Houston with approximately two-thirds answering correctly.

Flagger Ahead sign (CW20-7a) - Participants in Houston were shown both the isolated and field placement of this sign (see Figure 6-5A and 6-5B). Both signs tested well with approximately 80 percent answering correctly on both signs. The Dallas results were similar with only the isolated version being tested.

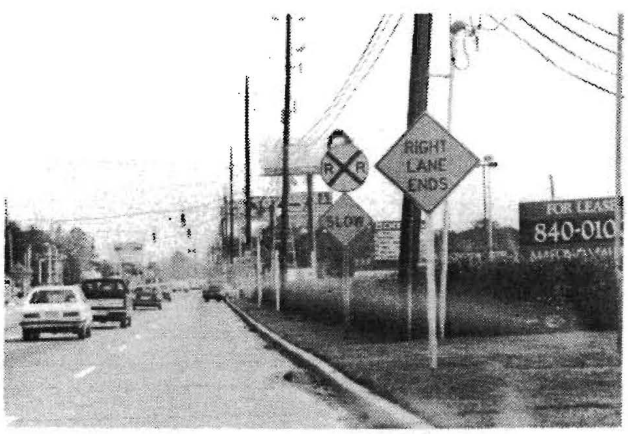
DO NOT BLOCK INTERSECTION sign (R10-7) - The isolated and field placement were both tested in Houston (see Figures 6-5C and 6-5D). Results were similar with approximately three-fourths answering correctly on the isolated version and almost 90 percent on the field placement. Only the isolated version was tested in Dallas with 90 percent answering correctly.

A. Low Shoulder Sign

D. Advance Road Construction Sign

B. RIGHT LANE ENDS Sign

E. Field Placement of Advance Road Construction Sign

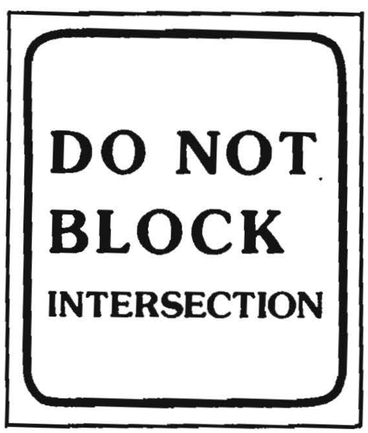


C. Field Placement of RIGHT LANE ENDS Sign

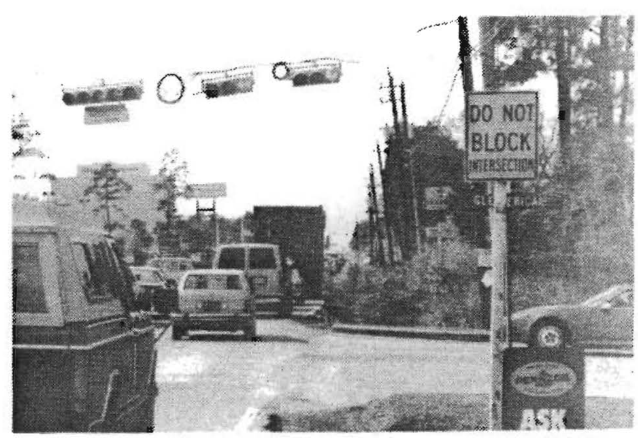
Figure 6-4. Devices Tested in Houston and Dallas.

A. Flagger Ahead Sign

B. Field Placement of Flagger Ahead Sign



C. DO NOT BLOCK INTERSECTION Sign



D. Field Placement of the DO NOT BLOCK INTERSECTION Sign

Figure 6-5. Devices Tested in Houston and Dallas.

Color Cue Testing - Figure 6-6A shows the two signs that were shown to the motorists in Houston and Dallas. Results in both surveys revealed that only half of the participants fully understood the difference between the colors. This would imply that motorists do not fully understand that orange is the color used for construction. Further education of the public seems to be the only positive recourse to correct this problem.

CROSSOVER sign (D13-1) - The field placement of the **CROSSOVER** sign was tested in both surveys (see Figures 6-6B). Responses in both surveys were similar, with only half of the participants able to correctly identify that they should turn before the sign.

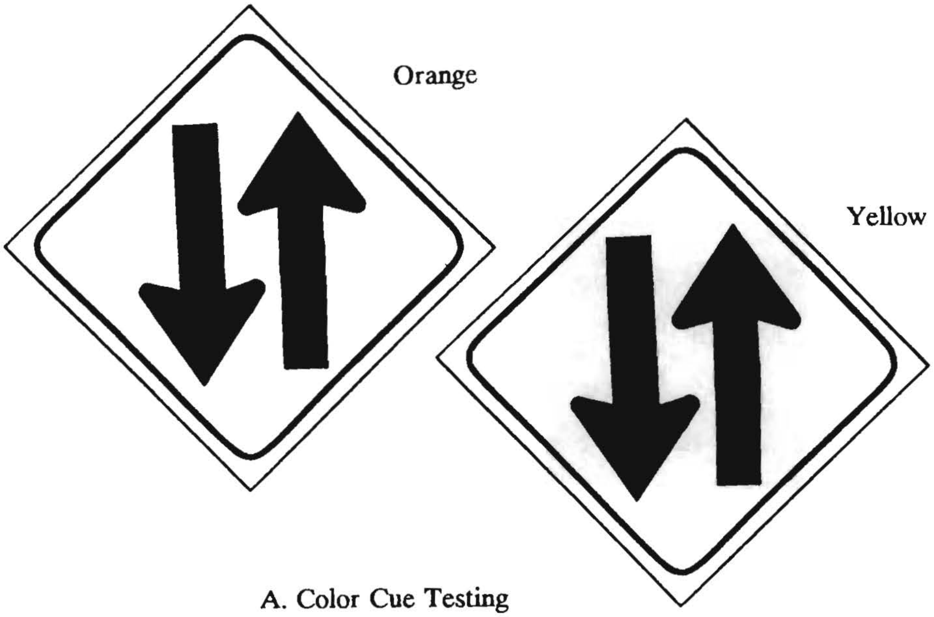
Vertical Panel - Figures 6-6C and 6-6D show the field placement and isolated versions of these signs. The Houston survey tested only the field placement and had just over two-thirds of the respondents correctly identify the sign. However, the Dallas survey tested only the isolated version of this sign and had less that one-fourth of the motorists correctly identify the sign.

White Delineator Post - Figure 6-6E shows the field placement of this device as used in both surveys. The Houston results revealed that approximately two-thirds selected the correct meaning of the device. The Dallas results improved somewhat with three-fourths of the respondents answering correctly.

Survey Results - Demographics

The demographic character of the survey participants are indicated in Table 6-8. The results indicate that the majority of the survey participants were Anglo individuals between the ages of 26 and 55, two-thirds of which have some level of college education.

The demographics for both surveys were compared to regional population statistics for the corresponding cities. The Houston and Dallas demographics were very similar to those of their respective regional population.



A. Color Cue Testing

D. Vertical Panel

B. Field Placement of CROSSOVER Sign

C. Field Placement of Vertical Panel

E. Field Placement of White Delineator Post

Figure 6-6. Devices Tested in Houston and Dallas.

Table 6-8. Summary of Survey Demographics

Characteristic	Category	Demographics	
		Houston	Dallas
Gender	Male	47%	48%
	Female	53%	52%
Age	< 25	15%	17%
	26-55	76%	60%
	> 55	9%	23%
Race	Anglo	81%	72%
	Black	7%	16%
	Hispanic	8%	6%
	Other	4%	6%
Education	less than high school	9%	4%
	high school graduate	24%	13%
	some college	30%	31%
	college graduate	37%	52%

Conclusions from the Motorists Surveys

The results of the two surveys conducted as part of this research study provide many interesting insights into how drivers perceived and react to urban arterial work zones and the traffic control devices used in these work zones. The following subsections summarize the findings of the four survey efforts and describe some recommendations which may improve the safety or operational efficiency of urban arterial work zones.

Motorists Opinions from Houston and Dallas Surveys

The motorist surveys indicated that traffic control device interpretation is not a primary source of concern for motorists in arterial work zones. More important construction issues involve the length of the project, duration of construction, problems associated with turning, direction finding, potentially hazardous road conditions, and travel delay. Yet, in spite of the construction difficulties identified in the surveys, 91 percent of the Houston and 84 percent of the Dallas survey participants believed the long term benefits associated with a better arterial will outweigh the short term inconveniences of construction.

These results seem to indicate that motorists place more emphasis on non-traffic control issues than they do on the use of traffic control devices and the traffic control plan. Agencies responsible for arterial construction should evaluate the impacts of construction on the factors mentioned above and attempt to minimize them. Motorists appear willing to accept construction activities in return for a better facility. This acceptance can be improved by reducing construction impacts.

Specific efforts which may improve motorists acceptance of arterial construction include:

- Minimize the length of arterial which is under construction at any one time.
- Do not leave unused construction equipment in public view for extended periods of time.
- Minimize the duration of construction as much as possible.
- Avoid construction activities which impact traffic flow during peak-periods.
- Provide increased street signing with block numbers at intersections.

Comprehension of Traffic Control Devices from Houston and Dallas Surveys

The motorist surveys confirmed previously conducted studies (23) that show that some aspects of construction traffic control are not fully understood by motorists. Most traffic control devices were correctly interpreted by 70 to 80 percent of the survey participants. However, there were some devices which had comprehension levels below 70 percent. Motorists generally exhibited higher comprehension levels when exposed to the field placement of a given device, as compared to isolated exposure to only the device itself. This would seem to indicate that although motorists may not grasp the specific message a device is attempting to convey on its own, they can better respond to the device when it is interpreted in the context of the overall environment. Despite the fact that orange has been used as the color of construction signs since 1971, motorists still do not recognize the relationship between the orange color and the presence of construction activities.

Specific efforts which may help to improve motorist comprehension of the intended message of certain devices include:

- Increasing education aimed at pointing out the color significance of orange signs.
- Reduce spacing of channelizing devices in the vicinity of crossovers in order to reduce confusion about the location of the crossover.
- The **CROSSOVER** sign should be placed immediately beyond the crossover opening, as called for in the MUTCD and in a manner consistent with permanent crossover locations.
- Educational plaques should be used with symbol signs, specifically the **Low Shoulder** sign (CW8-9a).
- The **Advance Road Construction** sign indicating a distance to the work zone (CW20-1A, CW20-1B, or CW20-1C) should not be used only as a single sign. At least two **Advance Road Construction** signs indicating decreasing distances to the start of construction should be used in advance of a work zone to give the motorist the message that they are approaching a work zone.

CHAPTER 7
CURRENT PRACTICE

The results of the literature review indicated a lack of information about traffic control for urban arterial work zones. Therefore, local and state level traffic professionals in Texas were contacted in order to determine the status of current practice in this area.

Local Agency Survey

Early in the study, it was realized that any guidelines developed in the study would be used, not only by Department personnel, but also by many local transportation agencies. Therefore, it was deemed desirable to contact local agencies to determine the problems they were encountering with urban arterial work zones, how they dealt with those problems, and the sort of guidelines they would like to see.

A telephone interview was used to determine how local agencies addressed urban arterial work zones. Five different agencies were contacted, four cities - Houston, Dallas, San Antonio, and Austin, and one county - Dallas. The interview was based on a survey questionnaire which addressed a number of the key issues related to urban arterial work zones. The questionnaire consisted of thirteen questions and is shown in Table 7-1. The questionnaire had several purposes including:

- Identify the level of effort of individual cities in providing traffic control for urban arterial work zones.
- Identify guidelines used by cities for urban arterial work zones.
- Identify problem areas in implementing urban arterial work zones.
- Identify deficiencies in the Texas MUTCD related to urban arterial work zones.
- Identify responsibilities when more than one agency is involved in a project.
- Identify responsibility for implementing and inspecting work zone traffic control.

Table 7-1. Local Transportation Official Questionnaire

URBAN ARTERIAL WORK ZONE SURVEY

NAME: PHONE:

AGENCY: DATE:

DESIGN PROCESS BACKGROUND:

1. What traffic control (TC) standards or guidelines do you use for long term construction work on urban arterials?
2. What problems have you experienced in applying the MUTCD to urban conditions?
3. How does your agency interact with projects where traffic flow is diverted from a city street onto a freeway or highway, or vice versa?
4. What efforts are extended before construction begins to insure that the contractor follows the traffic control requirements?
5. What person or position is responsible for insuring that traffic control requirements are followed once construction has begun?
6. Does this person receive specialized training in traffic control?
7. What enforcement measures are available to the responsible supervisor if the requirements are not being followed?
8. What are the major problems you have encountered with work zones on urban arterials and how do you deal with each problem?
9. How do you differentiate between short and long term arterial construction?
10. What traffic control requirements do you place on short term construction on urban arterials?
11. Do you employ any special traffic control techniques addressing driveway access within the work zone?
12. To what degree are other governmental agencies involved in work zone traffic control on urban arterial construction projects?
13. How is the responsibility for traffic control determined?

OTHER INFORMATION AND COMMENTS:

There were a number of conclusions that can be drawn from the results of the questionnaires. The major conclusions are described below:

- Most cities are not directly responsible for developing a TCP; it is either developed by the consultant or not included at all.
- All work zone traffic control is based on the Texas MUTCD; no other references are used by the cities.
- Most cities feel that the Texas MUTCD seems to be directed more toward rural situations. Urban difficulties include:
  - Street/blocks are not long enough to contain all required information.
  - Most problems occur at the approaches to the project rather than within the project.

- Physical constraints of the roadway restricts implementation of the traffic control plan.
- Minor/major cross-street intersections.
- Relocating or modifying traffic signals and their operation.
- Detours at major-major intersections.
- Texas MUTCD is too complicated for some field personnel.
- Traffic control for special events (parades, marathons, etc.).

- Construction inspection responsibilities typically belong to the Public Works or Street Department. The inspectors for the projects are typically more concerned with the various aspects of construction quality and progress than with traffic control. Some cities have traffic control inspectors which are part of the Transportation Department and whose only responsibility is to inspect the traffic control in work zones.
- Driveway access must be maintained at all times, but it is normally up to the contractor how that access is provided.
- In projects involving other governmental agencies, traffic control is the responsibility of the agency initiating and funding the project.
- In general, there is a lack of communication between the cities and the TxDOT in the area of work zone traffic control.
- The major traffic control problems in urban areas include:
  - Poor maintenance of traffic control devices.
  - Restoration of traffic control devices struck by traffic.
  - Poor nighttime visibility of the work zone and traffic control devices in it.
  - The effects of detours on traffic.
  - The reduced width of traffic lanes.

City Work Zone Traffic Control Manuals

Many cities have developed manuals for work zone traffic control and several of these were reviewed for this study. Manuals from the cities of Arlington, Austin, Fort Worth, Los Angeles, Seattle, and Victoria were reviewed along with a similar manual from the State of California (24 - 30). In general, these manuals repeat the requirements and information contained in the MUTCD. Each one contains some information specific to the city which produced it.

Time Restrictions

Most of the manuals identify when and where time restrictions on construction exist. The restrictions for several of the cities are described below.

Arlington	Restricts work during the hours of 7:00 to 9:00 am and 4:00 to 6:00 pm for all street that are 37 feet wide or wider.
Austin	Defines a downtown urban area where construction, repair, or other work affecting the free flow of traffic may be restricted to certain time periods. Lane closures are not permitted from 7:00 to 8:30 am and 4:30 to 6:00 pm. Between 11:30 am and 1:30 pm, traffic lanes approved for closures but which are not occupied by construction activities must be open to traffic.
Ft. Worth	Work shall not be performed on certain streets and in certain locations during peak traffic periods, which are normally 7:00 to 9:00 am and 4:00 to 6:00 pm. This restriction applies to any street where parking is prohibited during peak traffic periods and on specific streets listed in the manual.
Los Angeles	All work in the Central Business District (CBD) must be performed between 9:00 am and 3:00 pm.
Seattle	Prohibits work on arterial streets between 7:00 to 9:00 am and 4:00 to 6:00 pm without written authorization from the city traffic engineer. In the CBD, the time restrictions extend from 6:00 to 9:00 am and 3:00 to 6:00 pm.

Traffic Control Devices and Spacing

Most of the manuals address the use and placement of signs and channelizing devices within a work zone. In some cases, the guidelines for locating these devices are different from those contained in the MUTCD. Some of the specifics associated with signing and channelization are described below.

Arlington	**Signing** - High intensity sheeting is required for all barricades and signs. Advisory speed plates are required for all curve or turn signs. The sign spacing distance is greater than that in the MUTCD. The Arlington sign spacing distances are shown in Table 7-2.

Channelization - Taper lengths for cones and vertical panels are specified in the Arlington manual as shown in Table 7-2. When the speed is less than 35 mph or block lengths are less than 200 feet, the taper length may be half of the normal amount. Spacing between channelizing devices is equal to the posted speed in mph. This applies to devices both on a taper and on a tangent. However, a different table in the same manual shows taper lengths and channelization device spacing that is the same as the MUTCD.

Austin **Channelization** - Taper lengths are the same as the MUTCD. Spacing between channelizing devices should not exceed the legal speed limit in mph. This applies to devices both on a taper and on a tangent.

California **Signing** - California uses signs which have a different appearance than similar signs used in Texas. Several of these signs are illustrated in Figure 7-1.

Ft. Worth **Channelization** - The Fort Worth manual requires the police department to be notified at least 1 hour before any lanes are closed.

Seattle **Channelization** - Table 7-3 shows the sign spacing, taper lengths, and channelization device spacing used by Seattle.

Victoria **Signing** - Table 7-4 shows the spacing for the initial construction signs.

Channelization - Minimum desirable taper rates are 85th percentile speed per foot of offset, that is, a street with an 85th percentile speed of 40 mph should have 40 feet of taper for every 1-foot of offset. Spacing between channelizing devices is approximately equal to the posted speed limit in mph. This applies to devices both on a taper and on a tangent.

Table 7-2. Arlington Taper Lengths and Sign Spacing (feet)

Posted Speed (mph)	30	35	40	45	50	55
One Lane	150	200	275	450	500	550
Two Lane	600	800	1100	1800	2000	2200
Three Lane	1050	1400	1925	3150	3500	3850
Sign Spacing	125	160	200	250	300	375

Table 7-3. Seattle Sign and Channelizing Device Spacing (feet)

Class of Road	Warning Sign Spacing		Taper Length		Channelizing Device Spacing			
	Between Signs[1]	Between Sign and Taper[2]	10' Offset	12' Offset	Vehicle Barricades and Drums		Vertical Barricades, Cones, Guidepost	
					Taper	Tangent	Taper	Tangent
CBD	*	*	75	90	30	30	15	30
Arterial	150	75	150	200	40	50	20	50
Controlled Access Arterial	300	150	400	500	60	80	30	80

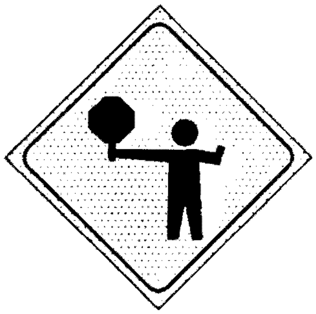
1 - Between signs when more than one sign is used or between sign and start of taper when only one sign is used.
2 - Between last sign and start of taper when more than one sign is used.
* - Use advance warning signs if feasible

Table 7-4. Victoria Initial Sign Spacing

Traffic Speed (mph)	Initial Sign Distance (ft)
≤ 15	50 - 90
25	90 - 150
35	150 - 240
45	240 - 360
55	360 - 550
≥ 65	550 - 850

State Level Discussions

Several TxDOT District and Division staff members were contacted for additional insight into the problems of urban arterial work zones. These individuals expressed a similar concern about the lack of urban arterial guidelines. Specific concerns and suggestions are listed in Table 7-5.



The Flagger symbol sign is intended for use to control traffic through a construction or maintenance project. Note that the figure in this sign is holding a **STOP/SLOW** paddle instead of the flag which appears in the Texas version of this sign.

The **ROAD WORK SPEED LIMIT** sign is authorized by the California Vehicle Code which provide authority to post a speed limit not less than 25 mph at locations where employees of any contractor, or of the agency in charge of the job, are engaged in work upon the roadway.

The sign should be place within 400 feet of the zone where workers are on the roadway or so nearly adjacent as to be endangered by traffic. It shall only be used in conjunction with appropriate advance warning signs. The signs shall be removed promptly when no longer applicable.

The **ACCIDENT AHEAD** sign is intended for use at accident cleanup locations where there is interference with traffic; e.g., lane closures, diversions, detours, etc. When used, it replaces the typical first advance warning sign(s).

The **SPECIAL EVENT AHEAD** sign is intended for use in lieu of standard advance construction warning signs for special events; i.e., bike races, movie filming, etc., where the event is close to or on the traveled way, or of such a nature as to cause a potential danger to motorists.

orange background

Figure 7-1. California Construction Signs

Table 7-5. State Level Arterial Work Zone Issues

Concerns
• Delineation of driveways.
• Citizen response to long term arterial construction.
• Inadequate signing for street names and block numbers.
• Citizen involvement and criticism does not materialize until construction begins.
• Lack of alternate routes for traffic diversion.
• Citizen perception of idle equipment and construction delays.
• Signal timing changes.
• Loss of signal progression.
• Signing for businesses.
Suggestions
• Hold public hearing prior to construction regardless of citizen interest.
• Use high early strength concrete to reduce construction time.
• Have regular public meetings throughout the construction.
• Construction should not begin between Thanksgiving and New Year's on arterials supporting retail traffic.
• Plan major arterial traffic control in the same manner as freeway traffic control, including traffic control and preparation of alternate routes.
• Remove idle equipment from public view.
• Speed construction to reduce user delay costs.
• Provide progression with Time Based Coordinators.

Low Profile Barrier

During the time that TTI was conducting this research study, a separate research effort was underway to develop a low-profile barrier for use in arterial work zones where speeds are 45 mph or less. The primary advantage of this barrier is that the reduced height of the barrier significantly improves driver visibility. The barrier is 20 feet long, 20 inches tall, 28 inches wide at the top, and 26 inches wide at the bottom. The barrier has been successfully crash tested at a speed of 45 mph with a 3/4-ton pickup truck, and it is recommended for immediate use under appropriate conditions. The same research team is currently developing an end-treatment for this barrier. The research activities and results associated with the development of the low-profile barrier are described in a TTI report (31).

Conclusions from Review of Current Practice

The review of current urban arterial work zone practices indicates how several various organizations are dealing with the difficulties posed by traffic control in urban arterial work zones. The majority of the information collected in this task was obtained from local agencies. Information from TxDOT and TxDOT-sponsored research activities at TTI also provided useful in developing urban arterial work zone guidelines.

The local agency survey indicated that, among the local agencies surveyed, there is variation in the degree in which traffic control is stressed. Most cities are not directly responsible for the development of a TCP. Several agencies indicated the Texas MUTCD did not sufficiently address work zone traffic control on urban arterials. The local agencies indicated that the most significant problem areas are related to intersections and intersection related traffic control. They also indicated a need to give greater attention to the nighttime visibility of the work zone and traffic control devices, even though construction activities may not be taking place during this period. Several cities described the positive benefits of having one or more inspectors whose only responsibility was inspecting the traffic control aspects of work zones within the city.

Work zone traffic control manuals produced by various local agencies heavily rely on the guidelines in the MUTCD, although some of these guidelines have been modified by the agencies. Virtually all of these manuals restrict arterial work zone activities during peak-periods. Some of these manuals specify signing and channelization device spacing which differs from the spacings contained in the MUTCD. In some cases, these spacings are greater, and in some cases, they are less.

During the time this study was underway, a low-profile barrier was developed by TTI as part of another project. This barrier has the potential to eliminate many of the limitations presented by the guardrail on drum barrier currently in use on most urban arterials. Research is continuing on the development of effective end treatments for this type of barrier.

CHAPTER 8
OTHER ARTERIAL WORK ZONE FACTORS

Chapter 1 of this report described many of the differences that exist between urban arterial work zones and work zones on freeways or rural highways. Several factors unique to urban arterial work zones were not described in the literature review or in the analysis of collected data. These factors can have an important impact on traffic control aspects of urban arterial work zones and were therefore analyzed as part of this research study. The factors described in this chapter include the capacity of a lane closure on an arterial street, the impacts of a lane closure on traffic signal operation, and the geometric design of a arterial work zone median crossover.

Arterial Lane Closure Capacity

The capacity of a lane closure is an important consideration in developing a traffic control plan for an urban arterial work zone. The number of vehicles which can pass by a lane closure on an arterial impacts when the lane closure can be made, where it can be located, and how many lanes can be closed. Therefore, the research team attempted to find locations where the capacity of a lane closure could be measured.

Measuring the capacity of a lane closure requires a location where a constant queue is present. Unfortunately, such a location turned out to be difficult to locate. Most traffic control plans for urban arterial work zones restrict lane closures to off-peak periods. Traffic demand is lower during these periods and any queues which do form are not present for any period long enough to obtain reasonable estimates of capacity. However, one site which met the requirements for study was identified during the last year of the research study and the lane closure capacity at this site was measured.

The study site was located on South Cooper Street (F.M. 157) in Arlington, Texas, approximately 2 miles south of I.H. 20. South Cooper Street is an urban arterial located on the southern part of Arlington. At the time of the study, it was being widened from a four-lane street. The area immediately adjacent to the arterial has significant retail development and the area surrounding the arterial is a residential area. On the day of data collection, one of the southbound lanes was being closed in order to accommodate paving operations in the center of the roadway. The taper for the lane closure was located on a curve. Due to the nature of the work, the paving operations were beginning prior to the start of the morning peak period and lasting through the afternoon. Therefore, there was a constant queue during the morning and noon peak periods.

Data was collected with a video camera during approximately 45 minutes of the morning peak period and 1 hour and 45 minutes of the noon peak period. These times were the only portions of the day during which constant queues were present. Tables 8-1 and 8-2 show the 5-minute and 15-minute flow rates for both the morning and noon peaks. Table 8-3 shows the equivalent hourly flow rates determined from the average 5-minute and average 15-minute flow rates.

Table 8-1. Flow Rates for Arterial Work Zone Lane Closure Morning Peak Period

Time Start	5-Minute Volume	Equivalent Hourly Flow	15-Minute Volume	Equivalent Hourly Flow
7:43	57	684		
7:48	54	648	176	704
7:53	60	720		
7:58	62	744		
8:03	39*			
8:08	52	624	163	652
8:13	51	612		
8:18	60	720		
Average	56.6	678.9	170.5	678.0
Minimum	51	612	163	652
Maximum	62	744	176	704

* indicates data determined to be unrepresentative of conditions and not included in averages

Table 8-2. Rates for Arterial Work Zone Lane Closure Noon Peak Period

Time Start	5-Minute Volume	Equivalent Hourly Flow	15-Minute Volume	Equivalent Hourly Flow
11:09	51	612		
11:14	53	636	169	676
11:19	65	780		
11:24	68	816		
11:29	68	816	192	768
11:34	56	672		
11:39	63	756		
11:44	63	756	189	756
11:49	63	648		
*				
11:57	68	816		
12:02	65	780	201	804
12:07	68	816		
12:12	61	732		
12:17	62	744		
*				
12:23	72	864		
12:28	68	816	202	808
12:33	62	744		
12:38	60	720		
Average	63.11	757.33	190.60	762.40
Minimum	51	612	169	676
Maximum	72	864	202	808

* indicates gap in data availability

Table 8-3. Average Flow Rates

Value	5-Minute Volume	Equivalent Hourly Flow	15-Minute Volume	Equivalent Hourly Flow
Morning Average	56.6	678.9	169.5	678.0
Noon Average	63.1	757.3	190.6	762.4
Average Both Periods	61.3	735.4	184.6	738.3
Minimum	51	612	163	652
Maximum	72	864	202	808

The average flow rates are highest during the noon peak period, therefore, these flow rates are assumed to represent the capacity of the lane closure. Both the 5-minute and 15-minute hourly flow rates are approximately 760 vehicles per hour. The maximum 5-minute hourly flow rate was 864 vehicles per hour. Both of these flow rates are considerably lower than what is considered to be the capacity of a freeway lane closure for similar geometrics. The 1985 *Highway Capacity Manual* (32) indicates the capacity for 2 freeway lanes when 1 of the 2 lanes is closed is 1,340 vehicles per hour. The urban arterial lane closure capacity measured at this one site is approximately 57 percent of the capacity for a similar freeway lane closure.

Although one site is not sufficient to determine the capacity with any precision, the data indicate that the capacity of an arterial lane closure is lower than that of a freeway lane closure with similar geometric conditions. Even considering the limitations imposed by the limited sample size, it is appropriate to use a lower lane closure capacity when developing a traffic control plan for urban arterial work zones. Table 8-4 contains suggestions for the capacity of urban arterial lane closures. The capacity values in this table were calculated by multiplying the freeway lane closure capacities found in Table 6-1 of the *Highway Capacity Manual* by 57 percent. **These capacity values should be used with caution, as they are based on a sample size of 1 and may not represent actual capacity of an urban arterial lane closure.** However, previous research has not addressed the capacity of urban arterial lane closures, therefore, the capacity values in Table 8-4 are the best estimate of what urban arterial lane closure capacities may be.

Table 8-4. Estimate of Urban Arterial Lane Closure Capacities
(This table represents estimates of capacity and should be used with caution)

Number of Lanes		Number of Studies[1]	Total Average Capacity (vph)	
Normal	Open		Freeway[2]	Arterial[3]
2	1	8	1,340	760[4]
3	1	7	1,170	667
3	2	9	2,980	1,699
4	2	4	2,960	1,687
4	3	4	4,560	2,599
5	2	8	2,740	1,562

Notes:
1 Number of studies upon which freeway lane closure capacity is based
2 Total capacity of open freeway lanes. From Table 6-1 of Highway Capacity Manual
3 Total capacity of open arterial lanes. Calculated by multiplying freeway capacity by 0.57.
4 Total capacity based on actual field data.

Lane Closures Near Signals

One of the major concerns associated with lane closures in urban arterial work zones is that the queue resulting from the lane closure may back up into an upstream intersection and prevent traffic movement across the intersection. This situation is particularly critical when the lane closure is located a short distance downstream of a signalized intersection. In situations where the queue from a lane closure located downstream of a signalized intersection would back up into the intersection, it may be appropriate to locate the lane closure upstream of the intersection. Figure 8-1 illustrates how a queue from a lane closure can block an intersection and how this situation can be addressed by locating the lane closure upstream of the intersection.

Several different analyses were performed to determine when it would be appropriate to relocate the lane closure upstream of the intersection. All of these analyses indicated that the maximum queue at a downstream lane closure forms as the result of saturated flow from the intersection during the initial portion of the green interval. In other words, a queue of vehicles forms at the intersection during the red portion of the signal cycle. When

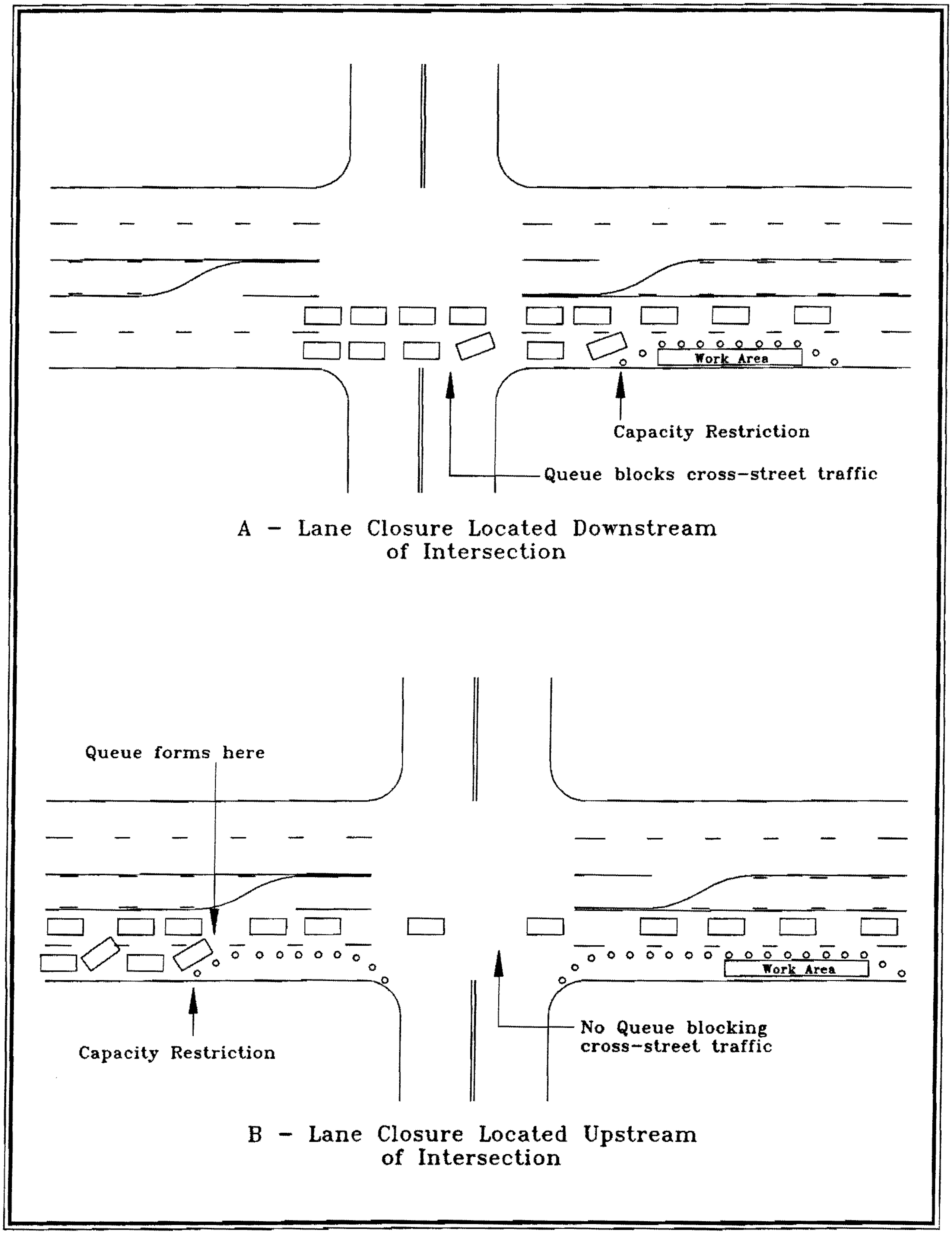


Figure 8-1. Impacts of Lane Closure on Signalized Intersection

the signal changes to green, this queue moves downstream to the lane closure as a platoon and forms a queue at the lane closure. If the capacity of the lane closure is greater than the arrival rate of vehicles, then the queue will get shorter after the queue from the signal arrives at the lane closure.

The length of the queue at the lane closure is primarily a function of the traffic volume on the arterial, length of the red interval at the signal, and the capacity of the lane closure. If the expected queue length is greater than the distance between the intersection and the lane closure, then the lane closure should be relocated upstream of the intersection. Table 8-5 indicates the minimum separation between the intersection and a single lane closure needed to prevent the queue from blocking the intersection. A minimum separation of 50 feet is recommended. The separation distances shown in Table 8-5 are based on an average arrival rate while a red indication is displayed to the arterial street.

Table 8-5. Separation between a Single Lane Closure and Signalized Intersection (feet)

Arterial Volume (vph)	2 Arterial Lanes				3 Arterial Lanes			
	Length of Arterial Red[1] (sec)				Length of Arterial Red[1] (sec)			
	20	40	60	80	20	40	60	80
300	50[2]	50[2]	63	83	50[2]	50[2]	50[2]	56
600	50[2]	83	125	167	50[2]	56	83	111
900	63	125	188	250	50[2]	83	125	167
1200	83	167	250	333	56	111	167	222
1500	104	208	313	417	69	139	208	278
1800	125	250	375	500	83	167	250	333
2100	146	292	438	583	97	194	292	389

Notes:
1- Minimum cycle length = 2 × arterial red
2- Separation calculated to be less than 50 feet, however, minimum 50-foot separation recommended.

Figures 8-2 and 8-3 use the Poisson Distribution to develop recommendations for the separation distance based on various probabilities of performance for two- and three-lane arterials, respectively. The separation distance is determined by multiplying the maximum number of queued vehicles by 25 feet. An example of how to use the chart is illustrated by the dashed line in Figure 8-2.

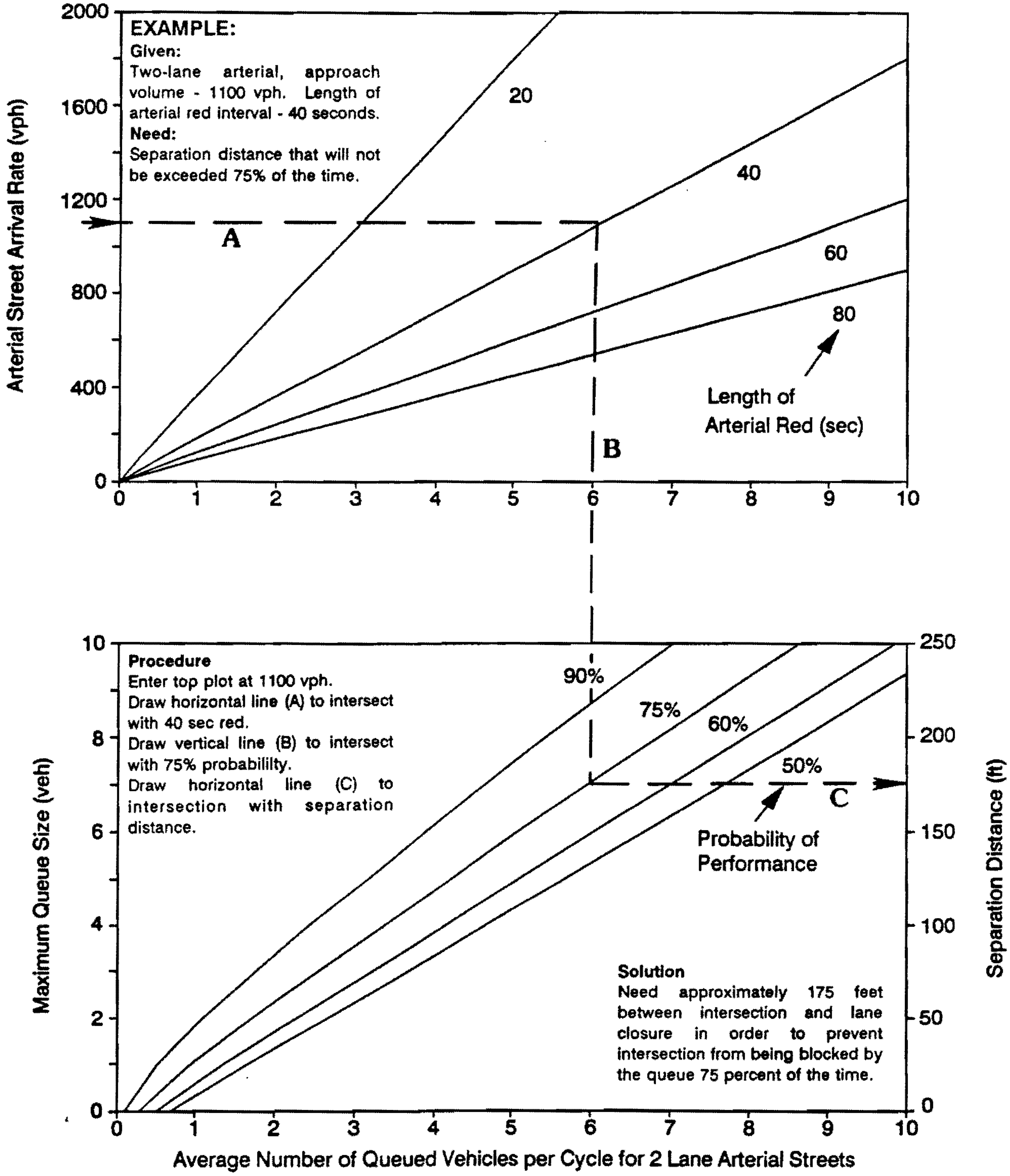


Figure 8-2. Lane Closure Separation Distance Probability Curves for Two-Lane Arterials

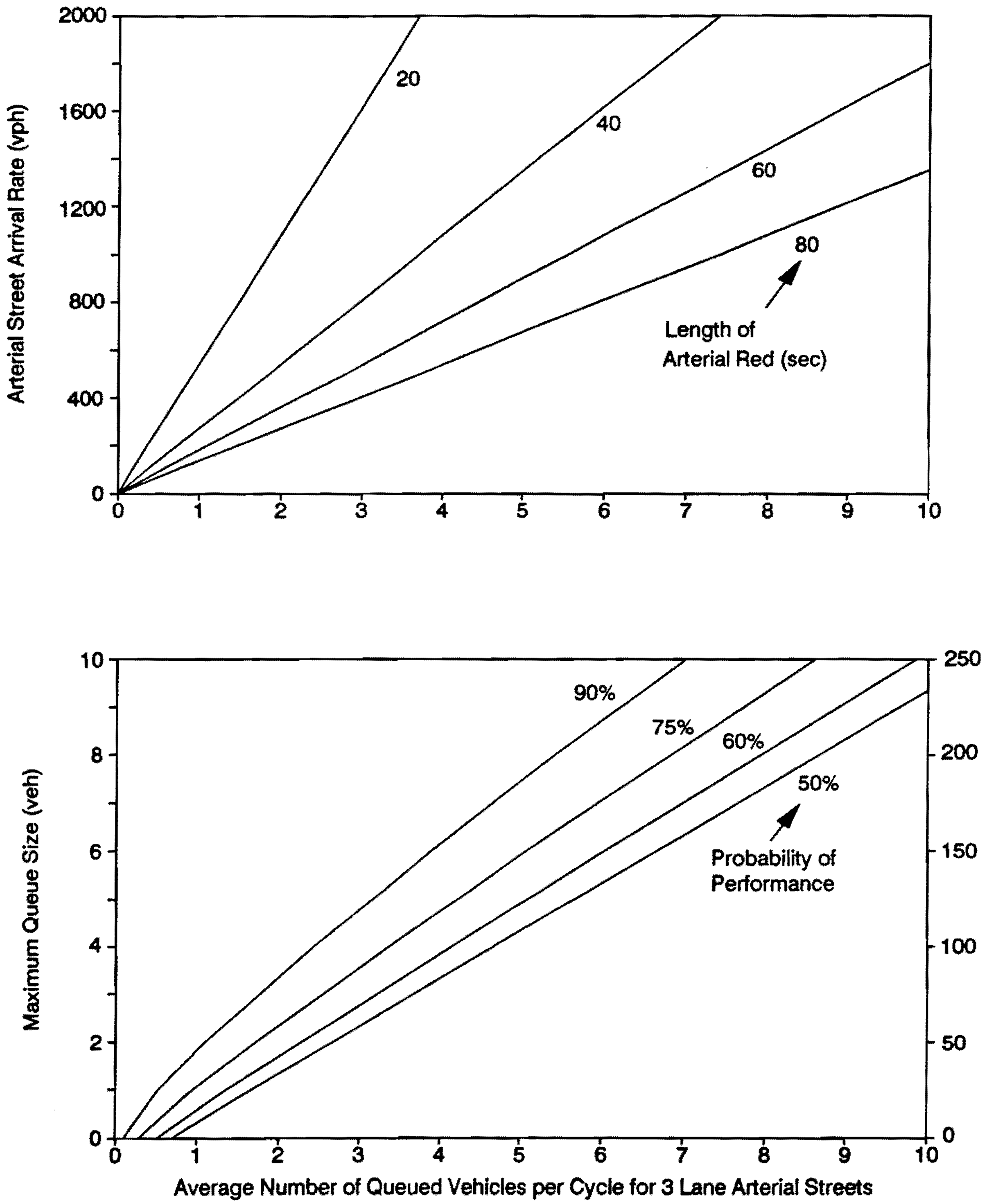


Figure 8-3. Lane Closure Separation Distance Probability Curves for Three-Lane Arterials

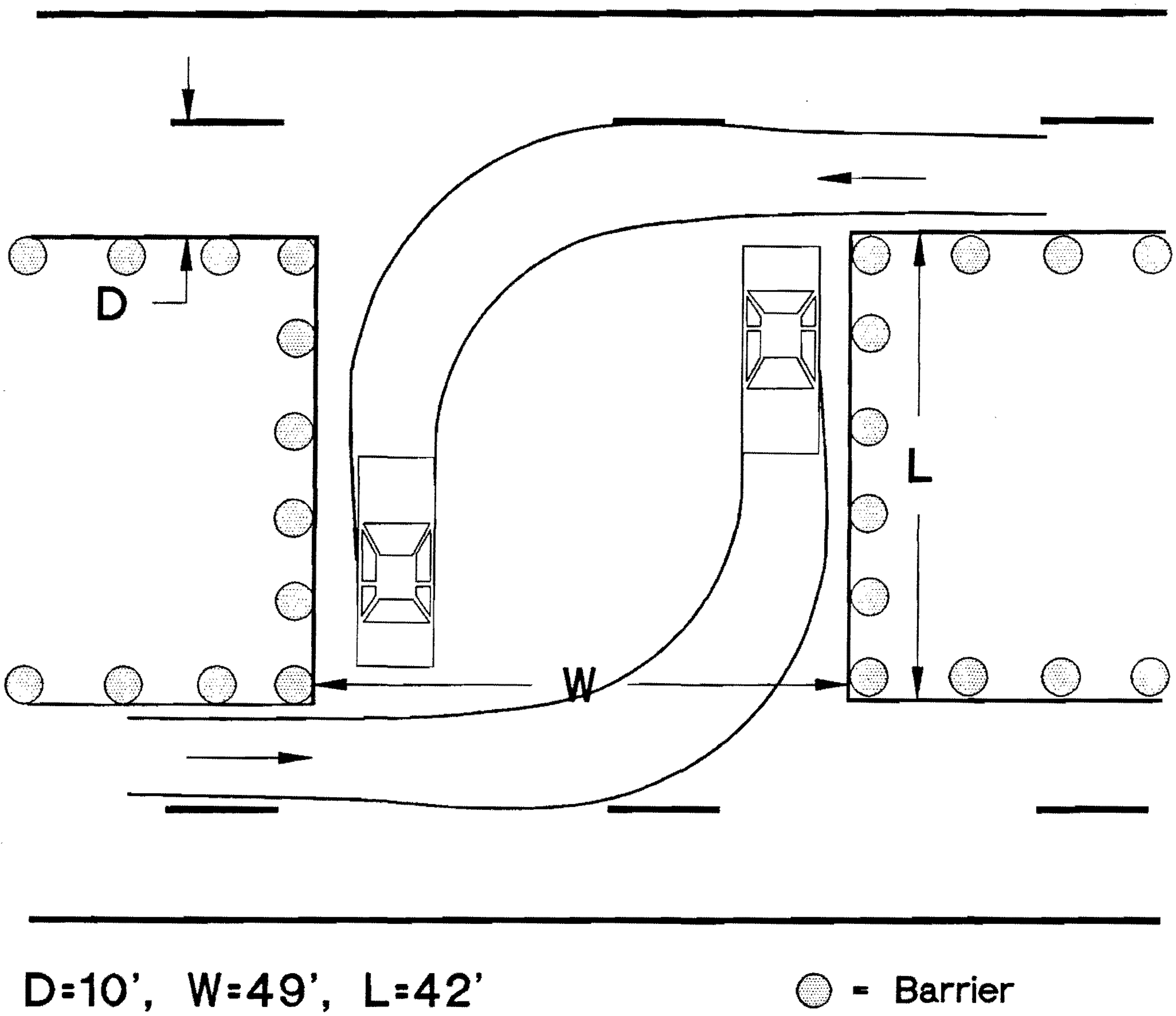
Median Crossover Design

Reconstruction of an arterial street requires at least one construction phase where the work area is located in the center of the roadway with traffic traveling on each side of the work area. When traffic in opposing directions is separated by the work area, it may be appropriate to provide median crossovers at selected locations between intersections. The locations and design of these crossovers should be carefully considered.

The appropriate number of median crossovers depends on the type of development on the arterial and the volume of left-turn traffic at the intersections. When there are too few crossovers, crossover traffic is shifted to the intersections which can be overloaded with left-turn and U-turn traffic. At a signalized intersection, a large number of left-turns and U-turns has a negative impact on the overall signal capacity, reducing the amount of green time available to through traffic and increasing delay. At unsignalized intersections, left- and U-turn vehicles may have difficulty finding adequate gaps in the opposing traffic. When there are too many crossovers, the progress of construction may be hindered. Other factors which impact the number of median crossovers included the type of access provided before construction (raised median, continuous two-way left-turn lane, or undivided arterial) and the differences in grade between the roadways on either side of the work area.

Typically, at least one crossover should be provided between each signalized intersection. This allows some left-turn and U-turn traffic to travel to the desired location without using an intersection. Crossovers may also be appropriate at major traffic generators. A crossover should be located to provide access to as many properties as possible. Sufficient distance should be maintained between the crossover and adjacent intersections in order to reduce the impacts of the crossover on the intersection.

The crossover itself should be wide enough to permit vehicles to turn into the crossover when it is already occupied by another vehicle. A wide crossover provides an sufficient turning radius for vehicles entering the crossover. The required width of a crossover is a function of the design vehicle and the width of the travel lanes. The ability of a vehicle to turn perpendicular to the traffic stream depends upon the width of the work area. Figure 8-4 illustrates that for 10-foot lanes and a work area 42 feet wide, the crossover should be 49 feet wide in order to accommodate passenger vehicles.



Note: Recommended design based on passenger vehicle.

Figure 8-4. Recommended Temporary Median Crossover Design for Urban Arterial Work Zones

Conclusions from Analysis of Other Factors

The analysis of these additional urban arterial work zone factors provided much useful information for the development of guidelines for urban arterial work zones. A study of lane closure capacity at a study site in Arlington indicated that the capacity of an urban arterial lane closure is approximately half of that of a freeway lane closure. However, this finding should be used with caution, as it is based on only one study site and may not represent actual arterial lane closure capacity. But the lack of documentation on this subject may warrant the use of this information.

Lane closures near signals create the potential for the intersection to be blocked by vehicles queueing at the lane closure. As part of this study, some guidelines were developed for defining the minimum distance needed between the lane closure and intersection in order to prevent the queue from blocking the intersection. The minimum separation distances can be determined according to the probability of that the separation distance will be exceeded.

Median crossovers are needed when the arterial work area is located between traffic traveling in opposite directions. A number of guidelines were developed for the design and location of median crossovers.

CHAPTER 9

ARTERIAL WORK ZONE GUIDELINE DEVELOPMENT

The information obtained during the course of this research project was collected and analyzed to develop guidelines for planning, implementing, and operating traffic control in urban arterial work zones. The guidelines developed as part of this project are described in this chapter, along with the basis for each guideline. In some cases, the research may not conclusively support the use of a particular guideline, however, engineering judgement indicates that implementation of the guideline will have a positive effect on safety, operations, or both. The guidelines developed in the course of this project have not undergone an extensive experimentation or evaluation period in the field. **Therefore, these guidelines should be implemented with care, and the effects of the guidelines should be closely monitored.**

The guidelines are organized into several different categories, according to the area which they address. These categories include project and work activity scheduling, construction planning, speed control, intersections, signalized intersections, signing, lane closures, channelizing devices, median crossovers, pavement markings, public relations, accidents, and inspection. For ease of identification, the guidelines are shown in *italics* typeface. Each guideline is followed by a description of the problem area the guideline addresses and the basis for developing the guideline.

Project and Work Activity Scheduling

- *Avoid lane and intersection closures during the morning, noon, and evening peak in order to minimize traffic conflicts.*

Traffic volumes on arterial streets are highest during the morning and evening peak periods. During these high demand periods, all available capacity should be provided for traffic flow. Avoiding lane closures and intersection closures during these peak periods reduces congestion, delay, and vehicle conflicts. At a minimum, lane and intersection closures should not be permitted from 7:00 to 9:00 am and 4:00 to 6:00 pm. It may be appropriate to use longer restricted periods for high volume arterials.

Many arterial streets have lunch-time traffic volumes that are as high or higher than the morning and evening peak volumes. This is especially true in heavy retail areas with restaurant and shopping opportunities. In addition, the lunch-time peak does not usually have a heavy directional movement. Therefore, construction activities should be scheduled to avoid lane and intersection closures between 11:30 am and 1:30 pm, if possible. Lane closures already in place should be reopened between 11:30 am and 1:30 pm, if no construction activities are taking place. In the situation where a moving construction operation is taking place through the lunch period, it is desirable to remove those portions of the lane closure which are no longer necessary in order to restore as much capacity as possible.

- *If possible, projects should not be scheduled to begin construction between Thanksgiving and New Year's Day in heavy retail areas.*

The heaviest shopping period of the year is between Thanksgiving and the end of the year. Retail businesses generate much more traffic and arterials adjacent to these businesses carry higher traffic volumes during this period. Therefore, it is desirable to avoid starting construction during this period. Doing so delays the impacts of construction until after volumes have decreased and it also reduces the exposure of workers to vehicles.

Construction Planning

- *Plan the construction phasing to minimize, as much as possible, the length of arterial which is under construction at any one time.*

The motorist surveys indicated that one of the largest complaints about the F.M. 1960 study site was the length of arterial which was under construction (approximately 8 miles).

- *Do not leave unused construction equipment in public view for extended periods of time.*

Comments from TxDOT personnel indicated that they received several complaints about construction equipment being left along the arterial for extended periods. These complaints reflected a concern that progress on construction was not occurring if equipment was not being used. Although the public does not understand the specifics of construction, it is important to avoid a lackadaisical appearance. Therefore, if construction equipment will not be utilized on a regular basis, it should be stored at an appropriate location.

- *Use high-early strength concrete to minimize the duration of construction as much as possible.*

The curing requirements of materials impact project scheduling and traffic flow. Numerous difficulties are related to the time spent waiting for concrete to cure before vehicles are allowed to travel on it. Additionally, the public does not understand the need for the concrete to cure and perceives dry concrete which is not open to traffic as an inefficient construction practice. The use of high-early strength concrete will allow newly paved areas to be opened to the public on a quicker basis.

- *Use low-profile barrier in areas needing barrier protection.*

Sight distance restriction due to the guardrail on drum type temporary barriers are a major concern of urban arterial work zones. The use of the low-profile barrier recently developed by TTI (31) will significantly reduce the sight distance restriction associated with barriers on urban arterials.

- *If the travel lanes are not the same width, the outside lane should be wider in areas with large numbers of driveways and intersections.*

One of the most important unique characteristics of urban arterial work zones is the large number of vehicles turning onto and off of the arterial. In some cases, these turns are occurring at locations with short turning radii on the curb return causing some turning vehicles to encroach on the inside travel lane. If the travel lanes are not the same width, the wider of the lanes should be placed on the outside where these turning movements are occurring.

- *Relocate bus stops to appropriate locations.*

The presence of a work zone can seriously impact transit operations. The presence of a work area may require elimination or relocation of bus stops and waiting areas. Passenger demand may also be influenced by the inconveniences associated with construction. Buses stopping at the near side of an intersection may reduce the capacity of the intersection. In the case of a four-lane roadway without turn lanes, flow through the intersection may be stopped when a bus stops in the outside lane and a left-turning vehicle in the inside lane waits for a gap to turn. Buses stopping on the far side of the intersection may cause traffic to queue and block the intersection. Temporarily relocating bus stops to mid-block or off-street parking areas may help to improve traffic flow through the arterial work zone.

- *Consider improving alternate routes prior to starting construction on a major arterial.*

Some motorists will reroute their trips in order to avoid construction on a major arterial. If construction is planned for a major arterial and the duration or impacts of the construction are expected to be significant, then consideration should be given to improving alternate routes to the arterial. These improvements should be completed before construction begins on the major arterial. At a minimum, one of the improvements which should be considered is a change in signal phasing and timing to accommodate the increased traffic volumes. Traffic signal operations on the alternate route should be checked on a regular basis during the period that the major arterial is under construction. Geometric improvements may also be appropriate.

- *Remove parking from the arterial prior to initiating construction.*

Most major urban arterials do not permit angle or parallel parking on the arterial. However, if on-street parking is present on an arterial in the vicinity of a work zone, the parking should be removed while construction is underway.

Work Zone Speed Control

- *Do not utilize speed restrictions in work zones, if possible. If speed restrictions are necessary, they should be carefully selected, recognizing that it may be necessary to supplement such speed guidance with other more positive means of controlling driver behavior. Advisory speeds should be selected to be consistent with site conditions.*

Research has shown that many drivers do not reduce their speed upon entering a work zone. Therefore, the normal arterial speed should be maintained in the urban arterial work zone, if at all possible. If speed restrictions are necessary, they should be carefully selected with the recognition that additional measures may be needed to slow arterial traffic.

- *Check for consistent appearance of speed information. Advisory speed plates and speed limit signs with different speeds should not be placed within view of one another.*

The placement of speed limit and advisory speed information should be evaluated to insure that conflicting speed information is not visible to the driver at one time. If a speed limit sign and advisory speed plate are visible to the driver at the same time, then the driver will likely select the higher of the two speeds.

- *Provide an enforcement area or areas for police activities.*

The restricted right-of-way associated with arterial construction also reduces the ability to enforce traffic laws. Police may not have an acceptable location to observe traffic and are hesitant to issue citations if a safe area to do so is not available. A lack of enforcement will be noticed by the public and will breed disrespect for the traffic laws. This may result in increased accidents and poor operations.

- *Request police presence on the project if traffic speeds are excessive even if enforcement is not possible.*

Most drivers reduce their speed when they see the police. Therefore, the presence of the police in a work zone will reduce vehicle speeds, even if citations are not being issued.

Intersections

- *Provide large street name signs with block numbers at major signalized intersections as a minimum, and at all intersection if possible. Whenever possible, these street signs should be placed overhead (on signal mast arms or span wire) to increase their visibility.*

When construction begins, many of the navigational aids that drivers use are removed or they become less visible. Such features as business signs and addresses may not be visible to help drivers find specific locations. In addition, the pre-construction street signs may no longer be visible to drivers if the work area is located between the sign and traffic. Locating street signs overhead at signalized intersections will improve the visibility of street name signs.

- *Maintain as large a turning radius as possible at driveways and intersections.*

The accident data at the three study sites showed that, not only was there an overall increase in accidents, there was also an increase in the proportion of accidents occurring at intersections and driveways. One potential method of reducing accidents is to make it easier for vehicles to turn into and out-of intersections and driveways by increasing the radius at intersections and driveways. Increasing radii reduces the potential for encroaching upon adjacent lanes, thereby reducing potential vehicle conflicts. However, it should be noted that no empirical evidence was found that indicated a relationship between accidents and intersection or driveway radii.

- *Driveways should be clearly marked and safe sight distances checked for each driveway.*

The presence of channelization devices may make it difficult for drivers on the roadway to identify the specific location of driveways and may also create sight distance restrictions. Therefore, each driveway within the work area should be checked to insure that it is visible to drivers traveling down the roadway and that drivers in the driveway can adequately see traffic on the roadway.

Signalized Intersections

Traffic signals are among the most important of the traffic control devices on arterial streets. The overall capacity of the arterial is typically limited to the capacity of the signals on that arterial. When traffic signals operate at a less than optimal level, congestion and traffic flow problems may result. Undesirable impacts of decreased signal performance include increases in congestion, travel times, motorists' frustration levels, and traffic signal violations. The following guidelines for traffic signals in arterial work zones may be helpful in reducing the undesirable impacts of the work zone.

- *Signal phasing and timing should be adjusted with each change in construction phasing. Signal operation should be checked in the field after each adjustment.*

Construction activities cause a significant disruption of normal traffic patterns, including traffic volumes and turning movements. In addition, construction phasing may alter the lane arrangements at approaches to signalized intersections. All of these factors may negate pre-construction signal phasing and timing. Because changes in construction phasing may take place on a relatively frequent basis, changes to phasing and/or timing may be required more often than normal. As with normal signal operation, the effectiveness of new phasing and/or timings should be checked in the field after implementation. They should also be checked on a regular basis during construction, as there is some variability in traffic patterns while construction is underway.

- *Short cycle lengths may be useful in reducing queue backup into the intersection.*

The effects of cycle length on queuing should be carefully observed at signalized intersections in the work zone. If queues due to construction activities or traffic generators are common, then a shorter cycle length may be effective at minimizing queue lengths.

- *The positions of traffic signal heads should be shifted to line up with lane arrangements anytime lane positions are modified. Signal heads should be located within the cone of visibility described in Section 4B-12 of the MUTCD.*

The typical construction phasing plan for an urban arterial utilizes narrow lanes and requires the positions of the lanes to be shifted from one side of the road to the other in order to provide a work area. If the signal head positions are not shifted, then they may not remain in the cone of visibility required by the MUTCD. Even if they remain in this cone, the visibility of the signal head may be increased by locating it directly over the approaching lanes to which the signal applies.

- *The operation of actuated signal detectors should be checked on a regular basis. If detection capability is lost, then actuated controllers should be converted to pretimed operation.*

Construction activities may destroy the detection capabilities of loop detectors located near intersections. Detection capability may be lost because the position of the lane is shifted so that it is no longer over the detector, due to scarifying of the pavement surface, damage to the pavement structure, damage to the loop wire between the loop and the controller, or other factors. Depending upon the cause of the detector malfunction, the detector may place a continuous call even when no vehicles are present, or it may not place any calls even when vehicles are present. The result of the former is that the signal will max out each cycle while the result of the latter is that no green (or the minimum green) will be displayed each cycle. Without detection capability, an actuated signal becomes little more than an inefficient pretimed signal by default, and the signal phasing and timings should be developed accordingly.

- *Time base coordination should be used to provide progression through a work zone encompassing several traffic signals if the interconnection between signals is disrupted.*

Interconnection between signalized intersections may be lost in the same way that detection capabilities may be lost. Both buried or overhead interconnect wire may be cut or otherwise rendered inoperable during construction activities. If this occurs, progression cannot be provided for a series of signals. Maintaining progression is especially important if the traffic signals must operate in a pretimed mode due to the reasons mentioned above. Progression can be maintained without a physical connection between controllers by using time-based coordinators (TBC). If progression is needed during construction to minimize the delay encountered by motorists, then TBC should be installed at the appropriate intersections.

- *Minimum pedestrian crossing time should be checked whenever signal timing is modified. If sufficient pedestrian crossing time cannot be provided, then the affected pedestrian movements should be prohibited with appropriate signing.*

Although the volume of pedestrian movements at signalized intersections in a work zone may negligible, the signal timings should be checked to insure that sufficient crossing time is provided for pedestrians. If adequate time cannot be provided or if pedestrian movements have an adverse effect on traffic flow, then the appropriate pedestrian movements should be prohibited at the intersection. If pedestrian movements are prohibited, the signing should indicate where the pedestrians should go to reach their destination. The minimum pedestrian crossing time should be sufficient to allow a pedestrian to cross from a non-work area to the middle of the far lane. A walking speed of 4 feet per second is commonly used, although it may be appropriate to use a slower speed if there are significant numbers of children or senior citizens present. It should be noted that the distance the pedestrian must cross should include the work area of the arterial.

- *An actuated pedestrian phase may be used to reduce the impacts of pedestrians on signal operation, even if the signal is operating as a pretimed signal due to the loss of vehicle detection capability.*

Even though construction may destroy the vehicle detection capability of an actuated signal and force it to operate in a pretimed manner, pedestrian pushbuttons can still be used to provide an actuated pedestrian phase. By doing so, the pretimed signal timings can be optimized to meet the needs of the vehicular traffic, thereby minimizing delay. The additional time required for pedestrians to cross the street is provided only when pedestrians are present and use the pedestrian pushbutton. The actuated pedestrian phase should be long enough to provide sufficient time for pedestrians to cross the street.

- *New or temporary signals in arterial work zones should use 12-inch signal lenses.*

The large number of traffic control devices, other vehicles, vehicle maneuvering, and development present in urban arterial work zones create many demands for the driver's attention. Using 12-inch signal lenses will help the driver to identify traffic signals in the work zone and respond accordingly. Desirably, all signals in the work zone should use 12-inch lenses. However, it is even more desirable to use 12-inch lenses when a new signal is installed or signal heads are relocated because drivers will not be used to the locations of these signals.

- *Left-turn lanes should be provided at major signalized intersections.*

Left-turn movements can be a significant hindrance to traffic flow at signalized intersections. The lack of a left-turn bay can significantly increase delay due to left-turning vehicles blocking a through lane while waiting for an acceptable gap. Experience at the F.M. 1960 study site confirmed that the lack of left-turn lanes create many difficulties, and as a result, left-turn lanes were added as a field change order. Although the addition of left-turn lanes may create some difficulties for construction scheduling and activities, the benefits associated with these lanes make it desirable to provide them at major signalized intersections where left-turning vehicles are present.

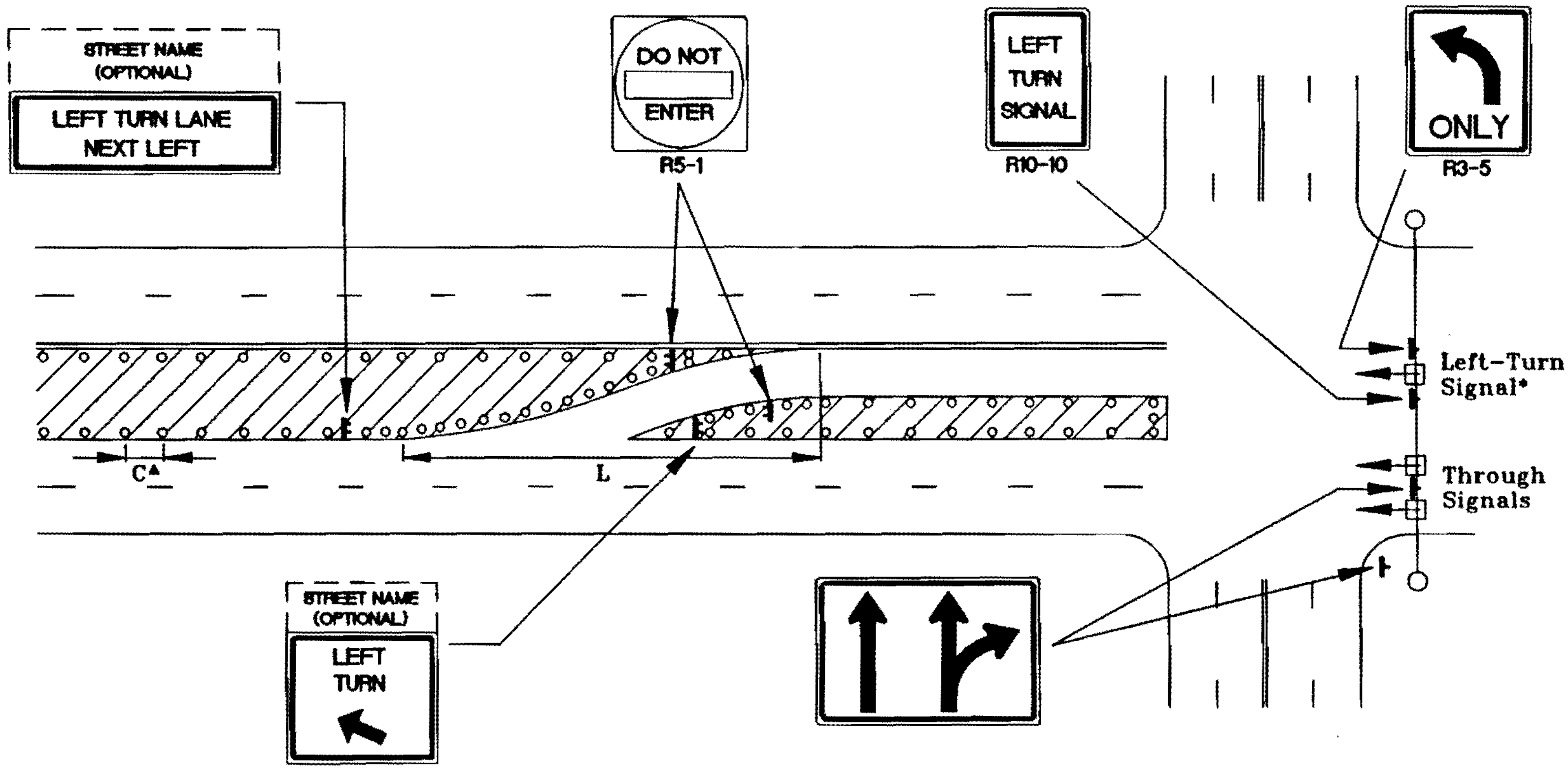
Figure 9-1 illustrates the layout of the left-turn lane used at the S.H. 6 study site when construction was taking place in the center of the road. The actual position of the lane can be shifted as needed to allow work to take place in the center area.

This research study was not able to determine the volume at which left-turn lanes are warranted in urban arterial work zones. The need to provide a left-turn lane should be based on engineering judgement and is related to the volume of left-turn vehicles, the opposing through volume, the presence of median crossovers between intersections, the classification of the cross-street, the area available for the left-turn lane, the amount of development on the arterial and cross-street, and other factors.

Work Zone Signing

- *Signs should not block the view of vehicles entering the area from gas stations, restaurants, cross roads, etc.*

The restricted right-of-way of urban arterials and the many driveways and intersections present along those arterials create the potential for sight distance restrictions from construction signs or other traffic control devices placed along the edge of the road. When traffic control devices are placed on the side of the road, the sight distance from nearby intersections and driveways should be evaluated. If a sight distance restriction exists, then the device should be relocated or the intersection or driveway should be closed.



Note:

- * Left-turn signal should be positioned over the left-turn lane
- ▲ Channelizing devices should be spaced at 1/2 C on the taper

LEGEND

- ▨ - Work Area
- o - Channelizing Device
- L - Taper Length
  - $= WS^2/60$ for $S \leq 40$ mph
  - $= WS$ for $S \geq 45$ mph
- C - Spacing of Channelizing Devices

Figure 9-1. Possible Design for Left-Turn Lane in Work Zone

- *High-intensity reflective sheeting may be appropriate for use on traffic control devices which indicate a change in the travel path of traffic.*

Analysis of the accident data at the study sites indicated an increase in the number of accidents occurring during dark with artificially lighted conditions. Increasing the reflectivity of traffic control devices located in transitions and other changes in the travel path may help to make these devices more visible and better define the intended travel path.

- *The* **CROSSOVER** *sign (D13-1) should be placed immediately beyond the crossover opening, as called for in the MUTCD and in a manner consistent with permanent crossover locations.*

Observations of the study site work zones indicated an inconsistent location of the **CROSSOVER** sign. The proper location is on the far side of the crossover opening. Consistency in location will assist drivers in locating the crossovers, especially in areas where the work area has the same appearance as normal pavement.

- *Educational plaques should be used with construction symbol signs.*

The motorist surveys indicated that many drivers do not fully understand the meaning of symbols used in construction signs. Using educational plaques below construction symbol signs will help to improve driver comprehension of these devices.

- *The Advance Road Construction sign (CW20-1A, CW20-1B, or CW20-1C) should not be used as only a single sign. At least two Advance Road Construction signs indicating decreasing distances to the start of construction should be used in advance of a work zone to give the motorist the message that they are approaching a work zone.*

Using at least two **Advance Road Construction** signs with different distances to the start of the construction area will help the driver realize the signs indicate the distance to the beginning of a work zone.

- *Traffic control devices which are no longer applicable should be removed or covered.*

Some arterial work zones involved traffic control measures which are in place only during portions of the day, typically daytime hours, and removed during other periods, such as at night. Signing for these traffic control measures should be removed or covered when the traffic control measure is not applicable. As an example, a lane closure may be necessary to conduct construction activities during daytime periods and is properly signed as such. The signing for the lane closure should be removed or covered at night if the lane is reopened during the night. Conflicts between the actual condition of the arterial and the message indicated by signing can lead to driver confusion and breed disrespect for signing.

- *Construction warning signs should be spaced according to the requirements of the Texas MUTCD (page 6B-2.2)*

There is variability between several agencies in the sign spacing between advance construction signs. Table 9-1 indicates the sign spacings used by TxDOT, City of Arlington, City of Seattle, and City of Victoria. In addition to these spacings, other references give the following rules-of-thumb for sign spacings: 200 feet between signs for multiple advance warning signs (14), 4 to 8 times the speed limit (14), 250 feet for speeds less than 40 mph (7), and 500 feet for speeds greater than 40 mph (7). In addition, distance restrictions can be imposed by the length of city blocks or the location of driveways.

Table 9-1. Comparison of Sign Spacings

Speed (mph)	Distance Between Signs (feet)			
	TxDOT (6)	Arlington (24)	Seattle (28)	Victoria (29)
30	80	125	150[1]	
35	120	160		150-240
40	160	200		
45	240	250		240-360
50	320	300		
55	500	375		360-550

Note: 1 - Spacing for an arterial street. Seattle does not specify sign spacing according to speed.

Due to the variability of spacing requirements and the inability to identify information to justify the sign spacings used by other agencies, it is recommended that the sign spacing requirements of the Texas MUTCD be used.

Lane Closures

- *Use a flashing arrow panel for lane closures on major arterial streets.*

Major arterial streets typically have higher speeds and heavy volumes -- conditions well suited to the use of a flashing arrow panel for lane closures. On high-speed, high-volume major arterials, a flashing arrow panel should be used for lane closures in the same manner as used for freeway lane closures. Flashing arrow panels help motorists to identify the location of the lane closure and they may be more visible than some advance signing due to their higher mounting height. In addition, the numerous driveways and access points on many arterials mean that motorists coming from these locations may not be aware of the lane closure.

- *Provide the minimum separation distance between the lane closure and upstream signalized intersection as indicated in Figures 9-2 and 9-3.*

During periods of heavy congestion, motorists enter the intersection during a green indication. However, the heavy congestion may prevent vehicles from clearing the intersection before the red indication appears. At this point, vehicles in the intersection become obstacles to cross-street traffic which has the right-of-way. This scenario is especially likely if a lane closure is located too close to the intersection. Sufficient distance should be provided between the lane closure and the intersection so that the maximum queue will not block the cross-street. Figures 9-2 and 9-3 identify the minimum separation distance for various combinations of arterial approach volume, length of arterial red, and probability of performance. Figure 9-2 contains an example of how to use these two figures.

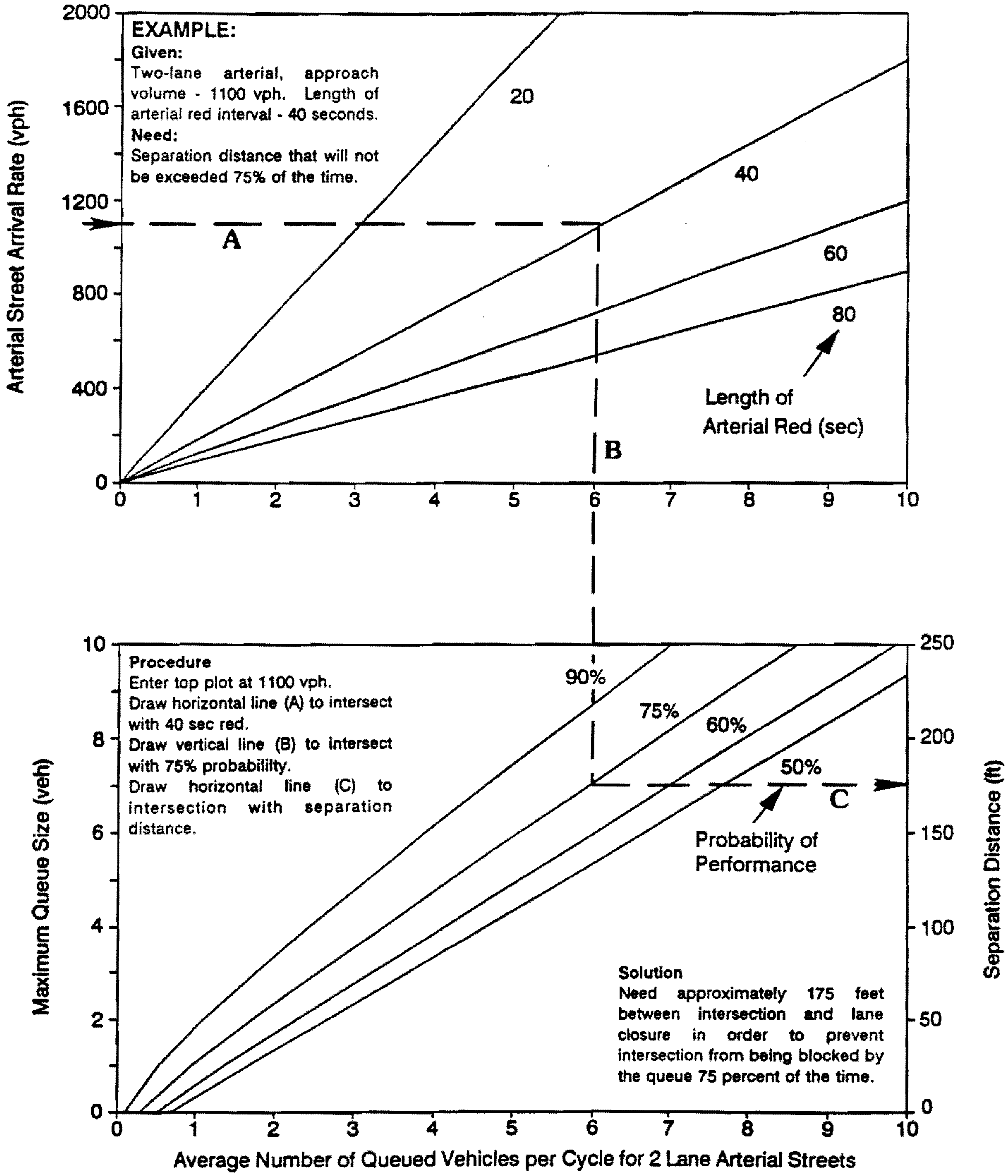


Figure 9-2. Lane Closure Separation Distance Probability Curves for Two-Lane Arterials

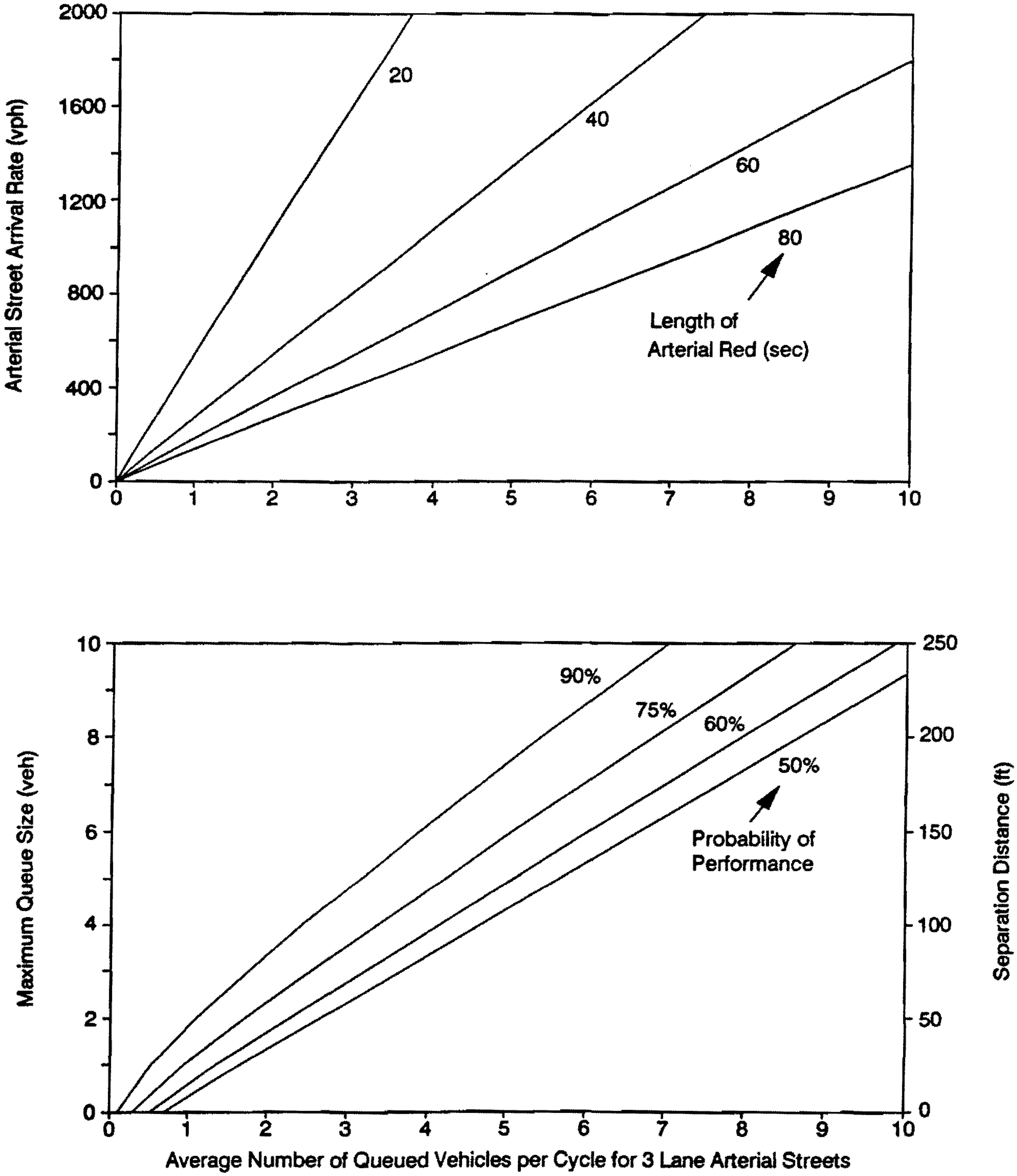


Figure 9-3. Lane Closure Separation Distance Probability Curves for Three-Lane Arterials

- *Lane closures should be located on a tangent section of roadway, if possible.*

Lane closures located on a curve present sight distance and maneuvering difficulties. By placing the lane closure on a tangent section, it is more visible to approaching drivers, allowing them to change lanes farther in advance of the merge point. Also, the lane change maneuver becomes less complicated because the driver is not negotiating a curve while changing lanes.

- *If possible, the lane closure should be located so that there are no intersections, driveways, or median crossovers in the area between 200-300 feet upstream of the beginning of the taper and the end of the taper, as illustrated in Figure 9-4.*

Introducing turning and crossing maneuvers from an intersection or driveway into the area where lane changing and merging are taking place introduces additional turbulence into the traffic stream, creates more conflicts, and limits operational efficiency. Desirably, an intersection, driveway, or median crossover should be located in the area where the arterial traffic stream is flowing as normal lanes before the lane closure or a reduced number of lanes after the lane closure.

- *The capacity of an arterial lane closure should be assumed to be approximately 57 percent of the capacity of a freeway lane closure.*

Measurements of the capacity of a lane closure in an urban arterial work zone indicate the capacity of two lanes being closed to one lane is about 760 vehicles per hour. This value is approximately 57 percent of the capacity of a freeway lane closure with similar geometrics, as given in the *Highway Capacity Manual*. The lower capacity of an arterial lane closure should be considered when planning and implementing lane closures.

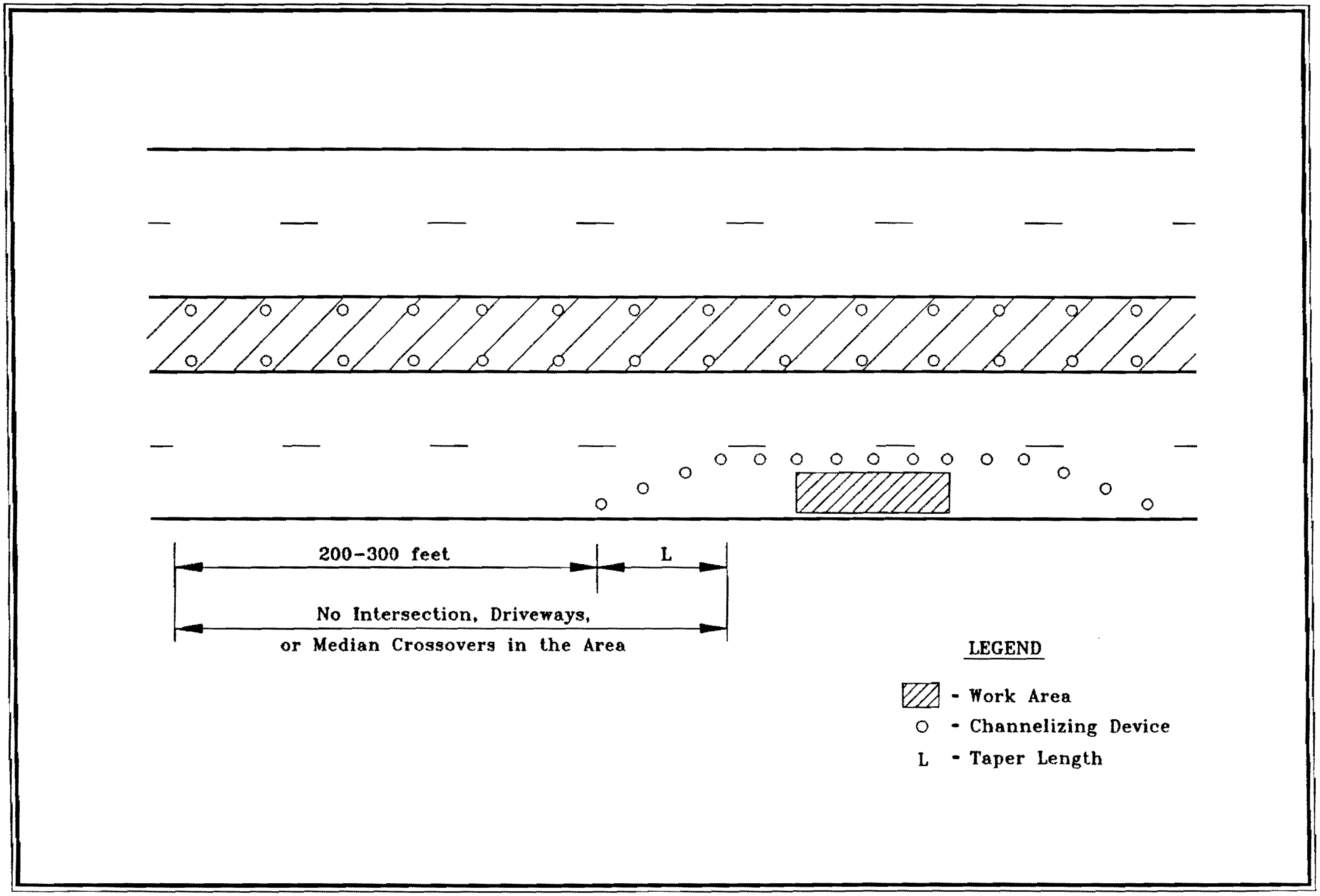


Figure 9-4. Locations of Lane Closure and Nearby Intersections

- *Lane closure signing should be located upstream of a signalized intersection if the lane closure is located within 1,500 feet of the signalized intersection and traffic volumes on the arterial are high.*

Drivers may not be able to see a lane closure or signing for a lane closure when that lane closure is located close to a signalized intersection. However, the higher traffic density associated with saturation flow from a signalized intersection eliminates many lane changing opportunities. By placing the lane closure signing in advance of the signalized intersection, drivers can change lanes before reaching the queue of vehicles at the intersection, improving traffic operations downstream of the intersection.

Channelizing Devices

- *The minimum taper length for channelization should be* $W \times S^2/60$ *for speeds of 40 mph and less and* $W \times S$ *for speeds of 45 mph and greater, where* W *is the width of the offset in feet and* S *is the speed in miles per hour.*

These are the equations contained in the Texas MUTCD for taper lengths and they remain the same in the proposed revisions to Part VI of the National MUTCD. However, it may be appropriate to use longer taper lengths in some cases.

- *Spacing between channelizing devices should be reduced in areas where vehicles may want to encroach on the construction area (such as onto new pavement to make a turn). At these locations, a spacing in feet equal to or less than the speed limit in miles per hour may be appropriate.*

The standard spacing for channelization devices on a tangent is a distance in feet equal to twice the speed limit. At the speeds found on many arterials, vehicles can travel between the devices and drive on the wrong side. Also, a spacing of twice the speed limit may cause some confusion in drivers looking for a driveway or median crossover.

In some cases, it is obvious to drivers that they should not drive on the other side of the channelizing devices. An example of this is where there is excavation taking place on the other side of the channelization devices. However, in other cases, it is not obvious to the driver that they should not drive on the other side of the channelization devices. Examples of this situation include where new pavement has been poured and is curing and a buffer area between vehicles and workers. In these cases, drivers may cross the line of channelization devices to make an illegal turn, to pass an area of congestion, or because they are confused. Reducing the spacing of channelizing devices to a distance equal to the speed limit will discourage drivers from crossing into the work area.

Median Crossovers

When the work area is located between traffic flowing in opposite directions, left-turn movements are restricted to intersections and locations between intersections where median crossovers have been provided. The number, location, and design of median crossovers have an impact on the quality of traffic flow in urban arterial work zones. The following guidelines address specific aspects of temporary median crossovers.

- *In areas with heavy retail development and many access points on the arterial, it may be appropriate to locate one or more median crossovers between each pair of traffic signals when the spacing between the signals exceeds 1,000 feet. However, median crossovers may not be necessary if through and left-turn movements at the intersection are light and the intersection can accommodate the increase in left-turn and U-turn volumes.*

Some areas create a heavy demand for left-turn movements. Typically, this type of area has a significant retail development and many access points on the arterial. If median crossovers are not provided, then all left-turn demand is shifted to the intersections. If traffic volumes are heavy, the increased demand at the intersection may create operational problems and cause cycle failures. There should be enough distance between the signals so that the traffic turbulence created by the crossover does not affect operations at the signals. Desirably, median crossovers should be located a minimum of 300 to 400 feet from any intersections. Signals spaced less than 1,000 feet apart create some operational difficulties, which are compounded by the presence of a median crossover between the signals.

- *The width of a crossover (parallel to the traffic direction) should be 45 to 50 feet as shown in Figure 9-5 in order to accommodate passenger vehicles.*

Median crossovers should be of sufficient size to allow vehicles to maneuver in and out of the crossover with little difficulty. If the crossover is not wide enough and the crossover is already occupied by one vehicle, another vehicle will have difficulty entering the crossover. In this situation, neither vehicle can move and a gridlock type of situation is created. The design shown in Figure 9-5 is based on the turning radius of a passenger vehicle with a turning speed of less than 10 mph. A larger design vehicle or higher speed requires a wider median crossover.

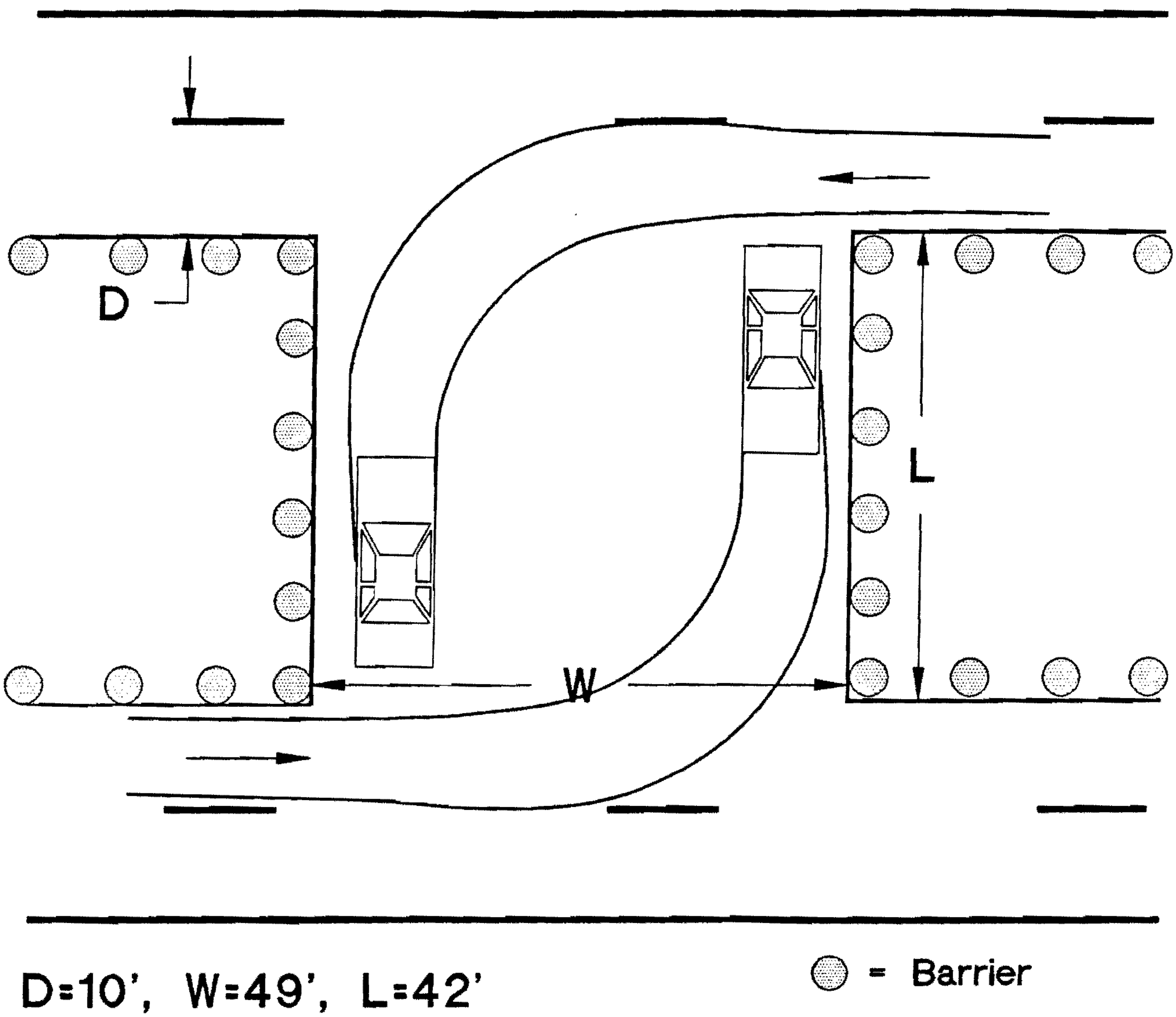
- *Crossovers should be located to provide the greatest access to properties adjacent to the arterial.*

The number of crossovers can be minimized by locating crossovers to maximize access.

- *The grade of a crossover should be as level as possible within 20 feet of the higher elevation roadway in order to reduce sight distance restrictions.*

If the median crossover is crossing an excavated area and has a pavement surface which is lower than the arterial, sight distance restrictions may be created by the channelizing devices along the work area. By providing a nearly level approach to the arterial, these sight distance restrictions can be minimized. In some cases, the size of the work area, or the difference in elevation between the arterial pavement surfaces may make it difficult to provide a level crossover. If this is so, the sight distance of the crossover should be checked. If sight distance is not adequate, then the crossover should be eliminated. Note that the use of the new low-profile barriers will greatly improve sight distance at median crossovers.

- *U-turns should be permitted at traffic signals if a median crossover is not provided between the signal and the previous signal.*



Note: Recommended design based on passenger vehicle

Figure 9-5. Recommended Temporary Median Crossover Design for Urban Arterial Work Zones

If a median crossover is not provided between signals, then vehicles will make left- and U-turns at the intersection in order to gain access to properties on the other side of the work area. Signal operation and intersection geometrics should be checked to insure that U-turns are possible. If U-turns cannot be safely accommodated, then alternate means of providing access to properties should be evaluated.

Pavement Markings

- *Use raised pavement markers, in conjunction with or in lieu of painted markings, to enhance lane delineation in potential hazard areas.*

The removal and placement of pavement markings is one of the biggest challenges in work zones. Short of placing an overlay over old pavement markings, there is no method which will obliterate permanent pavement markings without leaving any type of scar. Raised pavement markers possess many advantages for use in urban arterial work zones. They can be easily placed and removed, and after removal, the remains of the markings do not provide as visible an indication of the lane lines as other types of markings. Raised pavement markers have greater visibility in periods of wet weather. They also provide a tactile indication to the driver when the vehicle begins to change lanes. Reflective raised pavement markers have good visibility at night.

Public Relations

- *Hold a public hearing to explain the traffic plan whether requested or not and work hard to generate attendance.*

The driving public and retail businesses have a strong interest in the progress of construction activities on urban arterials. Typically, this interest does not develop until after construction begins and the severity of the impacts are realized. Disseminating this information at a public hearing may help to avoid much controversy when the construction actually begins.

- *Hold regular public meetings during the construction period to update progress of the project, answer questions, and identify problem areas.*

Many residents and businesses affected by arterial construction are interested in the progress of construction. Typically, the media does not provide the type of detailed knowledge desired by these individuals. Public meetings with business organizations, service organizations, and citizen groups will help to keep them informed and may improve the working relationship between these groups and the agency responsible for construction. Some of the specific issues of concern to the public include contract duration, location of activity, special working conditions, construction schedules, restricting ingress and egress of businesses and residents, transit schedules and/or parking restrictions.

Urban Arterial Work Zone Accidents

- *Accidents within the work zone should be monitored in order to identify accident trends and determine areas where increased traffic control emphasis should be placed.*

Accident frequencies and rates in urban arterial work zones will increase. The type, time, and location of accidents should be monitored in order to determine trends in the data. Any trends which appear should be evaluated in light of the existing traffic control in order to determine if changes in traffic control are necessary.

Work Zone Inspection

- *Inspectors with specific training in work zone traffic control should inspect urban arterial work zones on a regular basis.*

The primary concern for many construction inspectors is the quality and progress of the construction activities. In some cases, the construction inspector may have little or no formal training in work zone traffic control. Therefore, it is important that an inspector whose primary responsibility is traffic control inspect the arterial work zone on a regular basis. This individual should have specific training in work zone traffic control and risk management. This traffic control inspector may also be responsible for traffic control at many different work zones.

- *Traffic control in the work zone should be checked during periods of darkness on a regular basis.*

Accident data from the three study sites indicated that there was an increase in the number of accidents occurring during periods of darkness, despite the fact that construction activities were not taking place at night. Regular nighttime inspections by qualified traffic control inspectors can help to identify locations where visibility of devices can be improved, where glare from other lighting sources interferes with visibility of the work zone, the needs of large nighttime traffic generators, and also provide indications of the traffic characteristics during the night.

Miscellaneous Findings and Future Research

This research study was intended to identify the unique characteristics of urban arterial work zones and develop traffic control guidelines for this type of work zone. The completed research confirms the need for such guidelines and has identified numerous guidelines which should help to improve both traffic flow and worker safety in urban arterial work zones.

In addition to the guidelines described in this chapter, there are some additional findings for which no guidelines were developed, but which have some type of impact on urban arterial work zones. These findings include:

- It appears that traffic volumes in urban arterial work zones are lowest when the construction is taking place in the center of the roadway and opposing traffic was separated by the work area.
- Work zone traffic control devices are not a primary concern of motorists traveling through an urban arterial work zone.
- About half of the surveyed motorists do not understand that the color orange is associated with construction signing. This indicates a need to improve educational efforts.

The research conducted as part of this project also identified several aspects of urban arterial work zones which should be evaluated in more detail in future research. Specifically, the motorist surveys indicated that drivers do not understand the concepts behind the three drop-off signs -- **Low Shoulder, Uneven Lanes,** and **Shoulder Drop-Off**. Research is needed to develop better alternatives for these signs, or possibly develop one sign to represent all three conditions. The development and testing of the signing alternatives for four signs represents only a starting point for developing improved versions of these signs. Further testing of these alternatives should be conducted before they are used in the field.

CHAPTER 10

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