TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-91/1161-3, Volume 2		

4. Title and Subtitle Traffic Control Guidelines for Urban Arterial Work Zones - Volume 2 Appendices	5. Report Date October 1990 February 1991/Revised 6. Performing Organization Code
7. Author(s) H.G. Hawkins Jr., M.A. Ogden, E.C. Crowe	8. Performing Organization Report No. Research Report 1161-3, Volume 2
9. Performing Organization Name and Address Texas Transportation Institute Texas A&M University System College Station, Texas 77843-3135	10. Work Unit No. 11. Contract or Grant No. Study No. 2-18-89-1161
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation; Transportation Planning Division P.O. Box 5051 Austin, Texas 78763	13. Type of Report and Period Covered Interim: September 1989 August 1990 14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with DOT, FHWA.
Research Study Title: Design Process for Work Zone Speed Control and Traffic Control Guidelines for Urban Arterial Street Work Zones.

16. Abstract

A three-year study of urban arterial work zones is currently in progress. The objective of the study is to develop improved guidelines for selecting and implementing work zone traffic control on urban arterials. The second year study efforts are documented in a three volume report. The Technical Report appears in Volume 1. This document is Volume 2 and contains the Appendices for Volume 1, and Volume 3 contains the data used in the research analysis.

This volume includes the appendices describing study activities in the following areas: literature review, study site selection, data collection and analysis, motorists' surveys, and review of current practice.

The study activities of the first two years confirm the need for improved guidelines. Current research and guidelines do not thoroughly address the topic. A survey of local agencies indicates a variation in the significance given to work zone traffic control on arterials. Traffic data indicates a decrease in traffic performance in the vicinity of the construction zones studied. Surveys of motorists indicated they do not fully understand all construction signs and are concerned about the impacts of the construction on their mobility.

The preliminary findings and preliminary guidelines included in Volume 1 address a number of problem areas related to urban arterial work zones including traffic signals, left turns, lane widths, accidents, construction activities, driver needs, and public relations.

17. Key Words	18. Distribution Statement
Arterial Work Zone, Urban Work Zone, Work Zone, Urban Arterial Work Zone Guidelines	No restrictions. This document is available to the public through the National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	100	

Form DOT F 1700.7 (8-69)

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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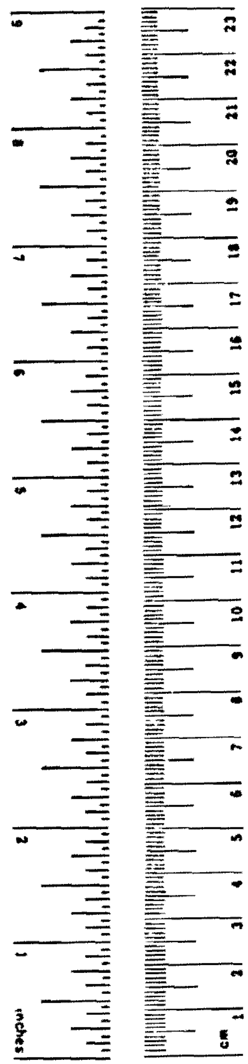
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

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

Symbol	When You Know	Multiply By	To Find	Symbol
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* SI is the symbol for the International System of Measurements



APPROXIMATE CONVERSIONS TO SI UNITS

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m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
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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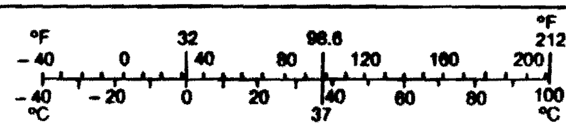

These factors conform to the requirement of FHWA Order 5190.1A.

TRAFFIC CONTROL GUIDELINES FOR URBAN ARTERIAL WORK ZONES

VOLUME 2 - APPENDICES

by

H. Gene Hawkins, Jr.
Assistant Research Engineer

Michael A. Ogden
Engineering Research Associate

Elizabeth C. Crowe
Engineering Research Associate

Research Report 1161-3, 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
Texas State Department of Highways and Public Transportation
in Cooperation with the
U.S. Department of Transportation
Federal Highway Administration

Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843

October 1990

ABSTRACT

A three-year study of urban arterial work zones is currently in progress. The objective of the study is to develop improved guidelines for selecting and implementing work zone traffic control on urban arterials. The second year study efforts are documented in a three volume report. The Technical Report appears in Volume 1. This document is Volume 2 and contains the Appendices for Volume 1, and Volume 3 contains the data used in the research analysis.

This volume includes the appendices describing study activities in the following areas: literature review, study site selection, data collection and analysis, motorists' surveys, and review of current practice.

The study activities of the first two years confirm the need for improved guidelines. Current research and guidelines do not thoroughly address the topic. A survey of local agencies indicates a variation in the significance given to work zone traffic control on arterials. Traffic data indicates a decrease in traffic performance in the vicinity of the construction zones studied. Surveys of motorists indicated they do not fully understand all construction signs and are concerned about the impacts of the construction on their mobility.

The preliminary findings and preliminary guidelines included in Volume 1 address a number of problem areas related to urban arterial work zones including traffic signals, left turns, lane widths, accidents, construction activities, driver needs, and public relations.

IMPLEMENTATION STATEMENT

This study was sponsored by the Texas State Department of Highways and Public Transportation with the major objectives of establishing a comprehensive work zone speed control design process and developing improved traffic control guidelines applicable to urban arterial work zones. The results of this research effort will provide more uniform implementation of work zone speed zoning and speed control measures as well as lead to improved operations, and safety for both workers and drivers in urban arterial work zones.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the Texas State Department of Highways and Public Transportation. This report does not constitute a standard, specification, or regulation.

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SUMMARY

Urban arterials are being required to carry a greater traffic load than in the past. Therefore, arterial construction has increased in order to provide additional capacity for the vehicular demand. The SDHPT has established the PASS (Principal Arterial Street System) program for the upgrading of major arterial streets. The resulting construction has led to a recognition of the lack of adequate guidelines for work zones on urban arterials.

One objective of this three year research study is to develop improved guidelines for selecting and implementing work zone traffic control on urban arterials. Study activities during the first two years include a literature review, selection of study sites, data collection at three study sites, two motorists' surveys, and a review of current practice. The data collected as part of this study includes traffic volumes, travel times, and accident histories.

Second year efforts related to the urban arterial work zone study are documented in three separate reports. Research report 1161-3, Volume 1, "Traffic Control Guidelines for Urban Arterial Work Zones - Technical Report" provides a brief description of research activities and includes the preliminary findings and preliminary guidelines developed during the first two years of study. Research report 1161-3, Volume 2, "Traffic Control Guidelines for Urban Arterial Work Zones - Appendices" (this document) contains several appendices which provide additional detail about specific research activities summarized in Volume 1. Research report 1161-3, Volume 3, "Urban Arterial Work Zone Data" contains data and supporting documentation related to the study sites and surveys.

Early research efforts focused on identifying and evaluating reference material addressing urban arterial work zones. The literature review indicated a discrepancy between the availability of research information on freeway and rural highway work zones, and that on urban arterial work zones.

Early in the research study, three study sites were identified where appropriate data could be collected. The study sites selected include a 7 mile segment of F.M. 1960 in

Houston, 6 miles of S.H. 6 in Houston, and a 2 mile segment of Abrams Road in Dallas. Data collected at the study sites includes traffic volumes, travel times, and accident records. Data has been or will be collected during the preconstruction and construction periods at most of the study sites. Preliminary analysis of the data was used in identifying preliminary problems and preliminary guidelines.

Two motorists' surveys were conducted in conjunction with this project. The first survey was administered on F.M. 1960 in Houston and the second on Abrams Road in Dallas. Both surveys were similar in format and delivery. The surveys were developed to ascertain knowledge about work zone signing in general, determine confusing or problematic areas of the signing, and elicit information from motorists about construction project concerns that may not be related to the understanding traffic control devices. The surveys were conducted at shopping areas and drivers license offices by asking participants to respond to a series of pictures and questions related to the work zone in the area of the survey.

Discussions were held with city and state traffic personnel in order to determine the current practice of traffic control on urban arterial work zones. A survey was conducted of traffic engineers from local transportation agencies. A survey of city traffic engineers indicated that there is variation in the degree in which urban arterial work zone traffic control is stressed. Several of these individuals indicated the Texas MUTCD did not sufficiently address work zone traffic control on urban arterials.

The research activities of the first and second year have identified a number of preliminary findings related to urban arterial work zones. These findings are listed in Volume 1. Most of the issues identify areas where guidelines may result in improved safety and efficient arterial work zones. Three categories have been developed for classifying the major issues: 1) traffic control and operations, 2) construction activities, and 3) driver needs.

Preliminary findings related to traffic control and operations address traffic signals, left turns, lane widths, pedestrians, traffic diversion, accidents, and transit. Preliminary findings related to construction activities address lane striping, barriers, lane closures, scheduling, crossovers, and grades. Preliminary findings related to driver needs address street signing, business signing, enforcement, and public relations.

An analysis of the preliminary findings led to the development of preliminary guidelines for use on urban arterial work zones. The preliminary guidelines are found in Volume 1 and are divided into those related to the traffic control plan, traffic control devices, construction or contractor activities, and public relations.

One year of research remains on this contract. Activities during the third year will include continuing previous study efforts and performing additional activities to evaluate the preliminary guidelines contained in this report.

APPENDIX A
LITERATURE REVIEW

Obtaining and evaluating available research material is a crucial task in developing guidelines for urban arterial work zones. One of the early project efforts was to conduct a literature search to collect reference material which addressed urban arterial work zones. The reference material was then evaluated to determine its applicability to the project.

The literature search was initiated with a computerized search of the Transportation Research Information Service (TRIS) data base. The citations identified by the search addressed a wide variety of issues related to work zones. These citations were evaluated to determine those which might contain information related to urban arterial work zones. The study team then obtained as many of the pertinent citations as possible. The reference lists of these papers were then evaluated to determine if additional research information was available. Other published material was also reviewed.

The literature review indicated that there is a discrepancy between the availability of research information on freeway and rural highway work zones, and that on urban arterial work zones. Nevertheless, a number of references were found to contain some degree of pertinent information about the desired subject matter. The most important documents are described in the following subsections.

Manual on Uniform Traffic Control Devices

The *Texas Manual on Uniform Traffic Control Devices* (MUTCD) (1) 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. The Texas MUTCD addresses devices in individual sections, such as regulatory signs, warning signs, signals, markings, and others. 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 (2) containing exactly the same information found in Part VI of the entire Texas MUTCD.

The 1980 Texas MUTCD is based on the *National Manual on Uniform Traffic Control Devices* (3). The Texas MUTCD basically follows the National MUTCD, although some modifications have been made to meet State laws or more closely fit conditions in Texas. References to the MUTCD in this report refer to the Texas MUTCD, unless otherwise noted. A new edition of the National MUTCD was released near the end of the first year of this study. The revisions included in this new edition have not yet been incorporated into the Texas MUTCD.

The construction and maintenance section of the Texas MUTCD sets forth basic principles and prescribes 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.

There are seven subsections to Part VI of the Texas MUTCD, as shown in Table A-1. Each of these subsections addresses specific control devices and/or the use of those devices. There is no section directly addressing traffic control on urban arterials, as there is with expressways and limited access facilities. However, urban conditions are addressed briefly in the introductory subsection 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 section, the term street refers to all the streets in any municipality, including cities, towns, villages, or other local jurisdictions.

Table A-1. MUTCD Part VI Subsections

A.	Introduction and General Specifications
B.	Signs
	General
	Regulatory
	Warning
	Guide
C.	Channelizing Devices
D.	Markings
E.	Lighting Devices
F.	Control of Traffic Through Work Areas
G.	Expressways and Limited Access Facilities

- 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 encroachments by adjacent building construction. Work on arterial streets should be restricted to off-peak hours to minimize conflicts with traffic.
- In situations not adequately covered by the provisions of the MUTCD, 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 subsections of Part VI address the specific use of individual traffic control devices. In most instances, the use of devices are described for a highway type environment. There are some cases where traffic control for low-speed or intersection work zones is addressed. Urban streets are addressed by using speed to determine spacing of devices. The lower speeds found on urban streets generally require shorter spacing of traffic control devices.

Part VI of the National MUTCD is currently undergoing a revision process. The 2nd draft of revisions (4) indicates a small increase in referencing urban area construction zones.

However, the additional material does not address many of the problem areas related to urban arterial work zones. It should be noted that the proposed revisions have not been adopted and may change substantially before being officially adopted. Proposed references to urban arterial work zones include:

- Work on arterial streets should be restricted to off-peak hours to minimize conflicts with traffic.
- When calculating minimum desirable taper lengths, for residential and urban streets, the formula $L = W \times S^2/60$ should be used.
- In urban areas, post-mounted signs shall be mounted laterally at a minimum of 2 feet from the edge of the traveled way, and shall be a minimum of 7 feet to the bottom of the sign. 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.
- On city streets with more congestion and lower speeds, advance warning signs may be spaced at closer intervals.
- Urban traffic control zones may be subdivided 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 should be provided.

The 1961 edition of the National MUTCD (5) included, for the first time, an extensive special treatment of traffic control devices for highway construction and maintenance operations. One section of this part of the 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, as follows:

- The general principles outlined in this section of 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 traffic volumes, limited maneuvering space, frequent turns and cross movements, and a significant pedestrian movement. 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.

Traffic Control Devices Handbook

The *Traffic Control Devices Handbook* (6), developed in 1983, is primarily intended to augment the National MUTCD by serving an interpretative function. The Handbook offers guidelines for implementing the standards and applications contained in the National MUTCD. It should be noted that the requirements of the National MUTCD take precedence over the Handbook in all cases. The part of the Handbook 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. The Handbook addresses urban arterial work zones in greater detail than the National MUTCD. Throughout this section of the Handbook, 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:
  - 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.

The Handbook also addresses typical applications or layouts for work zone traffic control for different situations. One of these typical applications is for urban areas. Pedestrians, bicycles, and intersections are also addressed. Diagrams of typical work zone layouts for different situations are provided and some of the major concerns are briefly mentioned.

City Transportation Manuals

The City of Austin has the part of their *Transportation Criteria Manual* (7) which deals with traffic control and work zone safety available as a separate document. This 47 page manual is intended to assist contractors in the proper use of traffic control devices in urban work zones. It addresses work zone safety in Austin with the following sections:

1) Procedures
2) Requirements
3) Work Zone Traffic Control Devices
4) Typical Applications
5) Maintenance and Inspection

The Austin manual is intended to supplement the MUTCD, recognizing that the MUTCD is the primary manual governing work zone traffic control on public streets. Unique aspects of the Austin manual include:

- Identification of a downtown urban area with restrictions on work zone activities, including:
  * Time restrictions.
  * Temporary lane closures.
  * Pedestrian protection.

The Austin manual addresses the use of various traffic control devices in work zones, describing many of the devices and typical applications. Most of this information is a repeat of the MUTCD, but the City of Austin has also added their own requirements, such as the number of signs and placement of signs at a work zone and requirements for bore pits.

The City of Arlington has developed a *Work Area Traffic Control Manual* (8) which deals with all aspects of urban area work zones. This manual requires all traffic control be in compliance with the most recent Texas MUTCD. The information in these sections repeats the most important aspects of Part VI of the MUTCD. The manual also requires a traffic control plan to be submitted to the city for any construction work on or adjacent to any public roadway. The manual is subdivided in different sections including:

1) Obtaining Approval to Work in City Streets
2) Contractor Responsibility
3) Traffic Control Devices
4) Types of Barricades
5) Types of Signs
6) Lighting Devices
7) Flaggers or Policemen
8) Other Traffic Control Measures
9) Temporary Facilities
10) Pedestrian Protection in a Construction Area
11) Illustrations
12) Ordinances

The City of Fort Worth has developed a similar manual entitled *Traffic Control Handbook for Construction and Maintenance Work Areas* (9). This manual addresses time restrictions, thoroughfare listings, and contractor responsibility. It also states that all traffic control devices shall conform to the requirements in the Texas MUTCD. The manual is intended to educate:

1) All City Employees
2) Contractors

3) Public Utility Companies
4) All those whose work affects roads, streets, and highways within the Fort Worth city limits.

The City of Victoria has a *Manual of Uniform Barricading Standards* (10). It addresses all types of construction barricades along with traffic control device application. The Victoria manual contains most of the same information as the MUTCD, although the format is slightly different. Some additional information on the use of devices in work zones in Victoria is also included. The manual addresses:

1) Construction Guide Signs
2) Traffic Control Devices
   a. Barricades
   b. Cones
   c. Drums
   d. Vertical Panel
   e. Delineators
   f. Pavement Markings
   g. Channelization
3) Construction Lighting
   a. Floodlights
   b. Electric Lights
   c. Hazard Beacons
   d. Barricade Warning Lights
   e. Lanterns and Torches
4) Flagging Procedures
5) Typical Detour Signing and Barricade Application

Research Reports

"Safety Design and Operational Practices for Streets and Highways" (11) is a report prepared by the Texas Transportation Institute in 1980 for the Federal Highway Administration. It addresses 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 is addressed briefly in several locations. These are restated as follows:

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 become 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.

Control Device Selection Criteria

The type and extent of traffic control depends to a considerable degree on the classification of the roadway and the area in which the work is located. On urban streets, traffic control may be complicated by the proximity of intersecting streets, the need to provide access to abutting property, and in general, the many more possible movements desired by motorists.

A 1981 study, "Effectiveness of City Traffic-Control Programs for Construction and Maintenance Work Zones" (12) evaluated the present state-of-the-art of city traffic control programs for construction and maintenance work zones. The study consisted of two efforts; a survey of 49 cities and field inspections of work zones in eight of the cities. The general findings were that the importance of traffic control programs varied widely and the majority of the cities surveyed do a less-than-adequate job in controlling construction and maintenance activity.

This study cited a report by the U.S. General Accounting Office (GAO) (13), which reviewed efforts by the Federal Highway Administration to increase safety through road construction work zones. The study found that at all levels:

- Officials did not always know how to make work sites safe.
- They did not always appreciate the need for safety.
- They placed higher priority on construction quality, economy, and deadlines, than on work zones.

The GAO review recommended that the National MUTCD be revised to include specific management guidelines for the implementation of traffic control measures and devices in construction zones. The report stressed the lack of guidance available on matters of specific applications.

Existing city programs were analyzed through a questionnaire along with field investigations of sites. The questionnaire was sent to 100 cities with populations between 50,000 and 1,000,000. It consisted of a series of twelve questions addressing four general areas:

- Permit and authorization procedures.
- Development, approval, and implementation of a traffic control plan and field inspection.
- Enforcement and training policies.
- General problems and areas for improvement identified by the cities.

Evaluation was split into two groups; answers to five rated questions which determined how active a role the cities had in regulating the traffic control for construction and maintenance activity, and seven nonrated questions which determined what the typical practices were. A significant finding of the study was that, despite the fact that the majority of cities' traffic control programs were less than satisfactory, 60% thought they had an adequate program. The findings also indicate 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 field investigation was conducted using a panel of traffic control experts to review slides of construction and maintenance zones in eight of the survey cities. Deficiencies at each of the work zones were ranked on 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.

This research is significant because it indicates that there is a weakness in urban traffic control. The reason for the weakness is not fully apparent from the questionnaire results. However, the results do indicate that cities 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" (14) 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 sites were selected for evaluation, one of which was an urban arterial.

The urban arterial work zone involved the construction of an urban interchange. An overpass was constructed over the cross street. Frontage roads were located on the overpass street. Comparisons between the Traffic Control Plan (TCP) and the field reviews of the work zone revealed evidence of the following:

- 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.

The majority of the analysis used speeds in different sections of the work zone to evaluate the effectiveness of the traffic control devices. The conclusions indicate: some confusion with work zone traffic control, TCP frequently not developed with full consideration of actual site conditions, unreliable motorist response to advisory speed signs, inadequate design standards for on-site detours, and problems with maintaining traffic control devices.

The conclusions of the study included:

- 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.

The general recommendations contained in this study are:

- 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 the overuse of unwarranted traffic control devices.
- Establish an ongoing program of field evaluation of the effectiveness of implemented traffic control plans.
- Continue to provide training in work area traffic control for field personnel.

A recent study (15) describes the development of a computer based methodology for the evaluation of traffic control systems at arterial street lane closures in the vicinity of signalized intersections. This effort was necessary in order to develop measures-of-effectiveness for evaluating urban arterial work zones.

The study conducted a review of previous research concerning the evaluation of arterial street lane closure performance. It found that no literature is available with respect to determining delay in work zones on arterials. The goal of the study was to develop a ranking procedure for the variables that affect traffic flow quality at arterial street lane closures.

The result of the study is the ARTWORK microscopic computer model. The model calculates the movement of individual vehicles through a work zone and the vehicles' reactions to the roadway, traffic control devices, and traffic signals. The model can only simulate movement through a two intersection system, with the work zone located slightly upstream of the second intersection. The model was found to represent true system behavior closely enough to be used as a substitute for the actual system.

The only research which specifically addresses urban arterial work zones in detail was performed by the Virginia Transportation Research Council (16). The objectives of this study were to: 1) analyze accident data for urban work zones in Virginia, 2) identify traffic characteristics that have significant impact on these accidents, 3) evaluate traffic control devices commonly used in urban work zones, and 4) develop guidelines for selecting devices for controlling traffic in 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 effect) 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 that 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 indicated that the most effective combination of traffic control devices for urban multilane work zones are cones, flashing arrows, and flagmen.
- Statistical analysis of accident and traffic control data also indicated that accident frequency was higher when barricades were included with 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 indicated that the most effective combinations of traffic control devices on urban two-lane highways are cones and flagman or static signs and flagman. The analysis also showed that flaggers are a very effective means of traffic control on urban two-lane work zones.

One paper, "Identification of Needed Traffic Control Device Research," (17) identified the need for additional traffic control devices research. This paper is based on a study performed by COMSIS Corporation for the FHWA (18). The study recognizes the fact that many traffic control device standards are based on subjective opinion and warrant further study. Of particular interest is the issue of the color of construction and maintenance signing. The study concludes that controversy continues regarding the adequacy of orange signs in terms of both perception and comprehension. The relative visibility and legibility of orange signs has been questioned.

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," (19) 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 survey concluded that:

- 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.

Shortcourse Materials

The American Traffic Safety Services Association has developed a shortcourse notebook, *Traffic Control in Urban and Utility Work Areas* (20) which addresses work zone control in a general manner. The course focuses on work performed by utility companies and municipal service organizations which install and maintain facilities within public streets and highways. For the most part, the notebook repeats information in the National MUTCD and the Traffic Control Devices Handbook.

Topics addressed in this notebook include:

- Devices used in utility work zones.
- Device location and placement.
- Designing traffic control zones.
- Planning and installing traffic control zones.
- Operating and managing work zones.

The notebook specifically addresses the problems of urban arterial work zones in a limited fashion. It states that high-speed urban arterials should be treated in a similar manner to that used for open highways. The required distances on low-speed, low-volume minor streets can be shortened and the number of advanced warning signs can be reduced from three to two. Urban work zone problems mentioned in the notebook include: intersections, driveways, pedestrians, and detours. Several diagrams for work zone situations on urban streets are shown.

Conclusions from 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. Additional research material will be evaluated as it becomes available. There are no plans to perform additional searches of data bases for research material.

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 which were identified in the literature review include:

- Work on arterial streets should be restricted to off-peak hours to minimize conflicts with traffic.
- When calculating minimum desirable taper lengths, for residential and urban streets, the formula $L = W \times S^2/60$ should be used.
- On city streets with more congestion and lower speeds, advance warning signs may be spaced at closer intervals.
- 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 traffic volumes, limited maneuvering space, frequent turns and cross movements, and a significant pedestrian movement.
- Rule of Thumb for Sign Spacing: 250 feet for urban streets with speeds under 40 mph; 500 feet for urban arterials with speeds over 40 mph.
- 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.
- 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.

- Although there is a general lowering of average speeds during reconstruction, speed variance tends to increase during work zone activities.
- Statistical analysis of accident and traffic control data indicated that the most effective combination of traffic control devices for urban multilane work zones are cones, flashing arrows, and flagmen.
- Statistical analysis of accident and traffic control data also indicated that accident frequency was higher when barricades were included with 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 indicated that the most effective combinations of traffic control devices on urban two-lane highways are cones and flagman or static signs and flagman. The analysis also showed that flaggers are a very effective means of traffic control on urban two-lane work zones.
- Mechanical means should be employed at all construction zones to force drivers to slow down.

APPENDIX B
STUDY SITE SELECTION

A total of 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 are F.M. 1960 and S.H. 6, which are both located in Houston, Texas as shown in Figure B-1. The construction at these sites began during the first year of this research study. The third project site is Abrams Road located in Dallas, Texas as shown in Figure B-2. The construction began in July 1989. The Abrams Road site represents a change from the original choice of a study site in the Dallas area. During the first year of the study, Skillman Avenue was selected as the study site. However, there were several delays in getting the project out for bid and the project principal investigator and technical coordinator determined that it was desirable to change the study site to Abrams Road.

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 B-1. Figure B-3 provides a plan view of the roadway construction sequence. Typical cross sections for each phase of construction, are shown for F.M. 1960 and S.H. 6 in Section V of Volume 3.

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.

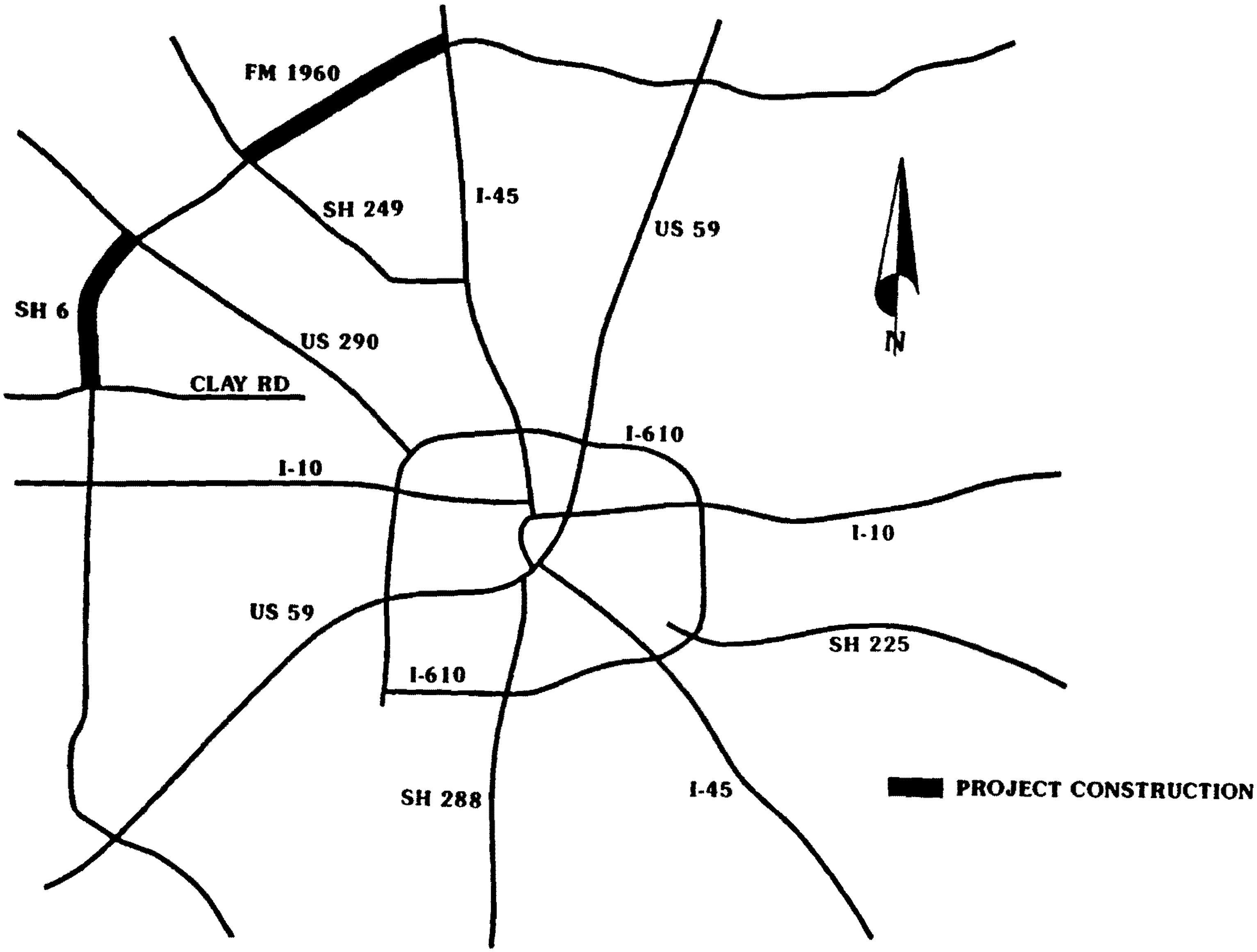

Figure B-1. F.M. 1960 and S.H. 6 Study Site Locations

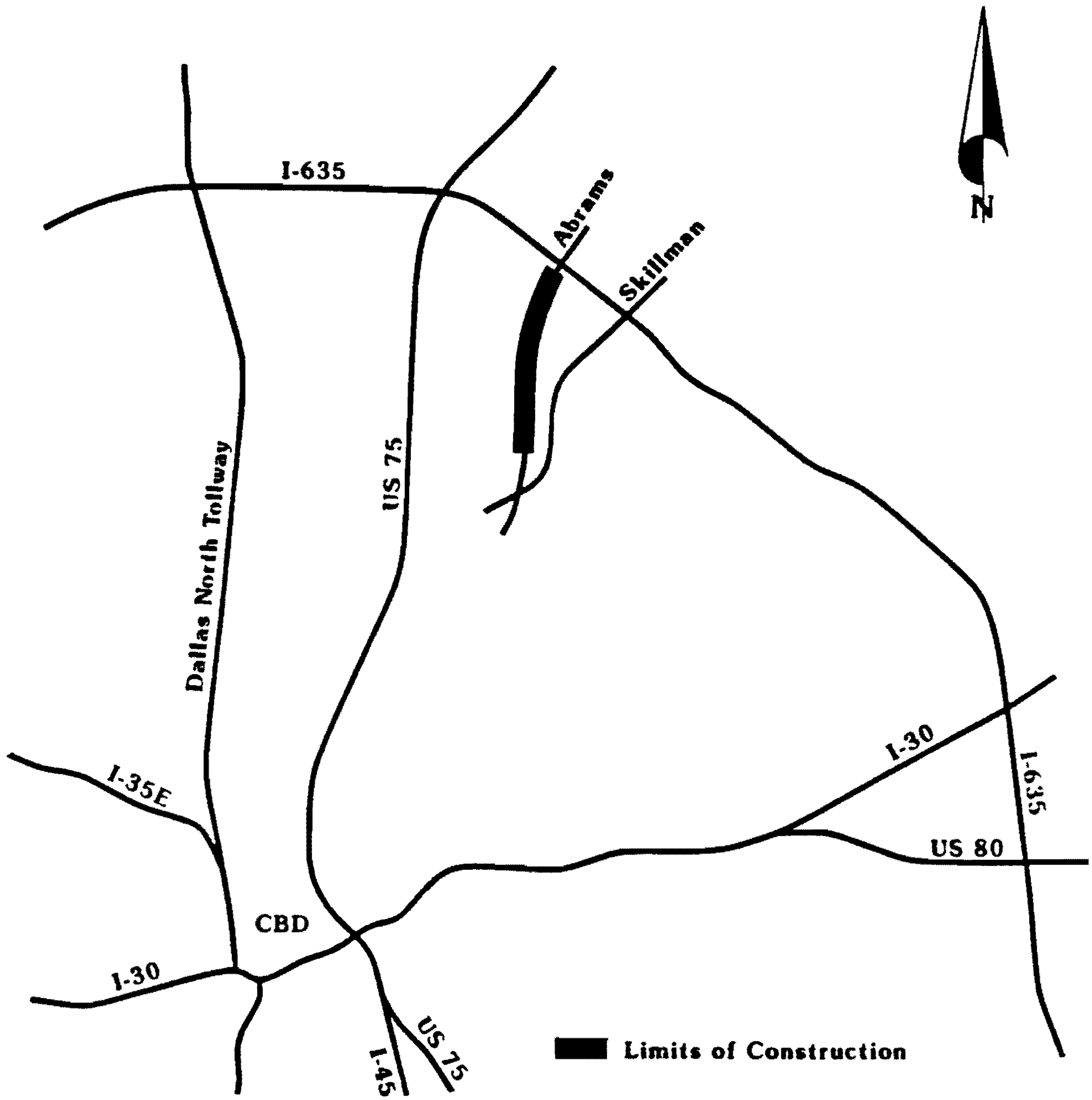

Figure B-2. Abrams Road Study Site Location

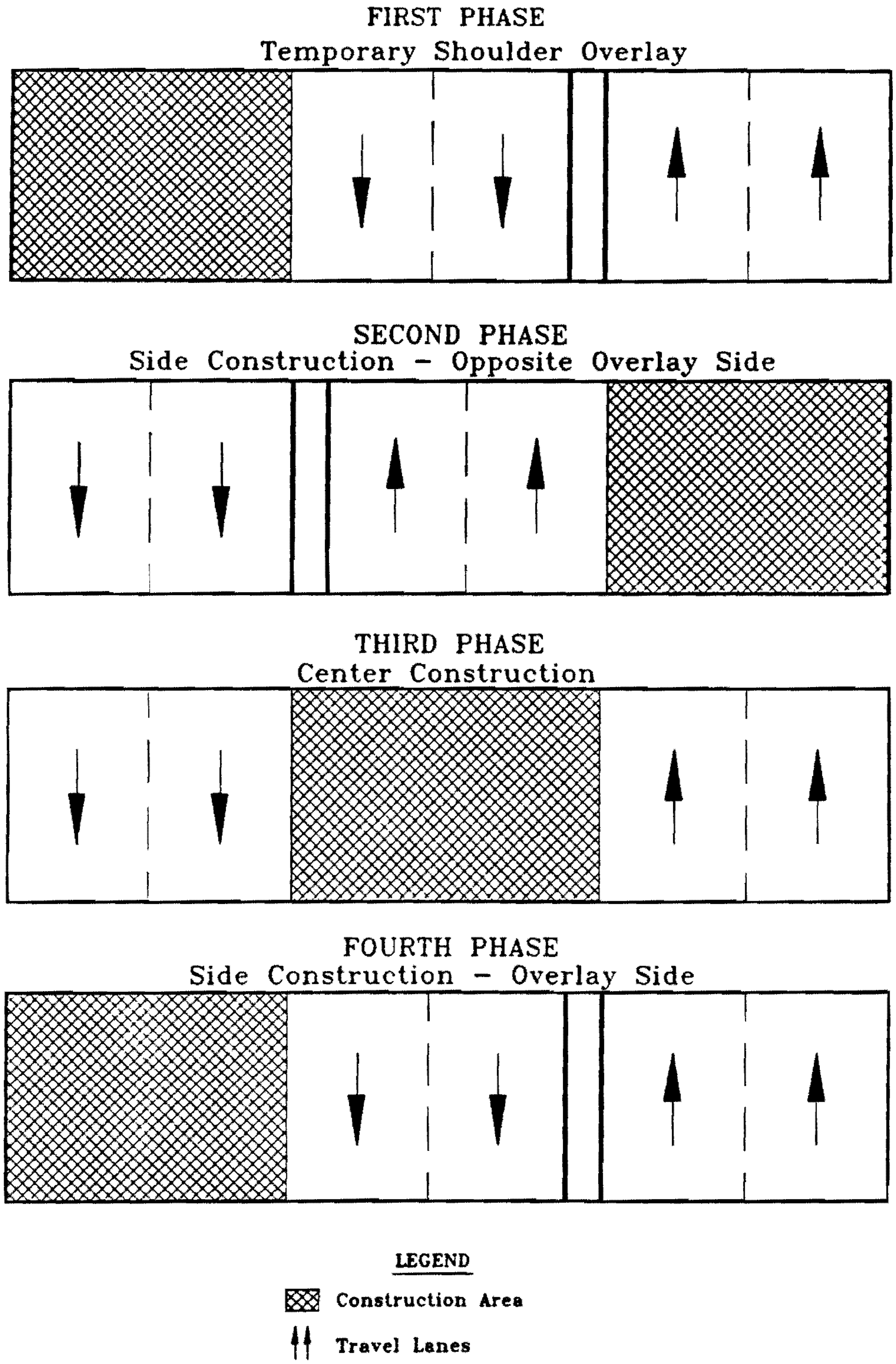

Figure B-3. Typical Construction Phasing

Table B-1. 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.

Construction at the F.M. 1960 study site is now complete. The construction study site was approximately seven miles long and was located between I.H. 45 (North Freeway) and S.H. 249, as shown in Figure B-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.) front 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 B-1 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 B-2 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 plan that accelerated progress was the use of high early strength concrete on intersections and driveways.

Table B-2. F.M. 1960 Construction Schedule

Phase	Date 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 extends from U.S. 290 (Northwest Freeway) south to Clay Road, as shown in Figure B-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 is approximately six 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 are 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 will include three lanes in each direction with a center continuous left-turn lane. The planned time to complete the construction is less than three years. The project is split into three segments as listed in Table B-3.

Each segment includes four phases of construction. The description and layout of each phase is identical to that of Table B-1 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 B-3 shows the progress of construction by segment and phase. S.H. 6 is currently in the fourth phase for Segments 1 and 2 and in the third phase for Segment 3. The project is scheduled for completion in Spring 1991.

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

Segment	Phase	Date of Construction
1 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*
2 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*
3 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*

* Scheduled Phase Change

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 B-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 summer of 1991.

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 B-4 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 B-4. Abrams Road Construction Schedule

Segment	Phase	Date of Construction
Northern	First	7/89 - 9/89
	Second	9/89 - 6/90
	Third	7/90 - 12/90*
	Fourth	1/91* - 7/91*
Southern	First	7/89 - 9/89
	Second	9/89 - 9/90
	Third	10/90* - 12/90*
	Fourth	1/91* - 7/91*

* Scheduled Phase Change

APPENDIX C
DATA COLLECTION AND ANALYSIS

After study sites had been selected for evaluation, the data collection process began. Data collection took place before, during, and when applicable, after construction so that changes in traffic conditions could be documented. The data collected included such information as daily and peak hour traffic volumes, travel times, and accident history. Turning movement volumes were also collected in limited situations.

As previously mentioned, the F.M. 1960 project is complete, S.H. 6 is currently in the third and fourth phases in different segments, and the Abrams Road project is currently in the third phase. The most extensive data collection and analysis has been performed on the F.M. 1960 project.

Traffic Volume Data

Automatic traffic counters were used to collect 24 hour data from Monday afternoon to Friday morning at all three study sites in order to obtain average weekday roadway volumes during each phase of construction. In most instances, two counters were placed at each location to insure accuracy against low or high counting. Averages were computed from the daily volumes to obtain one volume per roadway segment per phase. From this data, a morning peak period volume from 6:00 - 9:00 A.M. and an evening peak period volume from 3:00 - 7:00 P.M. were calculated.

F.M. 1960

Volumes were collected on four segments of F.M. 1960 as well as on the cross street approaches of three major intersections with F.M. 1960. Since this research study was initiated at approximately the same time as construction on F.M. 1960 began, the availability of preconstruction data is limited. However, daily traffic volumes from 1986 and 1987 were obtained and have been included for comparison. A comparison of the average weekday two-way traffic volumes within the F.M. 1960 study area is illustrated in Figure C-1.

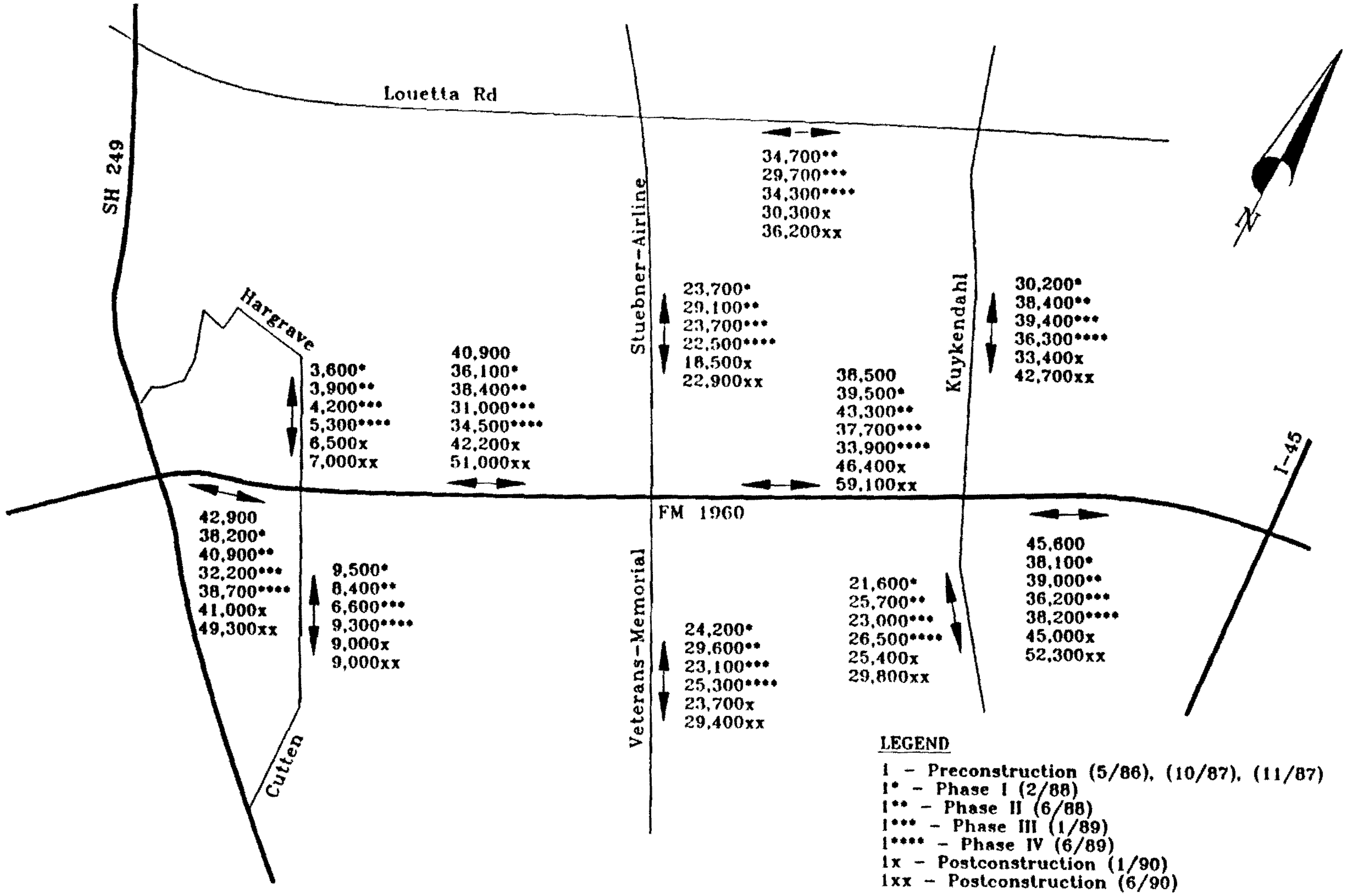

Figure C-1. Average Weekday Traffic Volumes, F.M. 1960

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 preconstruction levels. The post construction data collected in January 1990 indicates that the volumes have returned to preconstruction levels and post construction data collected in June and July 1990 show that traffic has increased above preconstruction levels. Section I of Volume 3 contains graphical representations of the travel volumes in the eastbound and westbound direction for the segments of Cutten Road to Veterans Memorial, and between Veterans Memorial to Kuykendahl. In most locations and directions, the noon hour traffic volumes are close to the 5:00 P.M. peak hour traffic volumes.

The initial decrease in volumes may be the result of driver diversion from the construction area. The motorists' survey in Appendix D discusses driver diversion . Traffic volumes on F.M. 1960 increased as construction entered the second phase. This increase in volume may have resulted from any of the following conditions: 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 efficiency improved, and travel time delays through the work zone were reduced.

During the third phase of construction (construction in the center of the roadway), traffic volumes dropped again. With the construction work area in the center of the road, left turns from both directions must pass across the work zone and visibility is hindered by the drums protecting the work area. The delays associated with these conditions may have led motorists to choose alternate routes or avoid the F.M. 1960 area.

During the fourth phase, the volumes once again increased, but not to the preconstruction level. During the fourth phase of construction, both directions of traffic are on the new pavement. This may have influenced the increase in vehicles using the facility.

Seasonal variability provides another explanation for the variations in traffic volumes. Data collection for the first and third phases occurred during the months of January and February when commercial activity is typically lower. Traffic volumes for the second and fourth phases were collected during the summer months when activity levels are generally higher, especially in a highly commercial area.

Traffic volumes were also collected on alternate routes and on approaches to F.M. 1960. Figure C-1 indicates that the traffic volumes on Louetta, as well as on the approaches to F.M. 1960, behaved similarly to the volumes along F.M. 1960. Traffic volumes dropped during the third phase and increased in the fourth phase.

The potential diversion to Louetta cannot be assessed due to the fact that preconstruction or first phase traffic volumes were not available on this road. The latest post construction volume indicates that traffic has risen above preconstruction levels.

Turning movement counts were also obtained during the morning, off, and evening peak periods. The turning movements observed at the intersections of Kuykendahl, Veterans Memorial and Cutten showed a consistent pattern throughout all the phases of construction. The data collected showed a range of approximately 5 percent from one phase to another. The through movements were approximately 80 percent of the total volume. These manual counts helped to verify the machine count data as well as monitor the turning movements. Figures illustrating the morning and evening peak period traffic volumes for the study area can be found in Section I of Volume 3.

The traffic volumes collected represent a sample from each of the construction phases. On any given day, the volumes in the F.M. 1960 area may fluctuate 5 to 10 percent. These fluctuations must be considered when examining specific data.

Traffic volumes along F.M. 1960 were also collected by District 12 of SDHPT. The volumes which represent Annual Average Daily Traffic are shown in Table C-1 for years 1987, 1988 and 1989.

As Table C-1 indicates, the average daily volumes decreased on every segment of F.M. 1960 from 1987 to 1988 as well as from 1987 compared with 1989. With F.M. 1960 construction beginning in January 1988 and continuing through the end of 1989, this decrease in volume appears to have been attributed to the construction conditions.

Table C-1. F.M. 1960 Annual Average Daily Traffic (AADT)

Roadway Segment	AADT			% Decrease During Construction	
	1987	1988	1989	1987 to 1988	1987 to 1989
S.H. 249 to Cutten	33,000	30,000	30,000	-9%	-9%
Cutten to Veterans Memorial	35,000	31,000	32,000	-11%	-9%
Veterans Memorial to Kuykendahl	33,000	29,000	31,000	-12%	-6%
Kuykendahl to I.H. 45	38,000	36,000	31,000	-5%	-8%

Source: District 12, SDHPT.

State Highway 6

The two-way average weekday traffic volumes for the S.H. 6 project are shown in Figure C-2. As indicated, preconstruction volume data is limited to that collected in 1985 on one roadway segment south of Clay Road. The first phase volumes do not represent a significant change from this preconstruction volume.

However, as the construction continued, the volumes decreased as construction progressed from the first to the second phase. The daily volumes decreased on all three segments. More specifically, the volume between West Road and F.M. 529 decreased by 18 percent, the volume between West Little York and Kieth Harrow decreased by 17 percent, and the volume south of Kieth Harrow decreased by 13 percent. Decreases are again apparent from the second phase data to the third phase data. The data collected for the third and fourth phases in June 1990 shows volumes close to the second phase levels. As four lanes of new pavement were completed, the traffic volumes increased, but not to preconstruction levels. Additional traffic volume data will be collected when all three segments will be in the fourth phase and also when construction is complete.

Morning and evening peak period and hourly volumes for S.H. 6 are illustrated in Section I of Volume 3. The figures show a decrease in volumes as construction progressed. The construction characteristics discussed for F.M. 1960 are assumed to have affected the traffic volumes on S.H. 6. Included are the absence of the center left-turn lane, presence of construction drums, adjacent north- and southbound travel lanes, and narrow lanes.

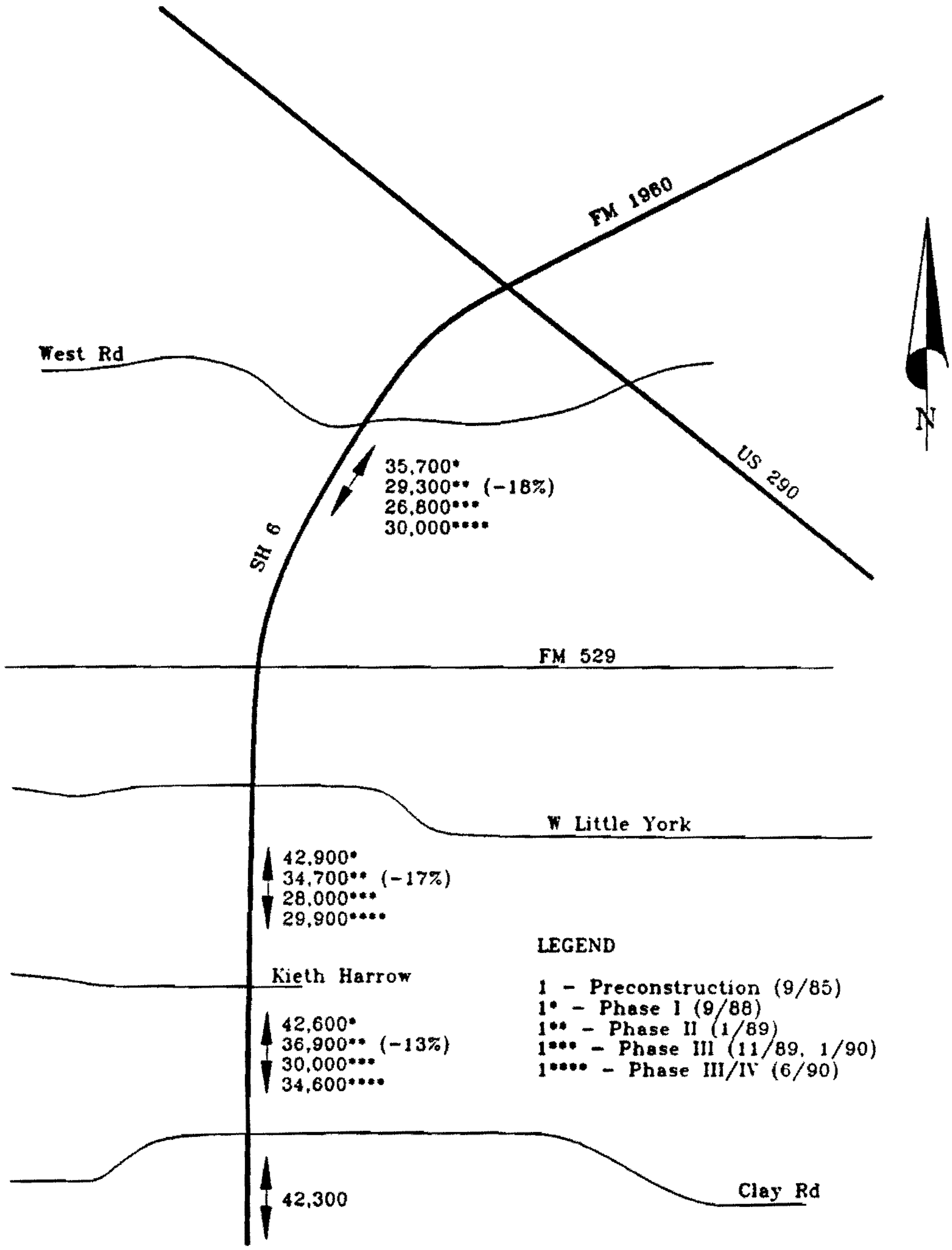

Figure C-2. Average Weekday Traffic Volumes, S.H. 6

Abrams Road

Average daily traffic volumes for the Abrams Road project are shown in Figure C-3. A thorough analysis of these volumes is not possible due to the limited time periods covered. However, most of the daily volumes appear to have decreased from January to July 1990.

A comparison of the two-way average weekday traffic volumes shown in Figure C-3 indicates that July volumes are lower than the January volumes. The exception to this statement is between Royal Lane and Church Street, where an increase of approximately 1,800 vehicles per day has occurred.

The morning and evening peak period data are in Section I of Volume 3. As typical for most urban arterials, the data illustrates that the roadway carries more traffic during the evening peak period than the morning peak period. Traffic volume data collection will continue for this project so that changes in traffic characteristics can be documented.

The morning peak period volumes also decreased from January to July on all segments except between Royal Lane and Church Street. The evening peak period volume resulted in a reduction in all segments along Abrams Road.

An analysis of the directional average weekday traffic volumes indicates the lack of any trend in traffic volume changes. However, a definite trend or pattern is present when analyzing the individual directional morning and evening peak period volumes.

An analysis of directional peak period volumes reveals that the evening peak period volume is higher than the morning peak period. This holds true for all segments along Abrams Road for both the January and July volume counts. This pattern may indicate that Abrams Road is more heavily used by commuters during the homebound trip.

The Whitehurst, Royal, and Church cross-streets also 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

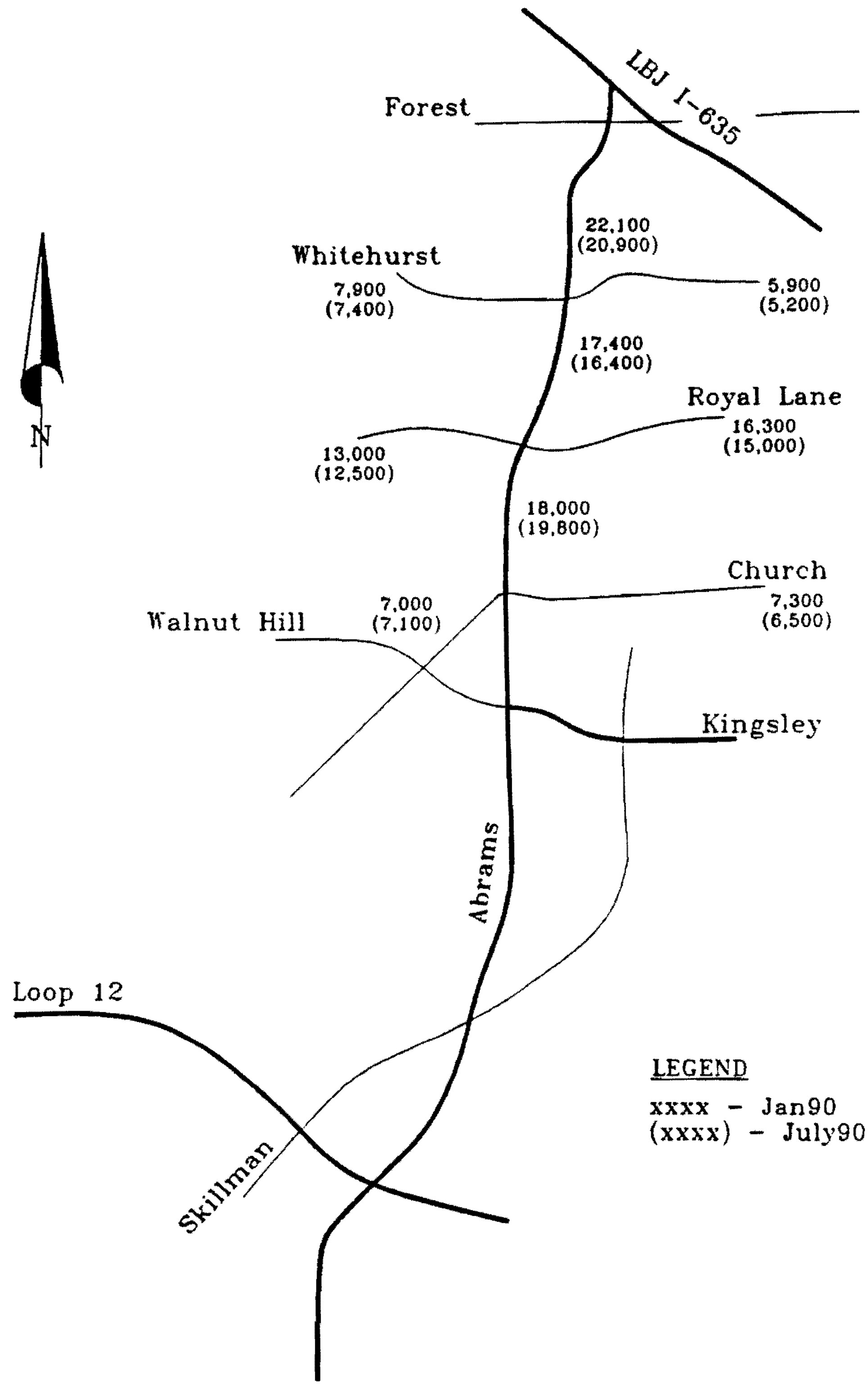

Figure C-3. Average Weekday Traffic Volumes, Abrams Road

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 runs were made on the major arterial at all three sites during the various phases of construction and post construction. 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 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. Tables located in Section II of Volume 3 contain the individual sets of data. It should be noted that the travel time runs are the average travel which include all delays.

F.M. 1960

The travel time data for F.M. 1960 is summarized in Table C-2. As previously noted, preconstruction data is limited. First phase information for travel times is also very limited and therefore, travel time comparisons are based on data from the second phase through post construction.

Table C-2 indicates an increasing trend for average travel times for the eastbound direction during the morning and evening peak periods as construction progressed. The average travel time for the westbound direction remained relatively constant from the second phase to the third phase. However, an increase is noted in the fourth phase for both peak periods. Post construction data illustrates significantly lower travel times in both directions for all time periods.

Table C-2. F.M. 1960 Travel Time Comparison
(Limits from 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 have occurred due to the construction zone 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 Appendix D explains drivers' perceptions of the F.M. 1960 construction conditions.

Table C-2 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 shown to be 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 C-3. As previously indicated, the S.H. 6 project has three roadway segments which are not always in the same phase of construction. Table C-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 C-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 C-3. State Highway 6 Travel Time Comparison
(Limits from 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
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

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.

Abrams Road

Travel time data have only been collected during the second and third phases of construction in January, February, and June 1990, respectively. A table representing the raw data is located in Section II of Volume 3. No significant changes are apparent from the travel time data collected to date. Further data collection is scheduled so that differences in traffic patterns can be documented.

The Abrams Road travel time data does not have a large variance. The travel time and corresponding speeds are roughly the same for morning and evening peak period travel runs. This similarity in travel time may be an indication of smooth traffic/construction interaction or that the work zone is such a short travel distance that a large variance is not possible.

Table C-4. Abrams Road Travel Time Comparison
(Limits from Forest to Kingsley)

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

Accident History Data

The safety impacts of work zones on urban arterials are being assessed by evaluating accident data which has been obtained for the study sites. The accident data for both of the Houston study sites was obtained from the Department of Public Safety (DPS) Master Accident File. This data is a computerized summary of accidents, which can be adapted to many different formats for analysis. It currently includes three years (1985-1987) of preconstruction accident data and two years (1988-1989) of construction accident data. Additional accident data will be obtained during the third year of the study. The 1989 accident data was not available until late in the second year of the study and has not been evaluated as closely as the other data.

Accident data for the Abrams Road site has been 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. As a result, the Abrams Road accident data is not addressed in this report.

Accidents were analyzed by dividing the data into several different categories and comparing the differences between the preconstruction and construction accidents. The categories into which the accidents have been divided include: accident frequency, accident rates, accident types, cause of accidents, and location of accidents. Statistical comparisons between the preconstruction, construction, and post construction period accident data will be made to identify where significant changes in accident categories may be related to construction activities. Because only one year of accident data during construction as been extensively analyzed, changes in trends can not be determined 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 initial accident analysis indicates that the frequency of accidents during the construction period increased significantly when compared to the preconstruction period. Table C-5 shows the total number of accidents that occurred within the project limits of the Houston study sites. The total number of accidents during the construction period represents an obvious increase in accidents, as illustrated in Figure C-4.

Table C-5. Total Accident Frequencies

Roadway	Total Accidents				
	1985	1986	1987	1988	1989
F.M. 1960	730	734	727	1055	923
S.H. 6	198	242	233	329	523

Note: F.M. 1960 construction began January 1988
S.H. 6 construction began September 1988

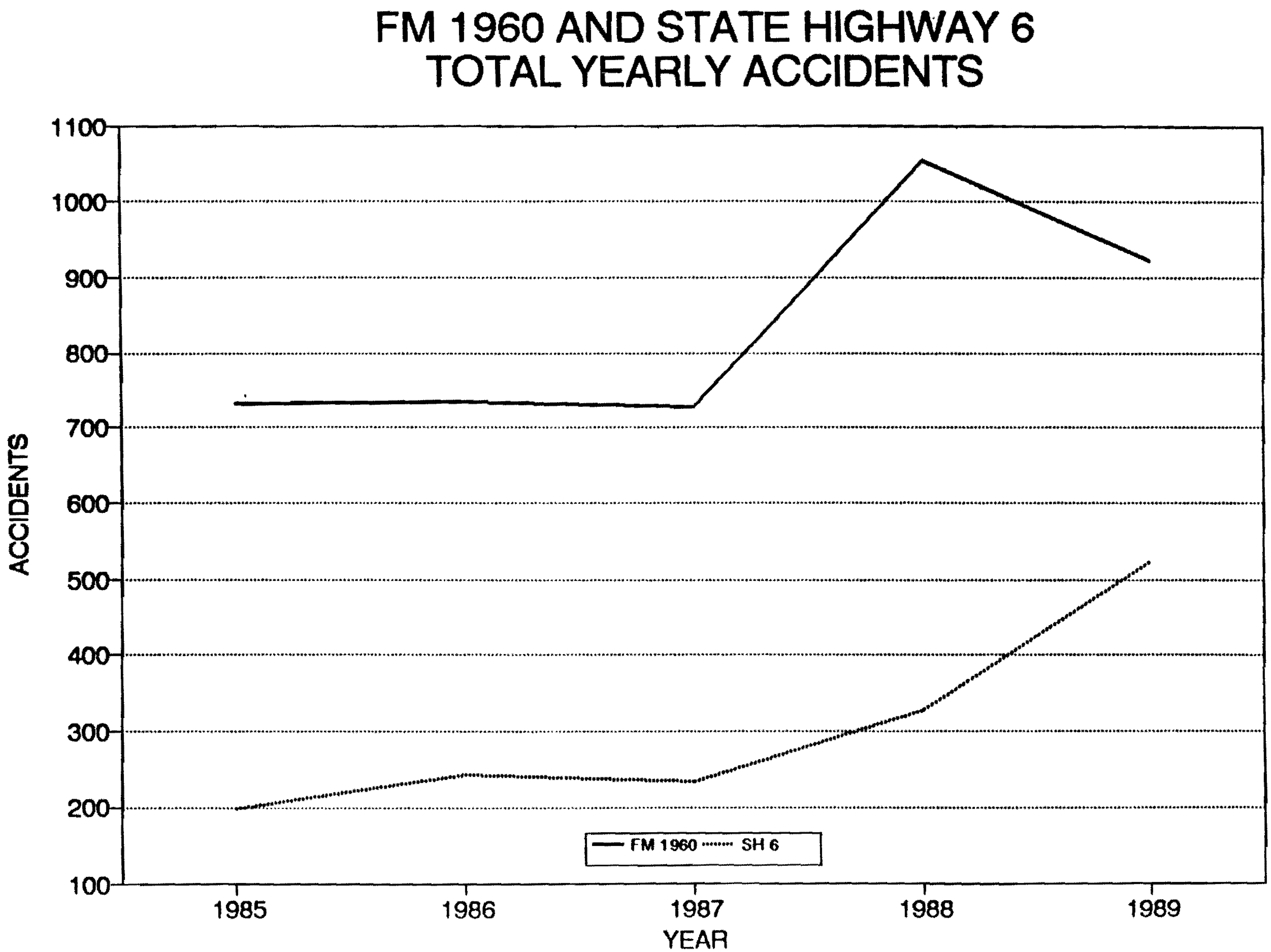

Figure C-4. Total Accidents, F.M. 1960 and S.H. 6

Accident frequency may not accurately portray the relative number of accidents if traffic volumes are not comparable. Therefore, accident rates for the two roadways were calculated in order to compare the relative change in accidents. The accident rates for F.M. 1960 and S.H. 6 are shown in Table C-6. On F.M. 1960, the average of the accident rate (accidents per million vehicle miles) for the two years of construction was 37 percent higher than the average accident rate for the three years preceding construction. Although construction did not begin on S.H. 6 until September 1988, the average accident rate for 1988-1989 was 110 percent higher than the average accident rate for 1985-1987. The accident rates for F.M. 1960 and S.H. 6 are plotted in Figure C-5. This figure graphically illustrates the increase in the accident rate, particularly on S.H. 6.

Table C-6. Accident Rates

Roadway	Accidents per Million Vehicle Miles				
	1985	1986	1987	1988	1989
F.M. 1960	6.11	6.41	6.92	9.03	8.75
S.H. 6	2.55	3.27	3.59	4.68	8.49

Note: F.M. 1960 construction began January 1988
S.H. 6 construction began September 1988

The types of accidents occurring in a work zone provide some indication of the potential problem areas. Table C-7 shows the numbers for four different types of accidents. Table C-8 shows the proportions of the total number of accidents for each type. The proportion of each type of the total number of accidents does not show any consistent change after construction began.

The accidents were also classified by general location, as shown in Table C-9. This data indicates that the majority of accidents occur at or near intersections, or at driveways. There are variations in the proportion of accidents for each location as shown in Table C-10. No definite trends are obvious, although there are some large changes in proportion in some years.

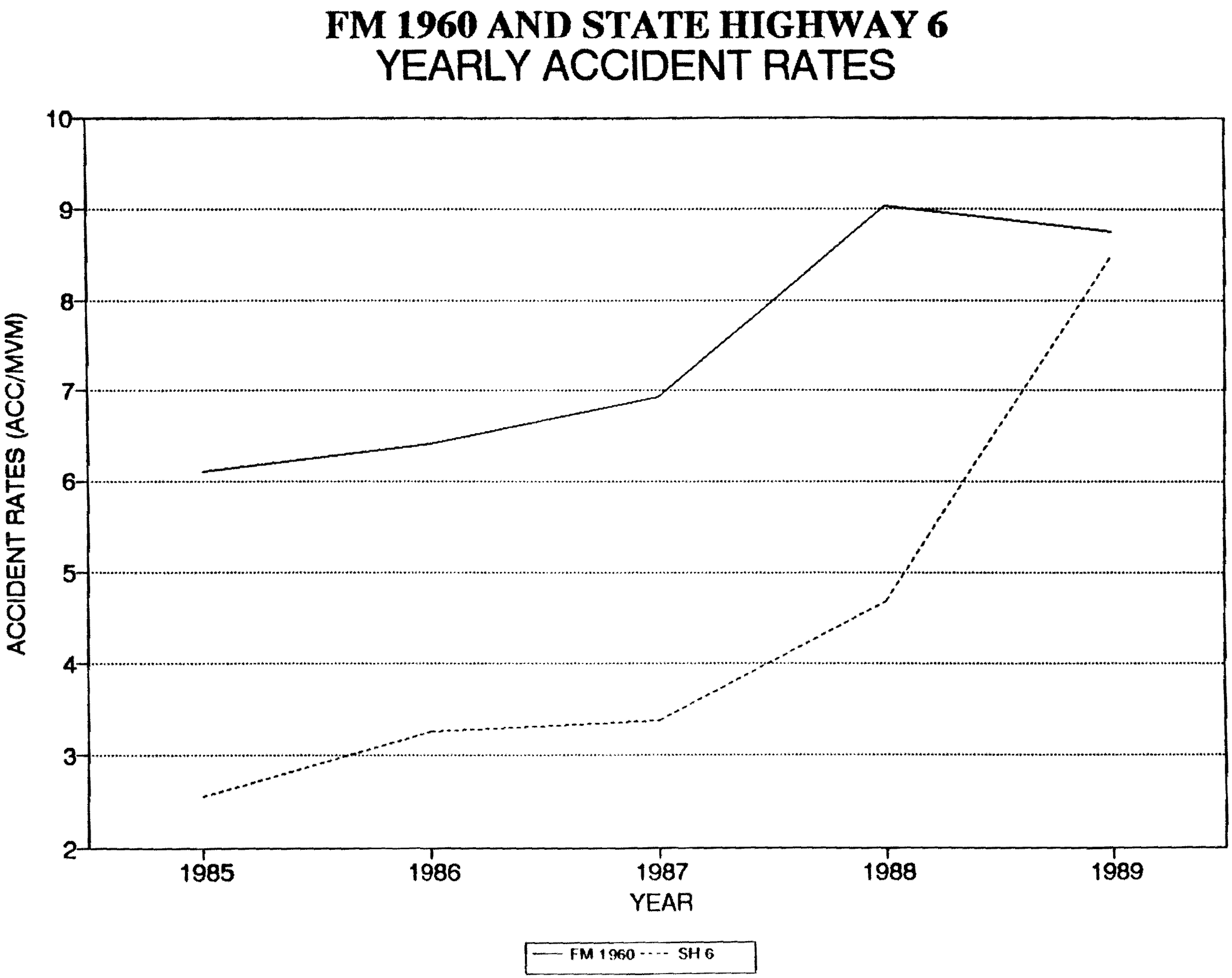

Figure C-5. Accident Rates, F.M. 1960 and S.H. 6

Table C-7. Accident Types

Roadway	Accident Type	Accidents				
		1985	1986	1987	1988	1989
F.M. 1960	Angle	230	253	262	357	269
	Rear End	271	227	260	332	332
	Sideswipe	37	44	32	82	65
	Other	192	210	173	284	257
S.H. 6	Angle	66	91	78	111	200
	Rear End	62	85	88	118	158
	Sideswipe	11	6	15	18	35
	Other	59	60	52	82	130

Note: F.M. 1960 construction began January 1988
S.H. 6 construction began September 1988

Table C-8. Proportion of Accidents by Types

Roadway	Accident Type	Proportion of Total Accidents - Percent				
		1985	1986	1987	1988	1989
F.M. 1960	Angle	32	34	36	34	29
	Rear End	37	31	36	31	36
	Sideswipe	5	6	4	8	7
	Other	26	29	24	27	28
S.H. 6	Angle	33	38	33	34	38
	Rear End	31	35	38	36	30
	Sideswipe	6	2	6	5	7
	Other	30	25	22	25	25

Note: F.M. 1960 construction began January 1988
S.H. 6 construction began September 1988

Table C-9. Accident Location

Roadway	Accident Location	Accidents				
		1985	1986	1987	1988	1989
F.M. 1960	At Intersection	146	169	203	338	288
	Intersection Related	158	124	124	138	141
	Driveway Access	263	281	224	304	254
	Non-Intersection	163	160	176	275	240
S.H. 6	At Intersection	52	69	54	72	184
	Intersection Related	32	55	45	72	77
	Driveway Access	65	81	77	111	151
	Non-Intersection	49	37	57	74	111

Note: F.M. 1960 construction began January 1988
S.H. 6 construction began September 1988

Table C-10. Proportion of Accidents by Location

Roadway	Accident Location	Proportion of Accidents - Percent				
		1985	1986	1987	1988	1989
F.M. 1960	At Intersection	20	23	28	32	31
	Intersection Related	22	17	17	13	15
	Driveway Access	36	38	31	29	28
	Non-Intersection	22	22	24	26	26
S.H. 6	At Intersection	26	29	23	22	35
	Intersection Related	16	23	19	22	15
	Driveway Access	33	33	33	34	29
	Non-Intersection	25	15	24	22	21

Note: F.M. 1960 construction began January 1988
S.H. 6 construction began September 1988

APPENDIX D
MOTORISTS' SURVEYS

Two motorists' surveys were conducted in conjunction with this project. The first survey was administered on F.M. 1960 in Houston and the second on Abrams Road in Dallas. Both surveys were similar in format and delivery.

The surveys were developed to meet the following objectives:

- To ascertain knowledge about work zone signing in general.
- To determine confusing or problematic areas of the signing.
- To elicit information from motorists concerning problems with the construction projects that may not be related to understanding traffic control devices.

More specifically, three concerns were posed: 1) are motorists having difficulties with the construction area due to confusion and/or the number of signs and traffic control devices, 2) are motorists having trouble finding destinations within the construction area due to problems with signing, 3) are primary concerns on the part of users related to traffic control and signing, or are other factors more important? The survey was conducted by personal interview at retail centers and drivers license offices. Participants were asked to respond to signs and work zone scenes and were also asked for their opinion on various aspects of the local arterial work zone.

The surveys indicate that some work zone signs were not fully understood by portions of the Houston and Dallas survey participants.

Houston Motorists' Survey

Complaints and comments from F.M. 1960 users and retailers in the construction area suggested that the high volume of traffic and high proportion of turning vehicles posed problems that warranted further investigation. A previous origin/destination and opinion survey (21) conducted by TTI indicated that additional study of motorists' understanding of the signing used throughout the reconstruction area might be useful in identifying sources of confusion for the motorists along this corridor. A motorists' survey was developed to meet the objectives previously described.

Survey Procedure

Personal interviews were conducted with 205 participants between February 16 and February 21, 1989 at two locations, Willowbrook Mall and the Grant Road Licensing Office of the Department of Public Safety (DPS). Response was strictly on a voluntary basis in the Mall (potential participants were not approached randomly). However, participants at the DPS office were asked to participate in the study. The result was that 115 participants were interviewed at the DPS licensing office and 90 participants were interviewed at Willowbrook Mall.

One segment of the interview was a discussion with the participant on their opinions about various aspects of the reconstruction project. Survey participants were asked to respond to questions regarding work zone signs and other forms of traffic control devices that were presented in a booklet of photographs. This set of questions was followed by a series of photographs or signs and scenes from the F.M. 1960 reconstruction project with corresponding questions. A brief set of biographical questions concluded the interview. The interview time averaged approximately 10 minutes. These survey documents are given in Section IV of Volume 3.

Results

In the first part of these questions, participants were asked to estimate the amount of delay they had experienced as a result of the construction activity. Of those who calculated the delay, in minutes, they had experienced the day of the survey (or on a usual basis), most estimated delay at 5 (22 percent), 10 (21 percent), 15 (22 percent), and 20 minutes (19 percent).

Participants were then asked if they traveled on F.M. 1960 during rush hour and if so, how much delay they experienced during these times. Less than half (45 percent) of those surveyed used F.M. 1960 during rush hour, and the modal response for estimated delay was 30 minutes (27 percent).

When asked if they thought the delay they had experienced was unreasonable, the majority said no. In fact, delays of five to twenty minutes during non-rush hour times were not considered unreasonable by two-thirds of the participants. The reported delay during rush hour was not considered unreasonable by 53 percent of the participants.

The survey also documented that most drivers avoid driving on F.M. 1960 when possible. Eighty-six percent reported the use of other routes because of the construction.

The second part addressed whether motorists were having difficulty locating or getting to their destinations because of the construction or signing in the construction area. Among other questions, they were asked, "*do you have trouble finding certain places you want to go because of the construction?*" Half of the participants said yes and half said no.

Subsequently, drivers were asked, "*are there too many, too few, or the right amount of signs that give directions to places alongside the construction area?*" The response given most often (49 percent) was that there are the right amount of directional signs for the construction area. However, 29 percent said there are too few and 18 percent said there are too many.

One of the objectives of the survey was to determine the relative importance of signing and the motorists' information system as a source of concern for the users of F.M. 1960 during the reconstruction activity. Therefore, survey participants were asked if they believed the signing and channelizing devices used were adequate. The responses were fairly positive overall -- 73 percent said there was the right amount of warning and directional signing, and 70 percent said there were the right number of barrels through the construction area.

When asked to give in their own words their biggest complaint regarding the F.M. 1960 construction area, 9 percent of the 171 who responded mentioned signs, barrels, or confusion. "*The construction is too slow*" was given by 18 percent, and 13 percent said the delay in travel time was their biggest complaint.

Participants were asked to select from a list the biggest problem in the construction area. This provided an opportunity for those who did not articulate a personal complaint to identify the biggest problem in general. The most frequently checked problem was regarding the length of the construction area. Percentages of problems ranked as number one were as follows:

23% -- The construction area (in miles) is too long.
18% -- Difficult to turn.
14% -- The work has taken too long.
13% -- Travel delay.
12% -- Hazardous road conditions.
11% -- General confusion.
9% -- Too much traffic.
1% -- Difficult to find where you're going.
1% -- Signs are confusing.

Participants were invited to comment freely about construction areas in general or about the SDHPT in general. Responses given most often by the 109 participants who chose to comment were complimentary to the SDHPT, for example, "*they're doing a good job, keep up the good work.*" Positive comments about SDHPT were given by 18 percent of those who had a comment to make. Other opinions elicited from this question were: "*they should work faster*" -- 14 percent; "*work zones should be shorter*" -- 10 percent; and "*there are too many roads under construction*" -- 10 percent.

Table D-1 shows a listing of all the questions with their response frequencies.

Table D-1. Houston Questionnaire Response Summary

1. How much did construction delay you in getting to the mall/driver license station today? 22% – 5 min. 21% – 10 min. 22% – 15 min. 19% – 20 min.	2. Was this delay unreasonable? 33% – yes 66% – no 1% – other
3a. Do you drive on F.M. 1960 to work or other places during rush hour? 45% – yes 55% – no	3b. If yes, how much are you delayed by the construction during rush hour? 12% – 10 min. 17% – 20 min. 27% – 30 min.
3c. Would you say that amount of delay is unreasonable? 46% – yes 53% – no 1% – other	4. Are you using other routes to get where you want to go, because of the construction on F.M. 1960? 86% – yes 14% – no 1% – other
5a. Do you think the benefits of widening this road will be worth the inconvenience now? 91% – yes 7% – no 2% – other	5b. If no, why not?
6. Do you have trouble finding specific places you want to go because of the construction? 50% – yes 50% – no 0% – other	7. Are there too many signs, too few signs, or the right amount of signs that give warnings and information about how to drive through the construction area? 9% – too many 14% – too few 73% – right amount 4% – Comments
8. Are there too many signs, too few signs, or the right amount of signs that give directions to places alongside the construction area? (Retail type signs) 18% – too many 29% – too few 49% – right amount 4% – Comments	9. Should there be more, less, or about the same number of barrels through the construction area? 5% – more 22% – less 70% – same number 3% – Comments
10. What is your biggest complaint about the 1960 construction area, if any? 18% – Construction too slow 13% – Delay 9% – Signs/Barrels	11. Do you have any other complaints or comments about the 1960 construction area? 15% – Turning problems 12% – Too much construction at one time 11% – Construction too slow
12. From the list below, what would you say is the biggest problem in the F.M. 1960 construction area? 23% - the construction area (in miles) is too long 18% - difficult to turn 14% - the work has taken too long 13% - travel delay 12% - hazardous road conditions 11% - general confusion 9% - too much traffic 1% - difficult to find where you're going 1% - signs are confusing	
13. Is there anything you would like to add about construction areas in general, or about the State Highway Department in general? 18% – Compliment to SDHPT 14% – Work faster 10% – Too many roads under construction 10% – Work zones should be shorter	
14. Do you prefer roads to have a continuous left-turn lane marked by painted lines on the pavement, or medians with turn lanes cut out of them? 50% – continuous left-turn lanes 50% – medians	

As predicted from previous research (22), the survey revealed that drivers have difficulty interpreting some of the word and symbol messages on signs. This was found to be the case in the motorists' survey of F.M. 1960 users. The following paragraphs and figures address the signs and the field placement of signs that were used in the survey and include brief summaries of the responses to the survey questions. The survey questions are in Table D-2 and Section IV of Volume 3 contains a summary of these questions. The summary includes the question, picture, and responses and percentages of each response.

Road Construction 500 Ft. -- Two-thirds (66 percent) of the survey participants correctly interpreted the sign in Figure D-1, which is intended to provide advance warning of construction located 500 feet beyond the sign. However, one-fourth (25 percent) of the participants incorrectly interpreted the sign as the beginning of a construction area that would continue for 500 feet.

Figure D-1. Advance Road Construction Sign

Participants viewed the same sign in a photographed segment of F.M. 1960. Within the context of the construction area, the percentage of correct interpretations did not increase. In response to the sign presented in Figure D-2, 33 percent of those surveyed said the next 500 feet of roadway are under construction, while 58 percent said construction would be encountered 500 feet ahead.

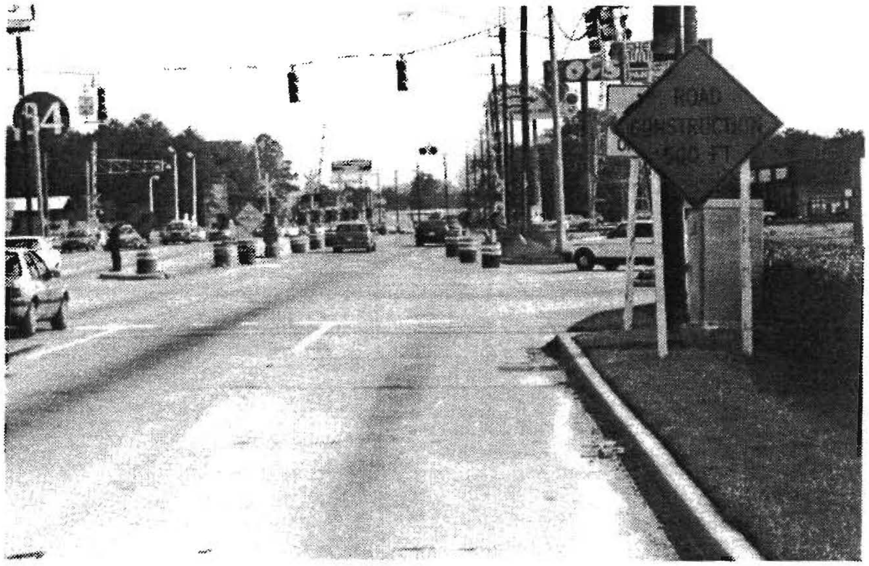

Figure D-2. Field Placement of Advance Road Construction Sign

Advance Flagger Symbol Sign -- In contrast to the advance construction word message sign, the **Flagger Ahead** symbol sign was interpreted correctly more often within the construction context presented by photograph. Figures D-3 and D-4 show the signs as presented to the survey participants. The symbol sign out of context was correctly interpreted by 78 percent of the participants. Within context, interpretation increased to 85 percent. In response to both questions, those who misinterpreted this sign most often said it indicated road construction ahead.

Figure D-3. Advance Flagger Symbol Sign

Table D-2. Houston Sign Questionnaire Summary

1. What do the following signs mean?	
Advance Flagger Sign A. Road construction ahead B. Flagger ahead C. Guard for school crossing ahead D. Not Sure	Lane Reduction Transition Sign A. Median narrows B. Right lane ends C. Right turn lane marker D. Not Sure
DO NOT BLOCK INTERSECTION Sign A. Leave room for crossing traffic B. Move a stalled car from the intersection C. Move through the intersection quickly D. Not Sure	Divided Highway Sign A. Divided road ahead B. Obstacles in the road ahead C. Merging traffic ahead D. Not Sure
NO CENTER LANE Sign A. Drive in the center, the lane is not marked B. Drive in the right lane only C. Be alert for cars stopping to turn left D. Not Sure	Low Shoulder Sign A. Low shoulder B. Uneven pavement C. Bumpy road D. Not Sure
Field Placement of NO CENTER LANE Sign A. Drive in the outside lane only B. You cannot go straight at the next light C. A lane for left turns is not provided D. Not Sure	Field Placement of Lane Reduction Transition Sign A. Left-turn lane marker B. Left lane ends C. Median narrows D. Not Sure
2. What do the orange and white striped signs mean? A. Do not turn between these signs B. Pay special attention to signs on these posts C. Drive to the right of these signs D. Not Sure	3. What does the green sign mean? A. Crossover here B. Crossover at the next signal C. Emergency vehicle cross here D. Not Sure
4. What do the orange/white posts on the right mean? A. Hazardous area on right, drive to the left of posts B. Shows the right edge of the pavement C. Park between these posts D. Not Sure	5. What does the second yellow sign mean? A. Obstacles in the road ahead B. Merging traffic ahead C. Divided road ahead D. Not Sure
6. Are you permitted to turn left in front of the barrel with the crossover sign? ___ yes ___ no ___ not sure ___ other	
7. Are you permitted to turn left behind the barrel with the crossover sign? ___ yes ___ no ___ not sure ___ other	
8. Do you think signs like the Auto Tint sign should be allowed in the construction area? ___ yes ___ no ___ not sure ___ other	
9. Are you permitted to turn right at this intersection? ___ yes ___ no ___ not sure ___ other	
10. Why are these signs different colors?	
11. You are driving the pickup, what should you do at this intersection?	
12. What is you opinion of these red signs?	

Figure D-4. Field Placement of Advance Flagger Symbol Sign

Low Shoulder Symbol Sign -- The correct interpretation of the symbol sign shown in Figure D-5 was very low. The vast majority of drivers (84 percent) thought this sign meant uneven pavement, rather than low shoulder.

Figure D-5. Low Shoulder Symbol Sign

Lane Reduction Transition Symbol Sign -- 16 percent of the participants checked "median narrows" as the meaning of this symbol sign in response to Figure D-6 (78 percent correctly checked "right lane ends".) In response to the photograph in Figure D-7, 10 percent thought the sign was a left-turn lane marker. The correct response was given by 79 percent of the participants.

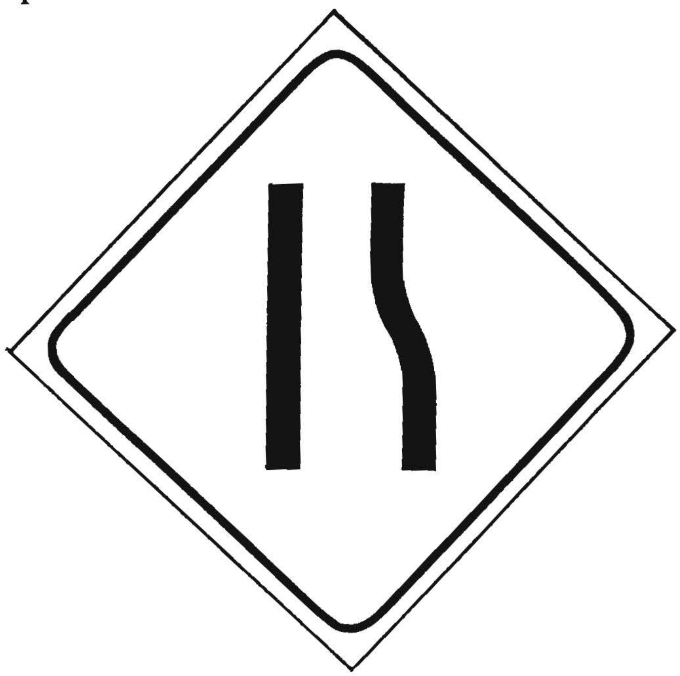

Figure D-6. Lane Reduction Transition Symbol Sign

Figure D-7. Field Placement of Lane Reduction Transition Symbol Sign

Participants were asked to describe the appropriate driving response to several regulatory and informational signs posted in the construction area. The results showed that for some signs a clear and single message was not interpreted.

No Center Lane and **No Center Turn Lane**, shown in Figures D-8 and D-9, are used throughout the F.M. 1960 construction area. These signs were confusing to many of the participants. When asked what the sign in Figure D-8 means, 46 percent said "drive in the right lane only" and 46 percent said "be alert for cars stopping to turn left." The sign in Figure D-9 provided a higher response, with 79 percent stating the sign means "a lane for left turns is not provided."

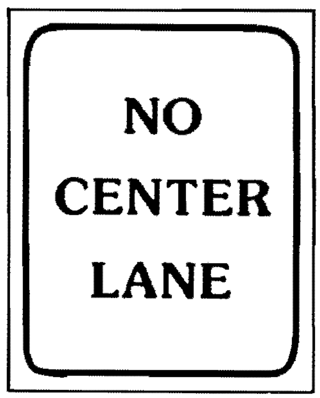

Figure D-8. No Center Lane Sign

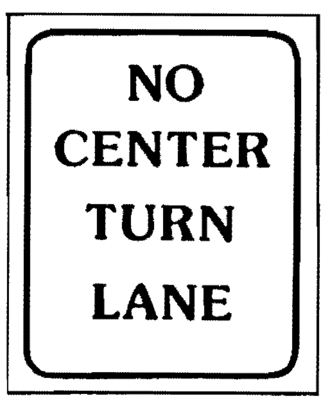

Figure D-9. No Center Turn Lane Sign

Green CROSSOVER signs, when posted on a free-standing barrel as shown in Figure D-10, do no clearly convey to the motorists where to crossover. Survey participants were asked if it is permissible to crossover before or after the CROSSOVER sign. Participants were asked two questions about this sign. When asked if they were permitted to turn left in front of the CROSSOVER sign, 55 percent said yes and 38 percent said no. When asked if they were permitted to turn left after the CROSSOVER sign, 42 percent said yes and 49 percent said no. String delineation with flagging between barrels, as shown in Figure D-11, simplified the response to the CROSSOVER sign. The string with flagging was used by the contractor to identify those areas with fresh concrete pavement. In this case, when asked if it was permissible to turn left before the CROSSOVER sign, 82 percent said no and when asked if it was permissible to turn left after the barrel with the CROSSOVER sign, 80 percent said yes. The string and flagging helped the participants to identify the location where turns were permitted.

Figure D-10. Field Placement of Crossover Sign

Figure D-11. Field Placement of Crossover Sign with String Delineation

Do Not Block Intersection -- Four response choices were provided for this sign out of context. Response frequencies for each answer were:

- Leave room for traffic crossing at intersection -- 74 percent
- If your car stalls, move it out of the intersection -- 10 percent
- Move through the intersection quickly -- 16 percent
- Not sure -- 1 percent

Figure D-12 shows the sign as presented in context. Participants were asked what they thought they should do if they were the driver of the pickup truck. In this situation, over 88 percent described in their own words an appropriate driving response. Again, only one percent said they did not know what to do in response to this sign.

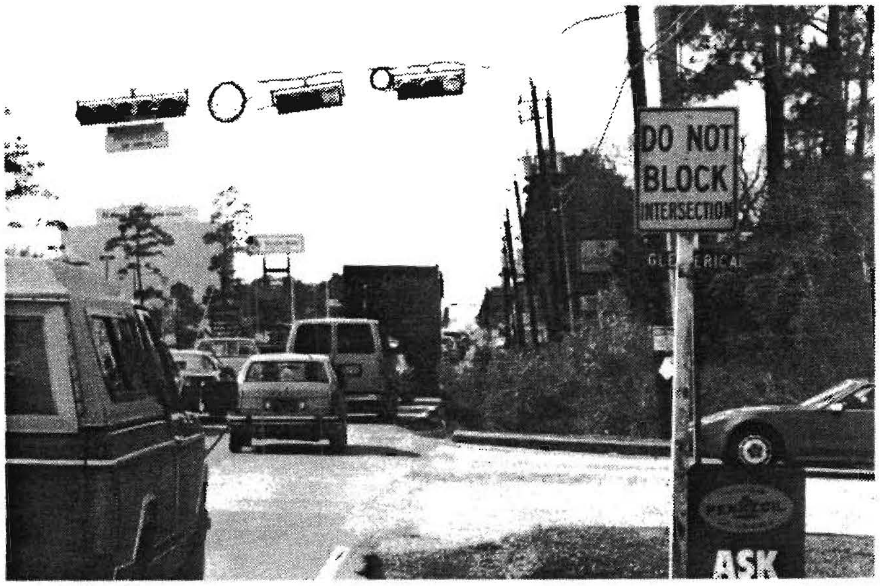

Figure D-12. Field Placement of DO NOT BLOCK INTERSECTION Sign

Results from this survey support other research findings (22) that color coding to distinguish construction from other types of signing is not well known by the motoring public. When shown the **Two Way Traffic** symbol sign illustrated in Figure D-13, one yellow and one orange, and asked the meaning of the two different colors, over 44 percent said they simply "did not know." Several participants remarked that they did not believe they had ever seen orange signs. A total of 44 percent knew that orange is the color designated for construction signs.

Figure D-13. Two-Way Traffic Symbol Sign

For some segments of the construction area, orange and white object markers were used at the pavement edge as shown in Figure D-14. Although 70 percent of the participants thought these markers indicated a hazardous area to the right, 26 percent thought they marked the right edge of the pavement. In contrast, solid white markers, shown in Figure D-15, were used in the construction area as pavement edge markers. The percentage of drivers who recognized these markers as pavement edge markers was 58, while 36 percent interpreted them as hazard markers.

Figure D-14. Field Placement of Construction Object Markers

Figure D-15. Field Placement of Edge Delineation

To optimize the visibility of their businesses and entrances to their businesses, some of the retail owners adjacent to F.M. 1960 posted directional signing. In most cases these signs pictured the business' name, logo, and an arrow as shown in Figure D-16. Participants were asked if they favored or opposed this type of signing. A majority (53 percent) felt that signs showing directions to retail businesses should be allowed in the construction area. The reasons given for objecting to such signs included that they are distracting (15 percent), they are confusing (4 percent), they are not official signs (4 percent), and they are too small (1 percent). Several comments were made by those who favored the signs suggesting that retail owners should be allowed to mitigate the disruptive effect of the construction in terms of visibility and accessibility.

Figure D-16. Field Placement of Business Directional Sign

Figures D-17 and D-18 are examples of non-standard signs developed by the Houston Northwest Chamber of Commerce. These signs were not installed by SDHPT nor were they part of the TCP. Because these signs seemed to represent an effort to add a certain "lightness" to messages given to motorists, their effect was measured. A majority of those surveyed (60 percent) said they like messages on the circular red signs. In general, drivers interpreted them as positive messages. Twenty percent said they did not like them, and 11 percent also said they were either distracting or hazardous.

Figure D-17. Field Placement of Chamber of Commerce Signs

Figure D-18. Field Placement of Chamber of Commerce Signs

To add some perspective to the problems experienced by users of F.M. 1960 during the reconstruction phase, the question of benefits to be derived was posed. Specifically, participants were asked, "*do you think the benefits of widening this road will be worth the inconvenience now?*" The overwhelming majority (91 percent) said yes. The few who did not think the benefits outweighed the inconveniences tended to have the viewpoint that the reconstruction should not have been initiated at all.

A number of biographical questions were asked at the conclusion of the survey in order to evaluate the socio-demographic makeup of the survey participants. A summary of the biographical information is contained in Table D-3. 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. Over three-fourths of the participants traveled on F.M. 1960 at least once a week.

Table D-3. Houston Demographic Summary

Sex:	47% Male	53% Female		
Race:	81% Anglo	7% Black	8% Hispanic	4% Other
Age:	15% under 25	76% 26-55	9% over 55	
Highest level of education received:				
	9% Less than high school		24% High school graduate	
	30% Some college		37% College graduate	

Dallas Motorists' Survey

A second motorists' survey was administered in the Spring of 1990 to investigate motorists' interpretations of construction signing and their perception of a urban arterial work zone. In addition to the objectives previously listed, this survey had the objective of substantiating or negating findings from the Houston motorists' survey.

Survey Procedure

Surveys were conducted with 345 respondents in May 1990 at three locations. Respondents at all locations were approached by the surveyors and asked if they would like to voluntarily participate in the survey. A daily demographic total was kept to address any biases that might develop. The result was that 147 respondents were interviewed at a Texas

Department of Public Safety licensing office and a total of 198 respondents were interviewed at the two commercial locations.

Survey participants were queried on their opinions about various aspects of the reconstruction project. This was followed by a brief set of biographical questions. The participants were then asked to respond to questions regarding work zone signs and other forms of traffic control devices that were presented in a booklet of photographs. The interview time was approximately 5-7 minutes.

__Results__

Motorists were first asked about their opinions of the Abrams reconstruction. *"Hazardous road conditions"* was the biggest problem as seen by the participants, followed by *"the construction is taking too long."* Subsequently, drivers were asked, *"if they were utilizing alternate routes?"* Approximately 65 percent responded that they were using alternate routes.

When asked, *"if there were too many, too few, or the right amount of construction signs that give directions to places alongside the construction area?"* the response given most often (54 percent) was that there are the right amount of directional signs for the construction area. However, 21 percent said there were too few, 21 percent also said they were not sure, and 4 percent said there were too many.

When asked the same question about the number of construction drums, the participants responded most often (50 percent) that there were the right amount. On the other hand, 23 percent said they were not sure, 16 percent said there were too many, and 11 percent said there were too few.

The drivers were also asked, *"if they had any trouble getting to specific places because of the construction?"* Over 68 percent of the drivers responded that they did not have any problem getting to their destinations. Finally, when asked, *"Do the future benefits of this construction outweigh the present inconveniences?"*, approximately 84 percent responded yes.

Table D-4 shows a listing of all the questions with their response frequencies.

Table D-4. Dallas Questionnaire Response Summary

1. Have you travelled on Abrams Road during the current construction? 84% – Yes 16% – No	2. How often do you travel on Abrams? 44% – One or more trips each day 32% – One or more trips each week 18% – One or more trips each month 6% – Less than once a month
3. What is the biggest problem in the Abrams construction area? 25% – Hazardous road conditions 24% – The construction work is taking too long 18% – Travel delay caused by construction 8% – Too much traffic 8% – Difficulty making turns due to congestion 5% – The construction zone is too long 5% – Inadequate or confusing lane striping 3% – Difficult locating drives and streets 3% – Construction signs are confusing 1% – Other	4a. During what time do you experience delay, if any, due to construction? 34% – Evening rush hour 26% – Morning rush hour 26% – Other time period 14% – No delay experienced
4b. How much time does the construction delay you? 34% – Less than 5 minutes 29% – 6-10 minutes 19% – No delay experienced 10% – 11-15 minutes 8% – More than 15 minutes	5. Is this delay reasonable? 52% – Yes 21% – No 16% – No delay experienced 11% – Not Sure
6a. Are you using alternate routes? 65% – Yes 35% – No	6b. If you are using alternate routes, what are they? 39% – Greenville 3% – Audelia 26% – Skillman 3% – None Given 23% – Other 2% – Arborside 3% – N. Central 1% – Plano
7a. Do the future benefits outweigh the present inconveniences? 84% – Yes 11% – Not Sure 5% – No	7b. If no or not sure, why? 28% – None Given 22% – Other 16% – Construction work is taking too long 12% – Fine before widening 8% – Cost too high, bad construction planning 4% – Added congestion in neighborhoods 4% – Road will need repairs soon 2% – Hazardous road conditions 2% – Not enough right-of-way 2% – Property values have dropped
8. Do you have trouble getting to specific places because of the construction? 68% – No 32% – Yes	9. Are there enough construction signs that give directions to places alongside the construction zone? 54% – Right amount 21% – Too few 21% – Not sure 4% – Too many
10. Are there enough barrels in the construction area? 50% – Right amount 23% – Not sure 16% – Too many 11% – Too few	11. How would you like to receive roadway project information? 27% – Radio 12% – Newsletter, flier, etc. 26% – Newspaper 9% – Utility bill stuffer 23% – Television 3% – Local cable channel

(continued on next page)

12. Which radio station(s) do you listen to for news? 26% -- Other 19% -- None 17% -- KRLD - 1080 AM 8% -- KVIL - 1150 am, 103.7 FM 5% -- KLIF - 190 AM 5% -- KKDA - 104.5 FM 5% -- KSCS - 96.3 FM 5% -- KERA - 90.1 FM 4% -- KTXQ - 102.1 FM 3% -- WRR - 101.1 FM 3% -- WBAP - 820 AM	13a. Where do you currently get traffic/road closure information? 54% -- Radio 19% -- Newspaper 18% -- Television 9% -- Other
13b. Other Traffic/Road Closure Information? 66% -- No information received 14% -- Road signs 8% -- Other 6% -- Call traffic information agency 6% -- Homeowners association	14. Do you have concerns about other highway projects in the Dallas area? 29% -- None given 24% -- N. Central - Miscellaneous 17% -- Other 7% -- Skillman - Miscellaneous 6% -- N. Central - Should have been done sooner 5% -- N. Central - Too much traffic, causes delays 4% -- N. Central - Causes congestion on arterials 4% -- N. Central - Finish Abrams first 4% -- Construction, in general, takes too long

The second part of the survey asked the participants to respond to questions regarding work zone signing. This part of the survey revealed that drivers have some difficulty correctly interpreting messages on construction signs. A sample of the work zone signing questions is shown in Table D-5. The response percentages for the signs are discussed in the following sections. Section IV of Volume 3 contains a summary of these questions including the question, picture, and responses.

Road Construction 500 ft. -- Over two-thirds (69 percent) of the participants correctly interpreted the sign in Figure D-19. However, approximately 22 percent of the respondents interpreted the sign to mean that the next 500 feet of road are under construction. The Houston survey produced similar results with only 66 percent correctly identifying the sign.

Table D-5. Dallas Sign Questionnaire Summary

1. What does this sign tell you? A. There are 500 feet of construction 500 feet ahead B. The next 500 feet of road are under construction C. A construction area is located 500 feet ahead D. Not sure	2. How would you respond to this sign? A. Turn left B. Stop C. Change lanes D. Not sure
3. Why are these signs different colors? A. Yellow is for school zones, Orange is the standard color for warning signs B. Yellow is the standard color for warning signs, Orange is for construction signs C. There is no difference between the two D. Not sure	4. What does this sign tell you? A. Low shoulder B. Uneven pavement C. Bumpy road D. Not sure
5. What do the orange and black arrows tell you? A. Do not turn left between signs B. Shows the direction of the roadway C. Sharp turns in the road D. Not sure	6. On which side of this sign would you drive? A. Drive to the right of these signs B. Drive to the left of these signs C. Drive to either side of these signs D. Not sure
7. Where would you turn left? A. Before the Crossover sign B. After the Crossover sign C. Either before or after the Crossover sign D. Not sure	8. What do the white posts on the right tell you? A. Shows driveway locations along the roadway B. Shows the right edge of the pavement C. Park between these posts D. Not sure
9. What does this sign tell you? A. Road construction ahead B. Flagger ahead C. Guard for school crossing ahead D. Not sure	10. What does this sign tell you? A. Median narrows B. Right lane ends C. Right turn lane marker D. Not sure
11. What does this sign tell you? A. Leave room for traffic crossing at intersection B. If you car stalls, move it out of the intersection C. Avoid driving through the intersection D. Not sure	

Figure D-19. Advance Road Construction Sign

Right Lane Ends Sign -- 90 percent of the respondents correctly interpreted the sign in Figure D-20 to indicate a change in lanes was necessary. The correct response in the Houston survey was approximately 93 percent.

Figure D-20. Right Lane Ends Sign

In the past, motorists have not recognized the distinctions between different sign colors. When drivers were shown the **Two Way Traffic** sign, one yellow and one orange, and asked the meaning of the two different colors, only 50 percent knew that orange is the color designated for construction. Twenty-five percent were not sure of the difference and the other 25 percent gave an incorrect interpretation. In Houston only 44 percent knew the correct meaning of the two colors and 45 percent said they were not sure of the difference.

Low Shoulder Symbol Sign -- This sign (shown in Figure D-21) was incorrectly interpreted by a vast majority of the respondents. Over three quarters (76 percent) thought this sign meant uneven pavement. The Houston survey had a similar response of 84 percent.

Figure D-21. Low Shoulder Symbol Sign

Orange and white hazard markers were shown to the survey respondents (see Figure D-22). Drivers were asked, "on which side of these signs would you drive?" Thirty-eight percent responded incorrectly, while 46 percent were not sure. The Houston survey did not specifically address this sign. However, some indications of the previous survey showed incorrect interpretations of the sign.

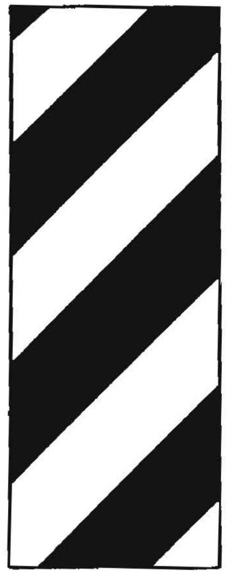

Figure D-22. Vertical Construction Panel

The green **CROSSOVER** signs do not clearly convey where to crossover within the construction area (see Figure D-23). When drivers were asked where they would turn left, 53 percent said before the sign, 26 percent said after the sign, and 13 percent were not sure. The Houston survey had similar results in that 55 percent responded that it was permissible to crossover before the sign and 42 percent indicated it was permissible to turn after the CROSSOVER sign.

Figure D-23. Field Placement of Crossover Sign

Solid white markers (Figure D-24) were utilized within the construction area as pavement edge markers. Seventy-five percent of the drivers interpreted these correctly, while 9 percent did not correctly interpret the markers, and 16 percent were not sure of their meaning. The Houston survey revealed that 58 percent interpreted the markers correctly, 36 percent misinterpreted them, and 6 percent of the respondents were not sure.

Figure D-24. Pavement Edge Delineators

Advance Flagger Symbol Sign -- The **Flagger Ahead** symbol, shown in Figure D-25, was interpreted correctly by 79 percent of the respondents; 21 percent interpreted the symbol incorrectly. The Houston survey revealed similar results with 78 percent correctly interpreting the symbol.

Lane Reduction Transition Symbol Sign -- The Lane Reduction Transition symbol, shown in Figure D-26, was interpreted correctly by 74 percent, 20 percent misinterpreted the symbol, and 6 percent were not sure. The Houston survey revealed that 78 percent interpreted the symbol correctly, 19 percent incorrectly interpreted the symbol, and 3 percent were not sure.

A brief demographic summary concluded the interview. The results are presented in Table D-6.

Figure D-25. Advance Flagger Symbol Sign

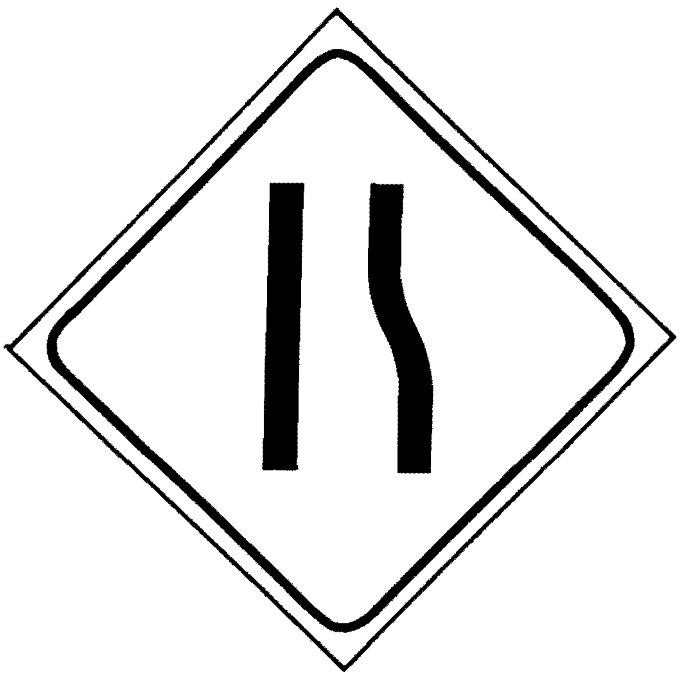

Figure D-26. Lane Reduction Transition Symbol Sign

Table D-6. Dallas Demographic Summary

Sex:	48% Male	52% Female		
Race:	72% Anglo	16% Black	6% Hispanic	6% Other
Age:	17% under 25	60% 26-55	23% over 55	
Highest level of education received:				
	4% Less than high school		13% High school graduate	
	31% Some college		52% College graduate	

Conclusions from Motorists' Survey

The survey of F.M. 1960 users confirmed previously conducted studies (22) that show that some aspects of signing are not fully understood by motorists. Most signs were correctly interpreted by 70 to 80 percent of the survey participants. Interpretation of signs shown in the field showed a slight improvement. Signs which appear more confusing to the survey participants include the Advance Construction sign, the No Center Lane sign, and the No Center Turn Lane sign.

However, traffic control device interpretation is not a primary source of concern for users of F.M. 1960. More important construction issues involve the length of the project, problems associated with turning, and travel delay. The length of the project (in time) was the most often cited personal complaint about the construction, while the length (in miles) was the most often checked from a list of problems.

The survey focused on problems that might have been encountered by users of F.M. 1960 during the construction activity. Yet, in spite of the construction difficulties identified in the survey, 91 percent of the drivers believed the long term benefits will outweigh the short term inconveniences. In general, the survey participants indicated a tolerance for construction and its related problems, and have positive attitudes toward the SDHPT.

The Abrams road project produced some confusion with the interpretation of the Advance Construction sign. The difference between the standard yellow warning sign and orange construction sign was incorrectly identified. The orange and white vertical panels was also identified as a problematic sign. The behavioral response to the placement of the standard crossover sign was interpreted incorrectly by some test subjects. The other survey results showed some indication of minor problems.

Motorists concerns seem to be concentrated around the construction work taking too long and the hazardous road conditions. Alternate routes are being utilized by many of the respondents. Motorists indicated that there were a sufficient amount of signs and barrels on the project. The overall perception of 84 percent of the respondents was that the benefits of widening the roadway would be worth the inconveniences they are experiencing now.

APPENDIX E
CURRENT PRACTICE

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

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 E-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 E-1. Local Transportation Official Questionnaire

<u>URBAN ARTERIAL WORK ZONE SURVEY</u>
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 approaches to project rather than within.
    - Physical constraints of roadway restrict implementation.

  * Minor/major cross-street intersections.
  * Moving traffic signals.
  * 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 belong to the Public Works Department. Some cities have traffic control inspectors which are part of the Transportation Department.
- Driveway access must be maintained at all times, but it is normally up to the contractor how that access should be 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 SDHPT in the area of work zone traffic control.
- The major traffic control problems in urban areas include:
  * Poor maintenance of devices.
  * Restoration of control devices struck by traffic.
  * Poor nighttime visibility.
  * The effects of detours on traffic.
  * Minimum width of traffic lanes.

State Level Discussions

Several SDHPT 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 E-2.

Summary

The 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

Table E-2. 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.

the development of a TCP. Several agencies indicated the Texas MUTCD did not sufficiently address work zone traffic control on urban arterials. Contact with local and state agency personnel will be continued throughout the course of the project. Some telephone interviews of additional city and county personnel may be performed during the second year of the study, if needed. Local level SDHPT personnel will also be contacted during the second year of the study to gather information about how urban arterial work zones are handled at the Department level.

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