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16. Abstract <p>Continuous industrial development in Texas led to a significant population increase. This caused an overlaod of the existing highway network, especially in the major urban areas, and in turn called for necessary alterations and improvements to bring the urban transportation system up to date. Numerous improvements projects on urban arterial streets currently cause significant changes in traffic operation and safety. This study focuses on determining, characterizing, and effectively communicating best treatments for improvement of traffic safety on urban arterial streets during roadworks.</p> <p>An extended literature review regarding different impacts of work zone on traffic operation and safety suggested the most frequent types of accidents and the major contributing factors. Based on the field observations of work zones on urban arterial streets in Austin, San Antonio, and Houston metropolitan areas, and the questionnaire survey of TxDOT personnel involved in traffic control design and inspection, existing traffic control problems were identified and classified. The researchers compared the obtained findings with current design standards and developed recommendations for improvements of urban arterial work zone traffic control plans. The developments include signing, marking, and other devices better suited to drivers' abilities and behavior. The first version of the typical traffic control plans and recommendations for improvements in MUTCD regarding urban arterial work zones were developed.</p>			
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Identification of Traffic Control Problems on Urban Arterial Work Zones

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1. General Aspects of Work Zone Traffic Operation and Safety

1.1 Introduction

With the largest amount of roadway mileage in the nation Texas' highway network requires high maintenance activity and consequently reflects a high accident frequency. During the past several years, the continuous industrial development of Texas as well as the North American Free Trade Agreement (NAFTA) lead to a population increase and a significant growth in freight movements through Texas. This caused an overload of the existing highway network in many Texas regions and in turn called for necessary alterations and improvements, to bring the transportation system up to date. Numerous work zones currently cause significant changes in traffic operation and safety. The identification of solutions for improvements of the work zone design standards and traffic control plans is one of the major priorities for the Texas Department of Transportation (TxDOT).

A significant amount of research has been conducted on various work zone problems. Many of them stem from ineffectiveness of assorted traffic control devices, traffic delays, work zone capacity for any given conditions. Through traffic in work zones is affected by many factors such as type of work activity, work zone geometry, and traffic volume. For significant improvements, a thorough investigation of work zone traffic is necessary. Presently there is little ongoing research for the development of a systematic method for the selection of appropriate traffic control strategies.

An understanding of roadwork activities, work zone types, accident statistics and general principles of traffic through work zones is necessary for the development of a systematic approach to the problem of safety in the work zone.

1.2 Problem Description

Work zone traffic control plans define how signs, pavement markings, barricades, channelizing devices, object markers and flashing warning lights are to be combined to delineate a specific situation such as a temporary lane closure, a pavement drop-off. Typically work zones involve a combination of these "situations" some of which overlap and often results in a large number of devices being implemented in order to meet the requirements of each of the applicable traffic control plans. In some cases, the combined set of devices can be visually overwhelming and actually cause confusion and safety problems for drivers trying to navigate through the work zone. Research is needed to determine the extent of this type of problem and the conditions under which it typically occurs. Research is also needed to develop guidelines that better address urban arterial work zone traffic control situations as an overall system.

Tasks to be included in this research are as follows:

- Determine the extent and key causes of the urban arterial work zone traffic control problem in Texas.
- Identify and evaluate opportunities for improving traffic control systems in such work zones.
- Develop recommendations for changes to TxDOT's traffic control standard sheets and the Texas MUTCD, and for supplemental guidelines on traffic control plan development from a system perspective.

1.3 Typical Work Zone Sections

Depending on the type of activity taking place, work zone areas fall into three categories: construction, maintenance, and utility zones. Maintenance and road repair is a major function of state DOTs. Taking into account labor and energy consumption, economic properties, and purpose of work, the activities taking place in work zones can be classified as: maintenance, current, partial or major repair, and utility work. Based on traffic management strategies, work zones can be characterized as lane closures, crossovers, temporary bypasses or detours. Depending on the effect on traffic conditions, roadwork may be subdivided into two groups. In the first group, the work takes place adjacent to the road and not on the road itself (road shoulders, earth slopes, medians). These projects present little possibility of danger for motorists or workers and are not considered in this study. In the second group, the work takes place directly on the pavement with the work zones channeling the traffic flow. The second group may be divided into two subgroups:

- There are no lane closures. The traffic lanes are adjacent to the work zone and although lane configuration has changed, work can proceed without major impact on traffic stream.
- Traffic continues through the work zone with one or more lane closures but with normal directional lane flow. For this particular subgroup there may be three principal types of traffic flow depending on where the work zone is located on the roadway. The major traffic flow schemes are shown in Figure 1.1.

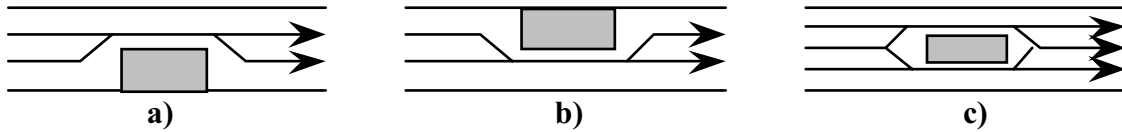


Figure 1.1 Principal Traffic Arrangements at Work Zones.

- a – traffic passes work zone on the left
- b – traffic passes work zone on the right
- c – traffic passes work zone on both sides

These three arrangements affect traffic flow differently and require different traffic control strategies.

A typical work zone consists of the following elements as shown in Figure 1.2:

- user information zone
- approach zone, including detour exits
- non-Recovery zone
- work zone
- termination zone.

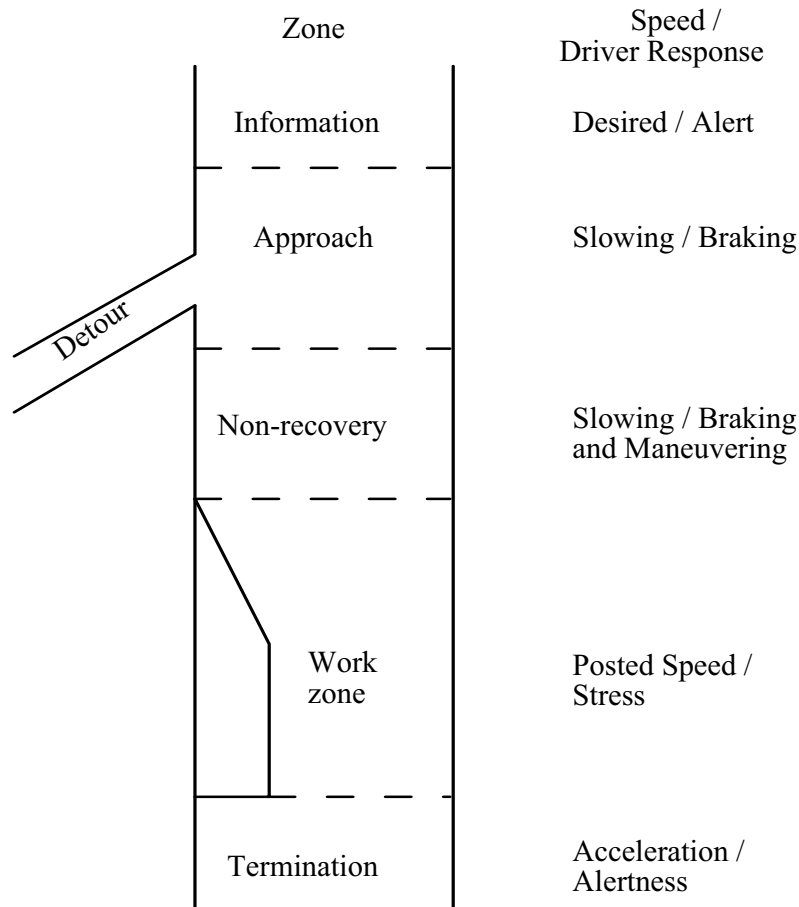


Figure 1.2 Sections of a Typical Work Zone and Associated Driver Responses

1.3.1 Information via User Information Zone

In this area of the work zone, the user is provided with information that warns about an approaching work zone and given directions with respect to traveling safely through the work zone. Typically, the length of the information zone depends on the type of highway and the geometry of the approach to the work zone. Such lengths can vary significantly, from over one mile on freeways and highways to just a few hundred feet on other roadways.

1.3.2 Approach Zone

The approach zone consists of a variable portion of the work zone where vehicle behavior, particularly speed and direction, may require adjustment. The approach zone includes a site distance relevant to these maneuvers and pertains to the distance from which a driver can recognize the emerging hazard and select the appropriate speed, path, and lane choice in a safe and effective manner. The approach zone should be of adequate length to enable users to detect hazards and respond safely.

1.3.3 Non-Recovery Zone

This zone comprises the distance required to execute an avoidance maneuver, or the point beyond which a motorist cannot avoid the hazard unless erratic maneuvers are undertaken. The distance corresponds to the stopping site distance and the speed of the vehicle. The non-recovery zone incorporates transitions to the lane configurations over the work zone site and configurations at the work zone activity site itself. Most current models address the issue of lane closure and any transitions required where closures are in effect. In the non-recovery zone, traffic is channeled from normal traffic lane flow to the designated lane(s) through the work zone.

1.3.4 Work Zone

At the work zone activity site itself, there are typically two components. First, a buffer zone is established where there is no work activity or equipment and materials. This allows the recovery of errant vehicles that stray into work zones. Buffer zones are particularly important where semipermanent deflection barriers cannot be implemented, as they act as another safety device for construction workers. Second, heavy equipment required for typical roadwork can be a distraction for many motorists.

1.3.5 Termination Zone

As the name implies, this zone directly follows a work zone where vehicles can accelerate back to their normal cruising speeds.

Work zones on urban arterial streets related to reconstruction or roadway widening projects require partial roadway closure, and in turn, have a major effect on the normal traffic operation. Such deterioration of traffic conditions has a significant effect on motorists, and creates a high probability of accidents. Close intersection spacing, numerous accesses to local businesses, left-turn bays, and other geometric features present special challenges to work zone traffic control plan designers. Furthermore, these multiple vehicle access points mean that many motorists do not travel past the advance warning signs upstream of the work zone.

Another important factor to be considered when providing drivers with information about work zone ahead is that urban areas are typically characterized by high levels of visual noise, that is, too much visual information in the driver's field of view that is not required for driving. In this case, road signs are more difficult to recognize, because they may be hidden among commercial and other signs.

1.4 Traffic Control in Work Zones

Traffic control strategies must operate efficiently to ensure the safety of motorists, and road workers. Road workers must be separated and protected from oncoming traffic and motorists must be adequately informed in order to adapt as expeditiously as possible to changing road configurations.

Work zones on urban arterial streets are especially complex from the traffic control plan point of view due to a variety of factors which include high traffic volume, limited spacing, frequent intersections, numerous accesses to the local businesses and left-turn lanes. Part VI of the Texas Manual on Uniform Traffic Control Devices (MUTCD) describes basic principles and standards for the design, application, installation, and

maintenance of signs, signals, markings, barricades, and channelizing,, required for rural and urban work zones (Ref 1). This document presents minimum standards for the most common situations. A detailed review of Part VI of the MUTCD allows one to conclude that the majority of standards is more applicable to rural conditions and does not adequately reflect the specifics of urban work zones. With the continuation of the urbanization process in Texas, this problem will have greater importance. For example, Part 6B-3 of the MUTCD formulates: "Signs should be placed in positions where they will convey their messages most effectively and placement must therefore be accommodated to highway design and alignment. Signs should be placed so that the driver will have adequate time to respond." Current requirements for advance driver information (MUTCD figures 6-2 to 6-10), on urban streets where numerous local accesses to the main roadway exist, cause situations where many drivers miss the advance warnings and have no adequate time to respond. On the other hand, to provide as much information as possible for all traffic participants, can possibly lead drivers to information overload. So, traffic control plans are greatly affected by the designer background and experience.

The investigation of complex work zones in Texas' main cities, conducted by the Texas Transportation Institute and the Center for Transportation Research identified some problems of the utilized traffic control plans: (1) signing, and (2) traffic regulation enforcement. It was observed that often information for drivers is insufficient, or excessive and unnecessary. Furthermore, temporary road signs during inclement weather had low visibility, due to poor technical design of sign support.

1.4.1 Urban Work Zone Signing Related Questions

Modern urban traffic conditions are complicated and stressful for drivers. High traffic volumes, numerous cross streets, limited visibility at intersections, obstacles near the roadway, pedestrians, and bicyclists require a high level of attention from drivers, especially when roadwork is present. Under such varying conditions, it is important to provide drivers with the information they need within a sufficient time frame for them to respond. Proper signing is one of the most important components of an urban traffic control system. Drivers' perception of road signs is determined by two groups of factors: 1) physical characteristics of road signs, including design parameters, such as size, form, and brightness, and 2) psycho-physiological parameters determined by human visual perception and human psychology. Investigations of the design parameters of signs in numerous studies over many years have contributed to the development of technically perfect road signs that are clearly visible from a long distance under any lighting condition. Significantly fewer studies have focused on psycho-physiological parameters in the perception of signs, leaving more unanswered questions. In the United States, Russia, Sweden, and other countries, extensive research has been conducted on drivers' sign recognition and reactions depending on the type of signs, combination of signs, and locations. Some of the research findings are described below.

The driver's tendency to recognize a sign depends on the type of sign. For example, a "speed limit" sign has the highest level of recognition (78% of drivers), whereas a "rough road ahead" sign was recognized by 55% of drivers (Refs 2, 3). Consequently, the recognition of a sign depends on the importance of the sign. Research on North Carolina work zones reveals that drivers have a better perception of fluorescent orange signs compared to standard work zone signs (Ref 4). Drivers' understanding of traffic signs is an

important element in the signs' overall effectiveness. Drivers' confusion and misunderstanding of signs may be attributed to increasing complexity of driving in an urban area, limited explanation of signs given in driver's education, or other factors. The findings of a study conducted by the Texas Transportation Institute indicated a high percentage of drivers' misunderstanding of signs (Ref 5). For example, incorrect definitions of given signs were made by the following percentage of respondents:

- Two-Way Left Turn Only Sign (R3-9b) 18.2%
- Lane Reduction Transition Sign (W4-2) 28.4%
- Right Lane Ends (W9-1) 19.0%
- Slippery When Wet Sign (W8-5) 37.5%

Changeable Message Signs (CMS) seem to work better than traditional signs. Research conducted in several countries has focused special attention on drivers' perception of message signs. This type of sign was analyzed based on the driver's reading speed and text understanding. The investigation took into account letter size, number of words on message, and vehicle speed. The available reading time, depending on letter size and vehicle speed, were determined. For example, at a speed 60 km/h the available reading time per word was 1.6 seconds at letter size 14 centimeters. With letter size 28 centimeters this value was 4.0 seconds (Refs 2, 3). A Federal Highway Administration study showed an 85th percentile reading time of about 0.8/1.0 seconds per word (Ref 6). Based on the reading speed, the maximum text volume on signs has also been determined. For the given example of vehicle speed and letter sizes, maximum text volumes were determined as eleven and twenty-nine syllables (Refs 2, 3). Reading time also depends on the number of words on signs and on their arrangement on the sign. Reading time for a message with horizontal arrangement of words will be shorter than with vertical arrangement. The maximum number of words which can be read and clearly understood by drivers at vehicle speeds around 37 mph (60 km/h) is three, given the total number of syllables is not greater than fifteen (Refs 2, 3). If the total number of syllables exceeds fifteen, drivers will read only two words. A Canadian investigation of drivers' perception of guide signs has indicated that with four or five names per sign, approximately one in eight subjects reported an incorrect direction for their target destination (Ref 7). Accordingly, a maximum of three names per sign was recommended. The New Jersey Department of Transportation research formulated the appropriate sign message design for CMS on work zones (Ref 8). As an example, one of the recommendations: "Drivers have difficulty relating calendar dates (e.g., Sept.25/Sept. 28) with specific days of the week. Consequently, calendar dates should not be displayed. Days of the week should be displayed instead (e.g., Tues/Fri)."

The next specific of urban conditions is a group of signs in close proximity to each other. Drivers perceive a single sign more easily than a group of signs; with too many signs in one place, individual signs are not easily recognized by drivers. Drivers took 0.42 to 1.25 seconds to recognize and understand single signs but 1.8/2.3 seconds to recognize and understand a group of four signs (Refs 2, 3). The perception of a group of signs apparently depends on the composition of individual signs. Abstract design principles that guide the organization of the so-called "good form" (Ref 9) play an important role in the composition and perception of a group of signs. These principles have already been taken into account in the design of regulatory and warning signs. Design concepts such as hierarchical

organization of elements, closure and unity, definition of dominance and balance, and figure-ground relationships in the visual field greatly affect the perception of the parts and the whole. The perception of the parts and the whole is a critical factor in the perception of a group of signs, as well. In most groups of signs, as well as in some guide signs, signs are not expected to be read in all their parts; instead, the driver will scan the group of signs and sort out the information that he or she is looking for. Appropriate design and composition of the individual signs can help the driver easily sort and focus on the piece of information that he or she seeks.

Another important aspect of drivers' perception of road signs in an urban area is visual noise, that is, visual information in the driver's field of view that is not required for driving. The amount of information along urban highways and streets that is not required for driving billboards, for example is high. Consequently, road signs are more difficult to recognize because they may be hidden among commercial and other signs. To identify the ways in which a driver's perception can be influenced by visual environments, researchers recorded the driver's eye fixation points using an eye-mark recorder and analyzed the difference in eye movements caused by objects appearing in the driver's field of view (Refs 2, 10). This study determined that eye fixation time decreases as the visual noise increases (Ref.11). Therefore, an increase in visual noise can be dangerous, since it reduces detection distance.

1.4.2 Enforcement of Traffic Regulation on Work Zones

At work sites, various devices are employed to provide motorists with information and to cause them to obey traffic regulations. Some of these devices include signs, lights, pavement markings, rumble strips, and noise strips. Each of these devices is utilized based on where and what type of work activity is taking place at a work zone. The literature search provided some solutions for improvements that are discussed below.

Road Signs. Road signs have little effect on the driving behavior of motorists. There are several reasons for this: 1) road signs may be poorly placed; 2) information provided on the sign does not necessarily agree with a motorist's perception of the situation; and 3) motorists' visual ability may be limited. Often, there are numerous warning signs placed at sites approaching work zones, and research of motorists' psycho-physiology indicate that they cannot adequately read more than two signs at the same time. For better results, signs can be supplemented by other devices. Some agencies use durable orange fluorescent sign sheeting on which the warning signs are mounted, and research indicates that such sheeting is more conspicuous than standard, nonfluorescent orange sheeting. A comparative investigation showed significant reduction of speed variance and traffic collisions when fluorescent signs were used (Ref 4). A CTR investigation of Texas highways determined that more than 80% of vehicles exceeded speed limits, even though all the observed highway sections were well marked with speed limit signs (Ref 12). These results correspond to previous research of road sign effectiveness that also concluded that signs have very little effect on motorists' behavior (Ref 13). A study of the effectiveness of different traffic control devices in reducing speeds at work zones, concluded that changeable message signs are more effective than passive controls such as signing (Ref 14). A very effectively dynamic message signs with auxiliary radar that identify and warn drivers with excessive speeds, were used for controlling speeds and speed variances, both in short-term and long-term work zones (Refs 14,15). At the same time, studies by the

Texas Transportation Institute show that after a few days of use, the effectiveness of controlling speed using DMS with auxiliary radar quickly diminishes.

Rumble Strips. Rumble strips are one of the most effective traffic control devices. The goal of the rumble strips is to generate sound and vibration as a vehicle traverses the strips to call the driver's attention to some changes of the roadway conditions. A survey conducted in 1993, revealed that 89% of state highway agencies have installed rumble strips at key locations such as approaches to intersections, horizontal curves, or work zones (Ref 16). Rumble strips are formed either by cutting grooves into the pavement or creating raised ridges by adding material, usually cold-mix asphalt, on top of the existing pavement. Because of this, the utilization of this treatment is limited on work zones, especially short-term. A new product, orange removable rumble strips, was successfully utilized by the Kansas Department of Transportation (Ref 17) for speed reduction through the work zones, which increased intersection safety. The easy installation and removal, combined with the positive safety effect, makes the removable rumble strips a very appealing traffic control device for work zones. Additionally, it is possible to design the strips so that they will be effective at selected speeds only.

Pavement Markings (longitudinal and diametrical). The role of pavement markings is to delineate the travel path and to improve visibility. Research has indicated that motorist behavior depends on parameters of pavement marks and that a noise frequency greater than 5 Hz communicates to them that they are driving too fast. An investigation demonstrated that motorists feel comfortable at a level of noise frequency no greater than 3 Hz. Changing the length of pavement marks and gaps simultaneously will affect the motorists' perception of speed. The same result can be obtained with diametrical marks on pavements with varying gaps between the marks. Research conducted in the U.S. and Canada reported that the use of optical speed bars could be an effective tool for the enforcement of speed reduction and have a positive impact on reducing the accident rate (Ref 18).

Other innovative technologies for speed management include: (a) unmanned radar drones which activate in-vehicle radar detectors; (b) unmanned decoy police vehicles with cruiser lights; (c) dynamic message signs with auxiliary radar that identify and warn drivers with excessive speeds; (d) pavement detectors upstream of work zones that detect erratic driver behavior and provide advance warning to workers; and (e) speed cameras that photograph speeders within the work zone and fax the photo to police vehicles downstream of the work area. The latter is practiced in some European countries and Australia where signs advise drivers of speed cameras ahead and has been effective in controlling approach speeds into work zones. Although the use of speed cameras to enforce speed limits is controversial in the U.S., no restrictions exist in using such devices for issuing warnings to drivers.

Research in the U.S. and in Europe show that an effective way to encourage drivers to observe speed limits is the use of psychological influences, which stimulate involuntary speed reduction. Possible sources are rumble strips, shaky strips, longitudinal and diametrical pavement markings, and painting or striping to create illusions of narrower roads or increasing speed.

All devices have both positive and negative aspects, depending on where and how they are placed. To fully understand why some devices work and others fail, it is necessary to analyze work zone design, traffic flow characteristics, and traffic control device

influences on driver behavior. Therefore, this study will focus on adopting a systems approach to evaluate traffic control plans and devices in urban arterial work zones.

2. Traffic Control Problems in Work Zones on Urban Arterial Streets

2.1 Literature Review of Work Zone Accident Statistics

Data indicate that the number of accidents in work zones is three to ten times greater than that in the absence of roadwork (Refs 19, 20). The U.S. data indicate that total accident rates during road construction increase 7.5% to 21.4% above the rate experienced before construction (Refs 21, 22, 23). Even higher accident rate increases are present on urban streets. An analysis of traffic accidents in Virginia indicated a 74% increase in accident rates at urban work zone locations (Ref 24).

Accident analyses conducted for seventy-nine construction projects in seven states indicate that 31% of the projects experienced decreased accident rates during construction, while 24% experienced accident rate increases of 50% or more (Ref 25). This data also showed how road configuration affects accident rates:

- four lanes divided reduced to one lane in each direction + 14.8%
- four lanes divided reduced to two lanes, two way + 15.9%

The data below illustrates changes in mean accident rates by types of construction activities (Ref 22).

- bridge work + 50%
- reconstruction of existing roadway + 33%
- median barrier work + 9%
- resurfacing, patching + 8%
- pavement widening + 3%

Accidents are not distributed evenly in the work zone impact area. They are concentrated directly in the work zone with 65% to 74% of the total number in the impact zone. Most of the accidents occur during daytime hours (Ref 26). The number of night accidents increased by 9.4% (Ref 25), but the percentage of night accidents to total accidents remained 30% both before and during construction. Sixty to 65% percent of the total number of accidents during a typical day and night occur between 9 a.m. and 6 p.m. When comparing daytime and nighttime accidents, it is necessary to take into account traffic volume differences. The index of the relative number of accidents (number of accidents per million automobile/kilometers) can be used. In this case, the nighttime accident rate will be characterized at a higher level because traffic is more dangerous under insufficient lighting conditions.

Data from the U.S. (Ref 25) show the following changes in collision type during construction:

- right angle - 18.8%
- rear end + 16.6%

- sideswipe - 9.6%
- head on + 15.2%
- turning + 15.0%
- running off road - 26.3%
- roll + 10.3%
- fixed object + 38.9%

Investigations in three other states found that a large percentage of work zone accidents involved rear-end collisions (Ref 27). The main accident types occurring in work zones are distributed as follows (Ref 26):

- vehicles running into the road-building materials and equipment 19.5%
- vehicles colliding with the road-building machines and mechanisms 4.9%
- joint collisions of vehicles 42.7%
- running into road workers 8.5%
- running into pedestrians 7.3%
- getting into the pits and potholes 11.0%
- other accidents 6.1%

National research (Ref 25) shows that around 31% of all accidents on work zones were multi-vehicle collisions and 38.9% were vehicles running into immovable objects. Other research shows that 8.5% of accidents involved road workers and 7.3% involved pedestrians (Ref 26).

In contrast to accidents in usual traffic conditions, accidents occurring in work zones are characterized by heavier consequences. The average number of fatalities in road and street accidents is roughly 10% of all people injured. In terms of the work zones, this index is 16.7% or greater (Ref 28). Approximately 81% of the total number of accidents in work zones result in injuries and 19% in property damage. Very alarming was the increase in the fatal accident rate to 132.4% during construction (Ref 21). The most advanced work zone fatal accident analysis, which was found during the literature survey, was conducted in Georgia (Ref 29). The research shows that during the period between 1995 and 1997, a total of 181 fatal crashes, approximately 60 fatal crashes per year, occurred within highway work zones in the state of Georgia. Fatal crashes occurred primarily in construction work zones rather than maintenance work zones. More than half of fatal crashes occurred in work zones that were idle compared to about 30% of crashes occurring in work zones in progress. Resurfacing and widening represent the primary type of construction activities during which fatal crashes in work zones occur.

Table 2.1 represents distribution of fatal crashes by manner of collision.

Table 2.1 Fatal Crashes by Manner of Collision

Manner of Collision	Percent of Fatal Crashes	
	Work Zone	Non-Work Zone
Single-vehicle Collision	48.6	56.3
Rear-end	12.1	5.0
Head-on	17.7	16.1
Angle	17.7	20.7
Sideswipe, same direction	2.8	1.1
Sideswipe, opposite direction	1.1	0.8

Fatal crashes within work zones in Georgia primarily involved passenger vehicles. These vehicles accounted for 80% of the vehicles involved in fatal crashes.

A significantly higher proportion of fatal crashes occurred during dark conditions in the work zone compared with non-work zone locations, with 42% of fatal crashes occurring in dark conditions in work zones and 32% in non-work zone locations. Table 2.2 shows the functional classification of roadways on which fatal crashes occurred in work zones and non-work zone locations in Georgia.

Table 2.2 Fatal Crashes on Work Zone Versus Non Work Zone Locations

Roadway Classification	Percent of Fatal Crashes	
	Work Zone	Non-Work Zone
Urban Principal Arterial (other than interstate and freeways)	12	10
Urban Minor Arterial	7	11
Urban Collector	0	4
Urban local Roads and Streets	3	9

Accident analysis for Kentucky work zones determined the work zone related factors that contributed to accidents (Ref 30). The most common factor was congestion, which agrees with the previous findings that rear-end collisions make up the most common type of work zone accidents. Restricted lane width was the second most common factor found. Other frequent occurring factors were striking or avoiding construction equipment, spilled material such as gravel or oil on the roadway, an uneven pavement, pavement (shoulder) drop-off, and late merging vehicles. The second phase of the research involved evaluation of traffic control and accident analysis at twenty case study locations (Ref 30). Accident analyses included a 3-year period before construction and the time period during construction. At fourteen of the nineteen locations where accident rates were calculated, rates during construction exceeded those before construction. When analyzing those fourteen locations, ten had rates during construction that exceeded statewide averages for their respective highway type. Analysis by accident type showed that the most frequent accidents were sideswipes and rear-end collisions. Contributing factors cited most often were driver inattention, failure to yield right-of-way, and following too close.

Similar results were found by J.W. Hall and V.M. Lorenz in their New Mexico research (Ref 31), and by S. Venugopal and A. Tarko for Indiana work zones (Ref 32). Conducted review lead to the following conclusions:

1. Collected data are contradictory. Some data show increase in accident frequency on urban work zones; other data indicate a significant reduction. Limited data provided in the references do not permit determining the reasons for such phenomenon. The reduction of accident rates on work zones may be explained by the insufficient accident record system, or by the fact that the given highway section was characterized by high accident frequency before road works.
Although some data show reduction in accident rates, the absolute quantity of injuries and fatalities in work zones is very high and is a clear indicator of the need for improvements.
2. Most dangerous types of construction activities are bridge works and reconstruction of existing roadway.
3. More accidents occur when work zones are inactive compared to work zones in progress.
4. Night time is more dangerous.
5. Most common accident types are collisions with fixed object, rear-end and head-on collisions.

2.2 Field Observations

The main purpose of the field observations was to identify current problems of the traffic control plans in work zones on urban arterial streets. The CTR research team observed several work zones in the Austin, San Antonio, and Houston metropolitan areas. In total, twenty-three work zones were generally observed and eighteen work zones were investigated in detail. Each selected work zone was investigated, including zone location, roadway design, traffic control strategy, and types and location of control devices.

The following work zones were observed in detail:

Austin

- | | |
|----------------|------------------------------------------------|
| Work Zone # 1. | Building construction at 600 Guadalupe Street. |
| Work Zone # 2. | Building construction on Lavaca Street. |
| Work Zone # 3. | Building Construction at 400 Guadalupe Street. |
| Work Zone # 4. | Reconstruction of Lake Austin Blvd. |
| Work Zone # 5. | Reconstruction of Barton Springs Rd. |
| Work Zone # 6. | Reconstruction of Manchaca Rd. |
| Work Zone # 7. | Reconstruction of Amherst Dr. |

- Work Zone # 8. Reconstruction of Rutland Dr.
- Work Zone # 9. Reconstruction of Research Blvd.

San Antonio

- Work Zone # 10. Reconstruction of Hilderbrand Ave.
- Work Zone # 11. Reconstruction of S. Flores Street.
- Work Zone # 12. Reconstruction of FM 2536.
- Work Zone # 13. Reconstruction of West Ave.
- Work Zone # 14. Reconstruction of FM 2696.
- Work Zone # 15. Reconstruction of intersection of Blanco Rd. and Jackson Keller Rd.
- Work Zone # 16. Reconstruction of intersection of Probandt Street and Mitchell Street.
- Work Zone # 17. Reconstruction of Rittiman Rd.
- Work Zone # 18. Reconstruction of O'Connor Rd.

Data regarding observed work zones in Austin and San Antonio are presented in Appendices A and B, respectively. Figures A.1 through A.19 show observed work zone locations in Austin and Figures B.1 through B.10 in San Antonio with detailed areas under work zone influence. Figures A.11 through A.19 and B.11 through B.19 represent the work zones' general schemes and lane closure strategies.

Video recording while driving through the work zone was selected as a main approach for the given investigations. A digital video camcorder was installed in the vehicle at the driver's eye level and recorded the driver's field of view. The team of observers included CTR researchers (in Austin) and in addition two TxDOT engineers (in San Antonio). All comments and identified problems were recorded through voice input on videotape. In the lab, collected video data was transferred to computer and DVDs were created. Such an approach allows a repeated analysis of the data by the CTR research team and creation of a video database, which can be useful for developing training materials for TxDOT staff and contractors.

Photos A.1 through A.33 and B.1 through B.28 in Appendices A and B, respectively, show general views of the observed work zones and areas of special attention.

Several TxDOT inspection reports in seven districts were provided by the Traffic Operations Division to CTR as well. The TxDOT Traffic Control Review Team (TCRT) inspected work zones in Lubbock, San Antonio, Lufkin, Pharr, Laredo, and Odessa districts. Each review was conducted in two parts. Part I consisted of a review and discussion of procedures on traffic accidents, traffic control plans, and traffic control device inspection forms. Part II was a field review of the implementation and inspection efforts associated with traffic control. These reports represent TCRT's reviews of approximately 100 ongoing construction projects.

Based on analysis of the collected data, traffic control problems were identified and are classified. Table 2.3 shows the percentage of work zones where particular problems were observed at least three times.

The first and second groups represent problems, which include the use of unspecified traffic control device placement and mixing, unstable installation, poor assembly of device supports, unused signs in a clear zone, and insufficient technical state of the devices.

The third group includes confusing signs, lack of necessary information, information overload, ineffective selection of control devices and similar problems. Such problems are possibly caused by traffic control plan inadequacy, contractor inability to follow original traffic control plan, or because MUTCD requirements do not recognize specifics of urban work zones.

The fourth group, "Other Problems," reflects opinions of the research team, but has no special MUTCD requirements and includes problems such as close proximity of the construction mechanisms to traffic, effect of the commercial displays, insufficient night lighting, numerous local access roads, and low-profile barriers effect on lane capacity.

Photos C.1 through C.21 in Appendix C show samples of the identified problems.

Table 2.3 Identified Problems on Urban Arterial Streets Work Zones

Traffic Control Problems	Percentage of Work Zones where Problem Was Observed
I. Control device installations not following MUTCD requirements: sign and barricades do not have required buffer space unstable device installation barricade placed with backside to traffic sign nailed to support barriers overlapping sign support not assembled properly barriers not assembled properly unspecified device mixing unspecified device placement (not meeting the minimum mounting height, lack of lateral clearance, etc.) old signs are still visible old pavement markings are still visible permanent signs covered inappropriately signs not in use lay down in a clear zone	61 30 13 26 4 100 17 26 44 4 17 4 17
II. Insufficient technical state of control devices: signs drums barricades chevrons conuses edge line channelizers vertical pannels pavement markings	44 44 44 22 26 17 30 17
III. Insufficient traffic control plans: confusing signs lack of necessary information information overload not effective selection of control devices selection of devices not following MUTCD advance information not visible at required sight distance	22 17 4 4 4 4
IV. Other: construction mechanisms working too close to traffic insufficient visibility of grey low-profile barrier insufficient protection of pavement drop-off bad sign support design commercial displays affect road sign perception low-profile barriers reduce lane capacity numerous local driveways dangerous entrances small radiuses on local driveways	17 9 22 100 4 9 44 4 78

2.3 TxDOT Personnel Survey

Based on the conducted field observations of urban work zones and identified traffic control problems, the research team developed a special questionnaire. The questionnaire, presented in Appendix D, was developed in two formats: (1) for traffic control plan designers; and (2) for work zone inspectors, and was distributed in the Austin and Houston TxDOT districts. Traffic control plan designers were asked to rate different problems by their significance for traffic operation and safety on urban work zones. The questionnaire for inspectors was focused on estimation of problem frequency. Tables 2.4 and 2.5 represent the survey statistics for the Austin district and Tables 2.6 and 2.7 represent the Houston district.

Analysis of the obtained TCP designers' responses indicates that the following problems require special attention:

- Problems related to work zone separation (questions 7,8,10,17,18) were indicated by up to 90% of all respondents as major and medium in significance in both districts.
- Problems related to insufficient drivers' information (questions 1, 2, 3, 4, 12) (up to 86% in Austin and up to 84% in Houston).
- Problems related to TCP design (questions 5 and 6) (up to 80% and 73% in Austin and Houston, respectively).

Table 2.4 TCP Designers Survey Statistics: Austin District

Problems	Answer Choices								
	(significance: 1-major; 2 - medium; 3 - minor)								
	1	2	3	1	2	3	1	2	3
#	#	#	%	%	%	%	%	%	%
1. Lack of necessary information	10	11	6	33	37	20	33	37	20
2. Information overload	3	17	8	10	57	27	10	57	27
3. Confusing signs	13	13	2	43	43	7	43	43	7
4. Insufficient advance information	10	13	5	33	43	17	33	43	17
5. Traffic control plan utilizing non effective control devices	10	14	3	33	47	10	33	47	10
6. Traffic control plan does not follow MUTCD	15	7	6	50	23	20	50	23	20
7. Insufficient work zone separation from main traffic	14	12	1	47	40	3	47	40	3
8. Lack of lateral clearance zone	7	18	3	23	60	10	23	60	10
9. Lack of pedestrian ways	6	10	11	20	33	37	20	33	37
10. Construction machines working too close to traffic	11	16	2	37	53	7	37	53	7
11. Insufficient protection of pavement drop-off	9	13	5	30	43	17	30	43	17
12. Commercial displays affect road sign perception	2	18	7	7	60	23	7	60	23
13. Lighting of local businesses disturb work zone sign visibility	3	10	13	10	33	43	10	33	43
14. Inappropriate work zone night illumination.	15	6	7	50	20	23	50	20	23
15. Low-profile barriers reduce lane capacity	1	12	14	3	40	47	3	40	47
16. Insufficient visibility of low-profile barrier	7	7	14	23	23	47	23	23	47
17. Numerous local driveways	14	10	4	47	33	13	47	33	13
18. Small radius local driveways permit turns at slow speeds only	8	11	9	27	37	30	27	37	30
Are problems on urban work zones mostly caused by:									
A. Site limitations.	11	9	4	37	30	13	37	30	13
B. Contractor inability to follow original traffic control plan	7	12	5	23	40	17	23	40	17
C. Traffic control plan inadequacy	4	16	3	13	53	10	13	53	10
D. MUTCD requirements do not recognize specifics of urban work zones	6	11	7	20	37	23	20	37	23

Total Respondents 30

Table 2.5 Inspectors Survey Statistics of Problem Frequency: Austin District

Problems	Answer Choices					
	(frequency: 1-regular; 2 - frequent; 3 - occasional)					
	1	2	3	1	2	3
	#	#	#	%	%	%
I. Control device installations not following MUTCD requirements:						
I-a. Unspecified traffic control device mixing	2	11	23	5	27	56
I-b. Unspecified device placement	8	17	12	20	41	29
I-c. Permanent signs are still visible	7	8	23	17	20	56
I-d. Permanent pavement markings are still visible	12	15	11	29	37	27
I-e. Unstable device installation	8	18	10	20	44	24
I-f. Sign support not assembled properly	5	14	18	12	34	44
I-g. Barricade not assembled properly	3	15	21	7	37	51
I-h. Signs not in use remain in a clear zone	4	15	17	10	37	41
II. Poor physical condition of control devices:						
III. Insufficient traffic control plans:						
III-a. Lack of necessary information	6	10	20	15	24	49
III-b. Information overload	7	12	20	17	29	49
III-c. Confusing signs	7	9	23	17	22	56
III-d. Insufficient advance information	6	11	21	15	27	51
III-e. Traffic control plan utilizing non effective control devices	5	10	22	12	24	54
III-f. Traffic control plan does not follow MUTCD	5	9	22	12	22	54
IV. Other:						
IV-a. Insufficient work zone separation from main traffic	4	14	17	10	34	41
IV-b. Lack of lateral clearance zone	7	13	17	17	32	41
IV-c. Lack of pedestrian ways	11	8	16	27	20	39
IV-d. Construction machines working too close to traffic	7	16	13	17	39	32
IV-e. Insufficient protection of pavement drop-off	6	14	17	15	34	41
IV-f. Commercial displays affect road sign perception	4	14	19	10	34	46
IV-g. Lighting of local businesses disturb work zone sign visibility	3	11	23	7	27	56
IV-h. Inappropriate work zone night illumination.	9	16	10	22	39	24
IV-i. Low-profile barriers reduce lane capacity	4	14	18	10	34	44
IV-j. Insufficient visibility of low-profile barrier	3	13	18	7	32	44
IV-k. Numerous local driveways	13	14	11	32	34	27
IV-l. Small radius local driveways permit turns at slow speeds only	12	11	14	29	27	34
V. Are problems on urban work zones mostly caused by:						
V-a. Site limitations.	12	14	10	29	34	24
V-b. Contractor inability to follow original traffic control plan	8	15	13	20	37	32
V-c. Traffic control plan inadequacy	7	11	18	17	27	44
V-d. MUTCD requirements do not recognize specifics of urban work zones	5	12	19	12	29	46
Total Respondents						
41						

Table 2.6 TCP Designers Survey Statistics: Houston District

Problems	Answer Choices								
	(significance: 1-major; 2 - medium; 3 - minor)								
	1 #	2 #	3 #	1 %	2 %	3 %	1 %	2 %	3 %
1. Lack of necessary information	20	13	11	44	29	24			
2. Information overload	7	24	13	16	53	29			
3. Confusing signs	24	10	11	53	22	24			
4. Insufficient advance information	24	14	7	53	31	16			
5. Traffic control plan utilizing non effective control devices	10	23	12	22	51	27			
6. Traffic control plan does not follow MUTCD	17	14	14	38	31	31			
7. Insufficient work zone separation from main traffic	14	26	5	31	58	11			
8. Lack of lateral clearance zone	19	17	9	42	38	20			
9. Lack of pedestrian ways	7	12	26	16	27	58			
10. Construction machines working too close to traffic	18	19	8	40	42	18			
11. Insufficient protection of pavement drop-off	18	16	11	40	36	24			
12. Commercial displays affect road sign perception	6	14	25	13	31	56			
13. Lighting of local businesses disturb work zone sign visibility	3	10	32	7	22	71			
14. Inappropriate work zone night illumination.	17	24	4	38	53	9			
15. Low-profile barriers reduce lane capacity	5	16	24	11	36	53			
16. Insufficient visibility of low-profile barrier	7	17	21	16	38	47			
17. Numerous local driveways	18	15	12	40	33	27			
18. Small radius local driveways permit turns at slow speeds only	12	17	16	27	38	36			
Are problems on urban work zones mostly caused by:									
A. Site limitations.	25	13	6	56	29	13			
B. Contractor inability to follow original traffic control plan	13	21	10	29	47	22			
C. Traffic control plan inadequacy	13	20	11	29	44	24			
D. MUTCD requirements do not recognize specifics of urban work zones	15	14	15	33	31	33			
Total Respondents									45

Table 2.7 Inspectors Survey Statistics of Problem Frequency: Houston District

Problems	Answer Choices					
	(frequency: 1-regular; 2 - frequent; 3 - occasional)					
	1 #	2 #	3 #	1 %	2 %	3 %
I. Control device installations not following MUTCD requirements:						
I-a. Unspecified traffic control device mixing	10	19	54	11	21	59
I-b. Unspecified device placement	13	32	41	14	35	45
I-c. Permanent signs are still visible	21	28	37	23	30	40
I-d. Permanent pavement markings are still visible	23	41	21	25	45	23
I-e. Unstable device installation	17	37	30	18	40	33
I-f. Sign support not assembled properly	13	33	41	14	36	45
I-g. Barricade not assembled properly	11	29	46	12	32	50
I-h. Signs not in use remain in a clear zone	23	26	38	25	28	41
II. Poor physical condition of control devices:						
46 26 8 50 28 9						
III. Insufficient traffic control plans:						
III-a. Lack of necessary information	17	32	33	18	35	36
III-b. Information overload	15	14	53	16	15	58
III-c. Confusing signs	14	29	39	15	32	42
III-d. Insufficient advance information	11	32	38	12	35	41
III-e. Traffic control plan utilizing non effective control devices	7	32	42	8	35	46
III-f. Traffic control plan does not follow MUTCD	8	14	59	9	15	64
IV. Other:						
IV-a. Insufficient work zone separation from main traffic	11	30	42	12	33	46
IV-b. Lack of lateral clearance zone	15	26	43	16	28	47
IV-c. Lack of pedestrian ways	11	18	50	12	20	54
IV-d. Construction machines working too close to traffic	26	43	15	28	47	16
IV-e. Insufficient protection of pavement drop-off	15	34	34	16	37	37
IV-f. Commercial displays affect road sign perception	12	22	47	13	24	51
IV-g. Lighting of local businesses disturb work zone sign visibility	7	13	62	8	14	67
IV-h. Inappropriate work zone night illumination.	15	34	31	16	37	34
IV-i. Low-profile barriers reduce lane capacity	9	29	42	10	32	46
IV-j. Insufficient visibility of low-profile barrier	8	31	41	9	34	45
IV-k. Numerous local driveways	38	28	17	41	30	18
IV-l. Small radius local driveways permit turns at slow speeds only	29	28	25	32	30	27
V. Are problems on urban work zones mostly caused by:						
V-a. Site limitations.	33	34	16	36	37	17
V-b. Contractor inability to follow original traffic control plan	24	30	28	26	33	30
V-c. Traffic control plan inadequacy	17	39	27	18	42	29
V-d. MUTCD requirements do not recognize specifics of urban work zones	24	27	31	26	29	34
Total Respondents						

Problems related to visibility during night in work zones (questions 13, 14, 16) (up to 70% in Austin and up to 91% in Houston).

Four major problems indicated in the Austin district are:

- inappropriate work zone night illumination - 50%,
- traffic control plan does not follow MUTCD - 50%,
- numerous local driveways - 47%, and
- insufficient work zone separation from main traffic - 47% of all respondents.

In the Houston district they are:

- insufficient advance information - 53%,
- confusing signs - 53%,
- lack of necessary information - 44%, and
- lack of lateral clearance zone - 42% of all respondents.

As a major reason for problems in urban work zones TCP designers in the Austin and Houston districts indicate (A) site limitations - 37% and 56% of respondents, (B) contractor inability to follow original traffic control plan - 23% and 29%, (D) MUTCD requirements not recognizing specifics of urban work zones - 20% and 33%, and (C) traffic control plan inadequacy - 13% and 29%, respectively. A different estimation was identified when taking into consideration both major and medium significance: (A) – 67% and 85%, (C) – 66% and 73%, (B) – 63% and 76%, and (D) – 57% and 64%. Therefore, it is possible to conclude that significant problems exist in TCP design and implementation, assuming that any TCP must be adequate to site limitations.

The majority of inspectors, 71% in the Austin district and 78% in the Houston district cited poor technical condition of control devices, especially signs, drums, vertical panels, barricades, and cones as the most frequent problems in work zones.

The most frequent cited problems related to traffic control device installations (Group 1) are:

- Permanent pavement markings and signs are still visible: 66% and 37% respectively of all respondents in the Austin and 70% and 53% in the Houston district.
- Unstable device installation: 64% and 59%.
- Unspecified device placement: 61% and 49%.

Other problems of the first group were marked frequent as well (32 to 53% of respondents).

Many respondents noted problems related to insufficient work zone separation from the main traffic. Fifty-six percent and 75% of inspectors, in Austin and Houston, respectively, indicated that construction machines were found working too close to traffic, and 49% and 45% noted lack of lateral clearance zone.

A high percentage of respondents feel that numerous local driveways (66% and 72%) and their small radii (56% and 62%) have a significant impact on work zone traffic. High

frequency was also indicated for insufficient protection of pavement drop-off (49% and 53%).

Up to 61% and 53% of inspectors noted problems related to work zone night visibility, and 44% and 37% indicated a great effect of commercial displays on road signs perception.

Insufficiencies of the traffic control plans were indicated as frequent problems by an average of 52% and 41% of inspectors in Austin and Houston, respectively. From this group of problems, information overload was prevalent (46%) in the Austin district, and lack of necessary information (53%) in Houston.

As reasons causing TCP problems on urban work zones, 63% and 73% of inspectors, in the Austin and Houston districts respectively, indicated (V-a) site limitations, 57% and 59%: (V-b) contractor inability to follow original traffic control plan, 44% and 61%: (V-c) traffic control plan inadequacy, and 41% and 51%: (V-d) MUTCD requirements not recognizing specifics of urban work zones.

2.4 Summary

Review of the literature sources related to accident statistics on urban work zones lead to the following conclusions:

- Most dangerous types of construction activities, are bridge work and reconstruction of existing roadway, which have major impact on roadway and traffic conditions.
- More accidents occur when work zones are inactive compared to work zones in progress.
- Night time is more dangerous.
- Most common accident types are collisions with fixed object, rear-end, and head-on collisions.

Based on work zone field observations, traffic control problems were identified and can be classified into the following three groups:

- Traffic control devices not following MUTCD requirements: Represents problems which include the use of unspecified traffic control device placement and mixing, unstable installation, poor assembly of device supports, unused signs in a clear zone, and insufficient technical state of the devices.
- Insufficient traffic control plan: Includes confusing signs, lack of necessary information, information overload, and ineffective selection of control devices and other similar problems.
- Problems not referenced by MUTCD: Includes close proximity of the construction mechanisms to traffic, effect of the commercial displays, insufficient night lighting, numerous local access roads, low-profile barriers effect on lane capacity, and other similar problems.

TxDOT personnel survey indicated that the following problems have major significance and are frequently observed in practice:

- Insufficient work zone separation from main traffic;
- Insufficient drivers' information;
- Inappropriate work zone night illumination;
- Numerous local driveways with small radiuses; and
- Poor technical state of traffic control devices and their inappropriate placement.

Significant number of respondents felt that MUTCD requirements do not recognize specifics of urban work zones.

Consequently, it is possible to formulate two general directions for urban work zone traffic control improvements:

1. MUTCD improvements for better recognition of specifics of urban work zones.
2. Enforcement of the traffic control plans as designed.

3. Traffic Control Improvements in Urban Arterial Streets Work Zones

Two general directions for urban work zone traffic control improvement were formulated in Chapter 2:

- MUTCD improvements for better recognition of specifics of urban work zones.
- Enforcement of the traffic control plans as designed.

3.1 Traffic Control Draft Guidelines Development

The major traffic control problems identified in urban arterial work zones were related to different insufficiencies of traffic control plan, such as confusing signs, lack of necessary information, information overload, ineffective selection of control devices and similar problems. High frequency of rear-end collisions on work zones also provides some concern regarding proper information for motorists alerting them to roadway and traffic conditions ahead.

With the purpose of developing draft guidelines for a traffic control plan in urban arterial work zones, the common principle schemes of urban arterial work zones are identified in Figures 3.1, 3.2, 3.3, and 3.4. All schemes are classified into four groups: (1) multilane arterial streets with raised medians; (2) multilane arterial streets with left turn lanes; (3) multilane undivided arterial streets; and (4) two lanes arterial streets.

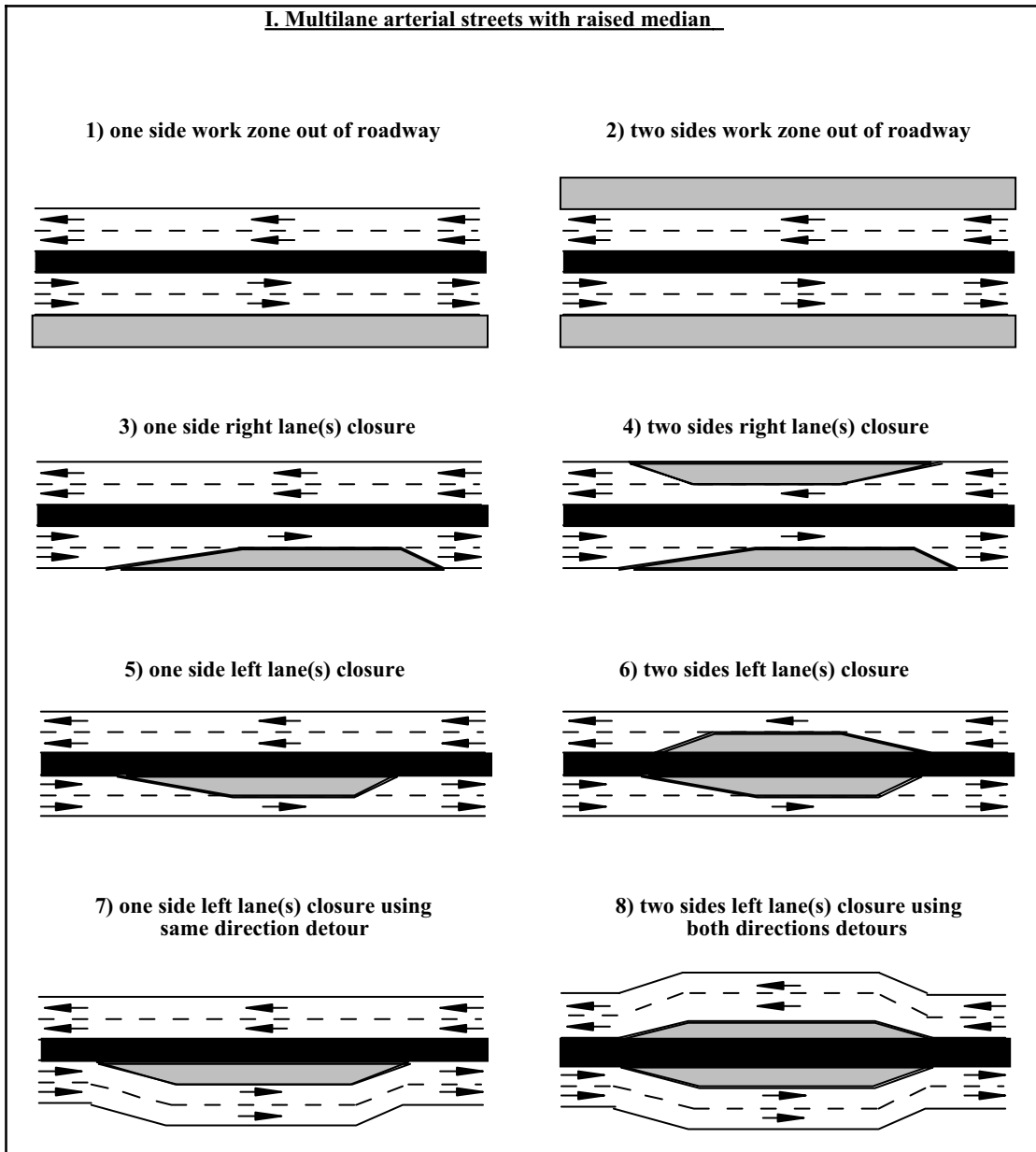


Figure 3.1 Work Zone Locations on Multilane Arterial Streets with Raised Median

II. Multilane arterial streets with left turn lane.

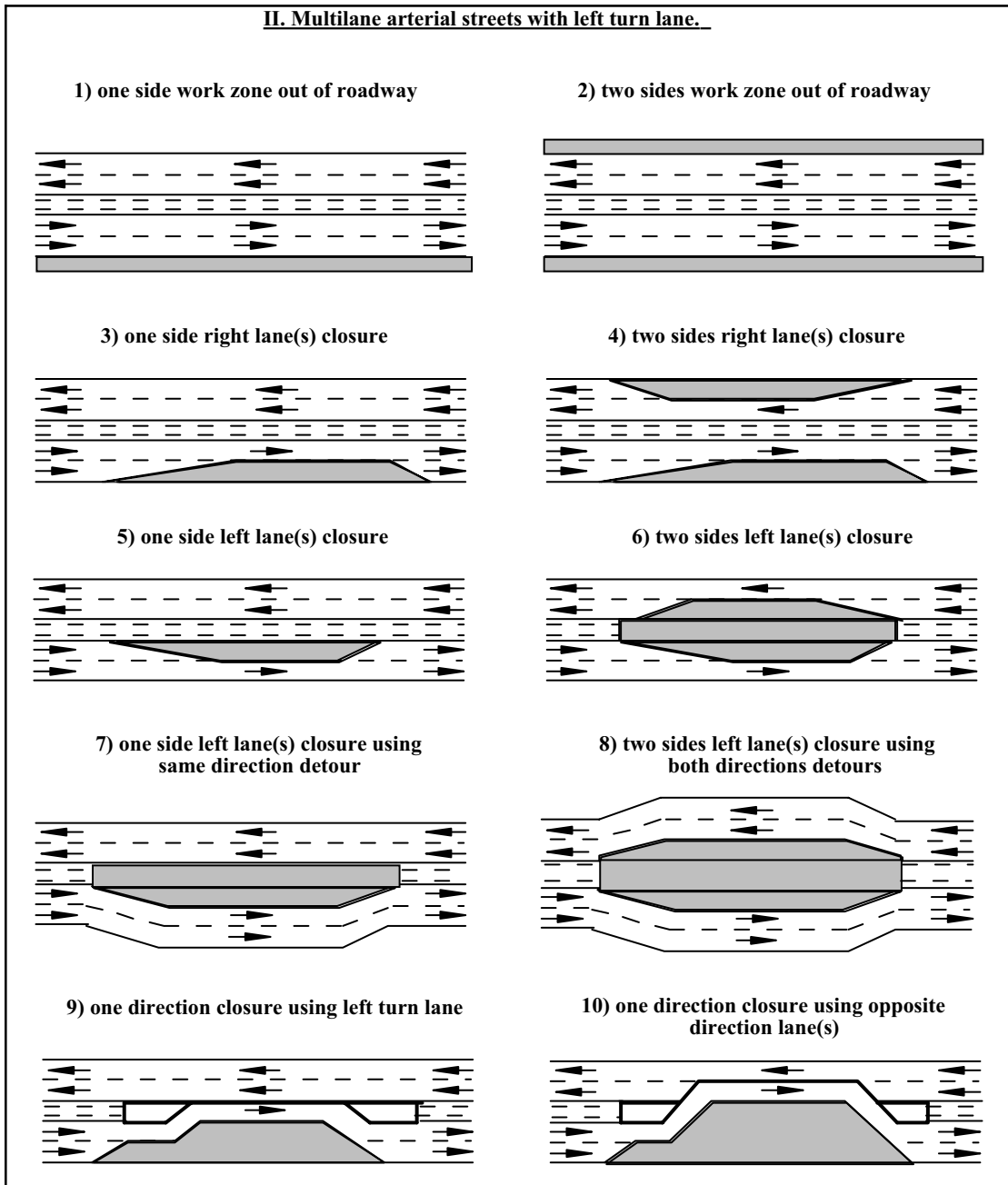


Figure 3.2 Work Zone Locations on Multilane Arterial Streets with Left Turn Lane

III. Multilane undivided arterial streets.

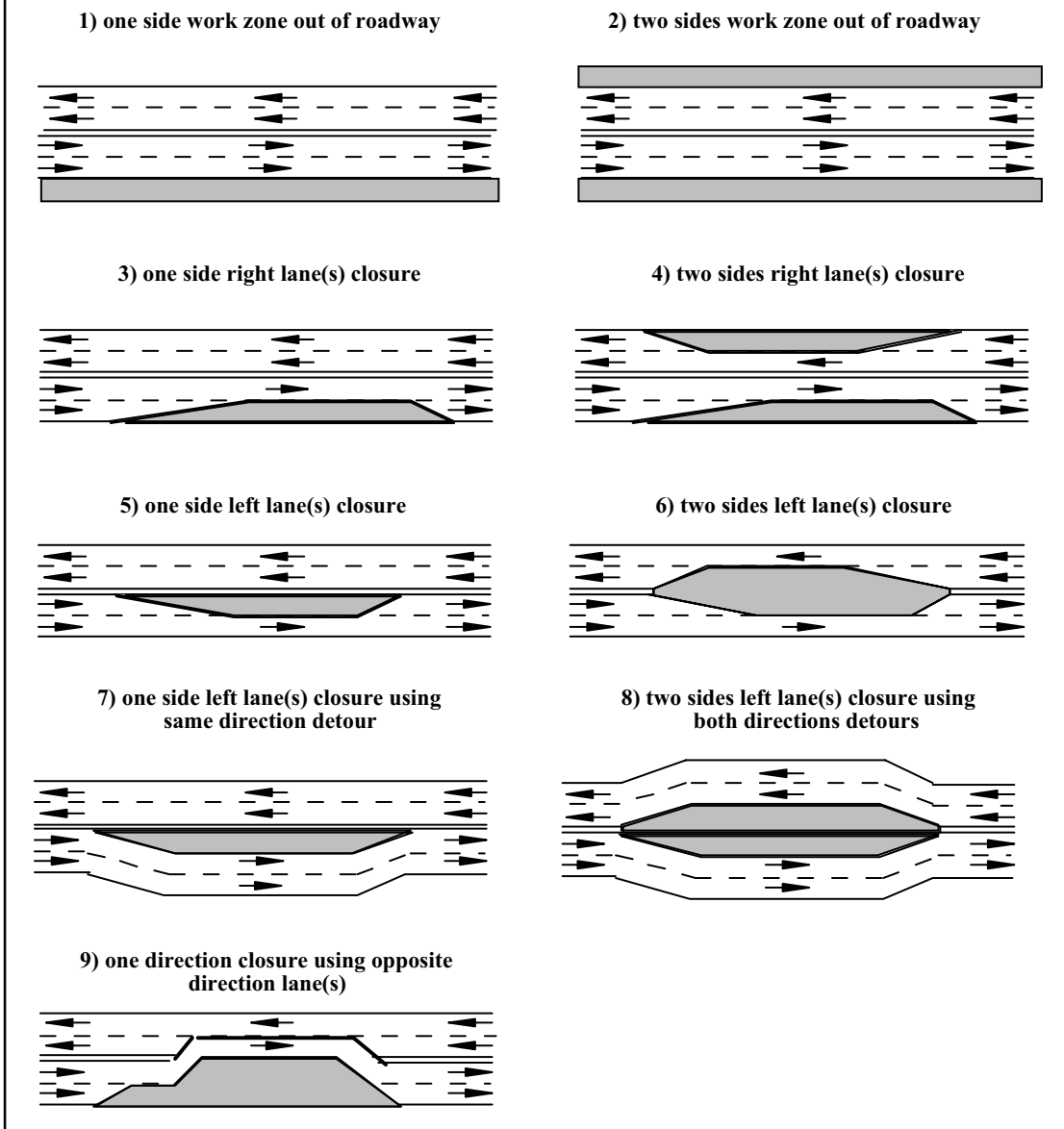


Figure 3.3 Work Zone Locations on Multilane Undivided Arterial Streets

IV. Two lanes arterial streets.

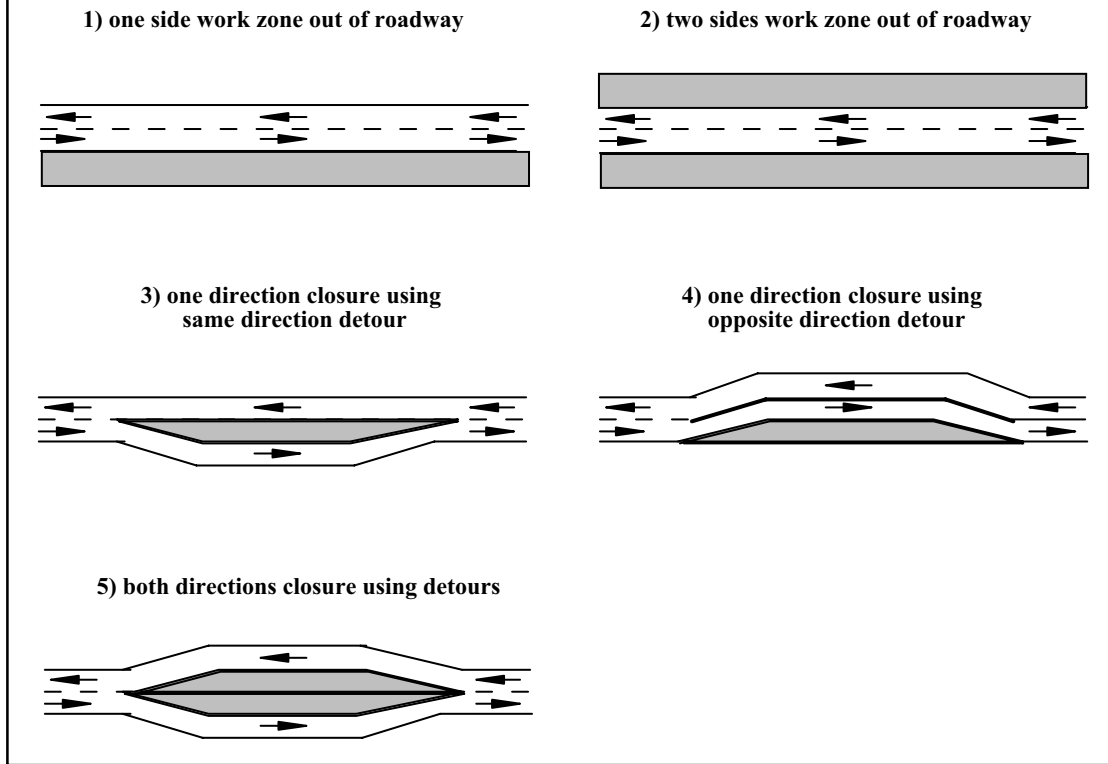


Figure 3.4 Work Zone Locations on Two-Lane Arterial Streets

Then, different traffic control sections on those work zones were analyzed. Figure 3.5 shows general traffic control sections in urban arterial work zones which are typical for all work zone types. The specifics of urban environment add special requirements for TCP design on each section. For example, the “Advance Information Zone” should provide exact information about work zone location, which will assist drivers in selecting alternative routes. The “Transition Zone”, where flow redistributes from the permanent to the temporary roadway, taking into account the effect of the intersections, should be transferred to the upstream street block. The “Active Roadwork Zone” should consider numerous access roadways to the local businesses. Also, on all sections, it is very important to enforce drivers’ attention to the work zone signs in a “visual noise environment”.

3.1.1 General Principles of Perception that Apply to Urban Work Zone Traffic Control Devices Placement and Design.

Literature review on signage perception has been conducted including research findings on threshold values for letter size and number of syllables or words at different speeds, and maximum number of signs in vertical or horizontal assemblies. Serious consideration has also been given to basic and relevant research on human perception. Basic research on human perception indicates that the abstract design principles that guide the organization of the so-called “good form” play an important role in the composition and perception of groups of elements in the visual field (Ref 33). Such principles have already been taken into account in the design of regulatory and warning signs. Design concepts that are directly related to the perception of a “readable,” or “good form,” such as hierarchical organization of elements, closure and unity, definition of dominance and balance, and figure-ground relationships, if seen in the context of signage perception, provide a better understanding of how drivers perceive individual or combined signs in work zones. Such concepts and principles are taken into account in the proposed recommendations for the placement and design of signage and traffic devices in urban work zones. The same concepts and principles discussed in the following sections, can also be considered as the broader perceptual framework that needs to be taken into consideration for case-specific decisions.

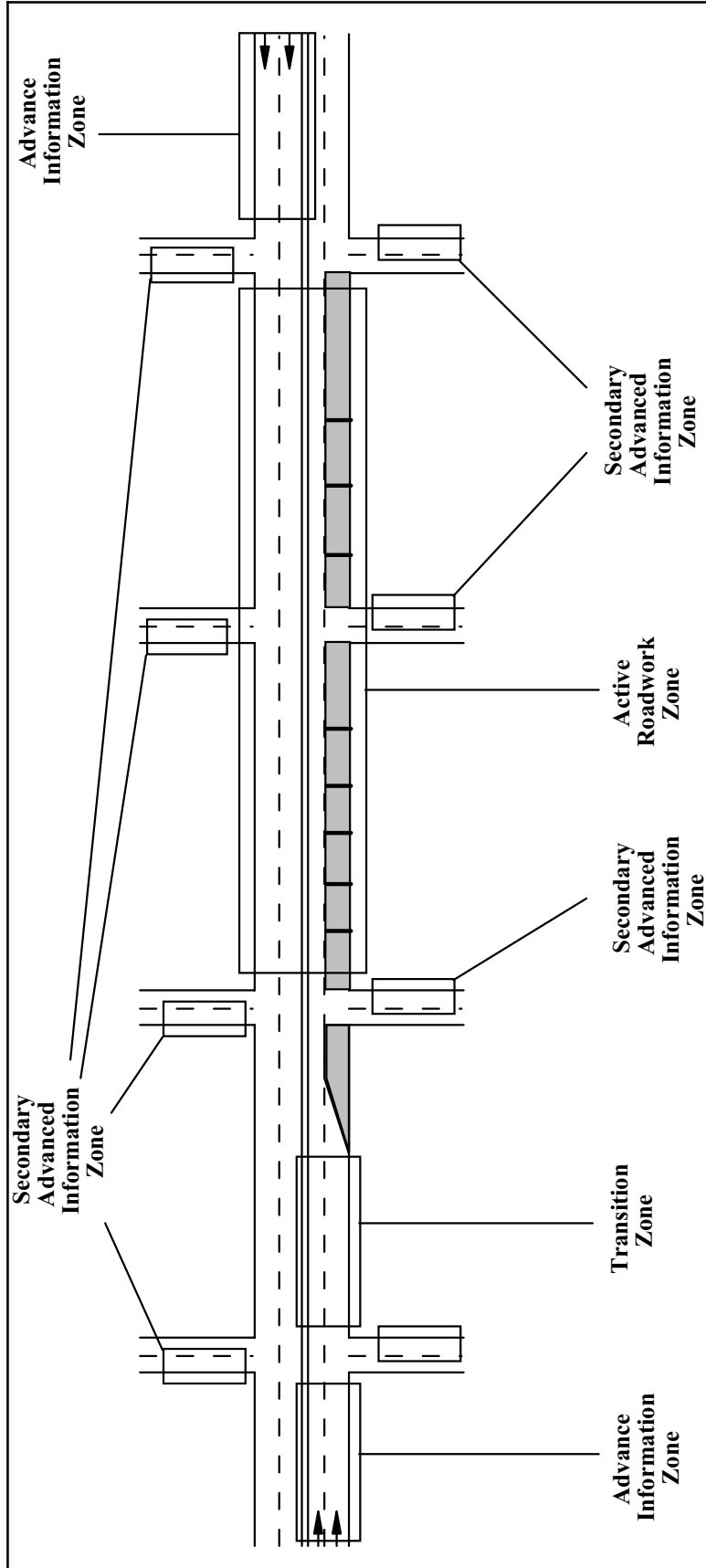


Figure 3.5 General Traffic Control Sections on Urban Arterial Streets Work Zones

3.1.2 Signage perception conditions specific to work zones

A relevant human perception principles has indicated that current research findings and practices do not address certain signage conditions which are specific to work zones. These conditions, already identified as problems in the field investigation, are as follows:

Permanent and temporary traffic sign overload. Typical of work zones on urban freeways with numerous exits is the plethora of permanent traffic signs that overload the visual scene and reduce drivers' attention to temporary signs. The placement of permanent and temporary signs on urban arterial streets very often exceeds requirements according to which the number of signs at each location should not exceed three. This overload of signs may result in drivers missing critical work zone information.

Way-finding information. Way-finding information is related to necessary information, typical of commercial zones, that should not be obstructed by the work zone signage. Directions on signage design and placement to optimize the driver's search for information in urban work zones are consequently needed, as well as a review of city regulations on commercial signage in major urban centers in Texas.

Visual noise. Visual noise refers to visual overload caused by information that is not required for driving, such as advertising information on billboards. Eye fixation is proven to decrease with visual noise, which results in reduced sign detection distance and inadequate time for response.

Taking into account the above mentioned signage perception conditions specific to work zones (sign overload, visual noise, way-finding), and the principles of human perception, a set of principles that apply to work zone signage perception, has been formulated. Accordingly, for the effective placement of signs, in addition to code requirements, geometric design, and other considerations that have already been addressed in previous sections of this report, attention now must be given to the following issues:

Dominance in the visual field. Dominance in the driver's visual field refers to the perception of a specific sign against its context. "Context" is the background of visual information or noise in the field that may interfere with the perception of the specific sign. "Dominance in the driver's visual field" means identifying the elements that call for attention in the immediate environment of a sign. Very often dominance is found in elements that contribute to visual noise, such as billboards or other structures in close proximity to the sign. In such instances moving advertisement information away from the immediate context of the intended position of a work zone sign, as mentioned in the previous section, is the obvious solution. Frequently groups of permanent signs, that cannot be removed or obstructed, are the most dominant features in the intended context of a work zone traffic sign. Dominance in the driver's visual field in this case should also take into account the design features and impact of certain signs on driver's response, such as the strong impact of a stop sign.

A recommendation in this case consists in signage placement adjustments that take into consideration the impact of other signs, background noise, or other information. In other words, before making decisions on the placement of signs and other traffic control devices, an analysis of each specific situation to determine existing and desired dominance in the visual field is required. Once a dominant element that cannot be removed or obstructed is identified, signs then need to be placed at a safe distance from it, so that this element does not interfere with sign perception. In this regard, although the placement and

distance of work zone signs is generally determined by the speed of the vehicle, additional adjustments, based on background noise or other information, need to be made. Devices that call for attention, such as flashing lights or moving arrows, can also be used to shift the dominance in the driver's visual field and to attract their attention to work zone information. In the proposed traffic control plan the placement of larger size road information signs, to assure dominance against a visually heavy context, is in accordance with this main principle.

Hierarchical organization and grouping of sign information. Urban work zones are often characterized by an overload of permanent, temporary, and commercial signs. To assist drivers' perception of signs, each traffic condition needs to be analyzed and signs that address the same type of information need to be organized in groups and hierarchies need to be established among different types of signs. After a hierarchy is established, decisions about removing or covering signs, that will reduce information overload or confusion in driver directions, should be made. Since the human mind tends to treat similar elements as belonging to the same group, grouping signs in assemblies will certainly facilitate drivers' perception of work zone information. Significant decisions on groupings of signage will need to take into account basic research factors which include vertical versus horizontal organization of information, maximum number of words per sign, and maximum number of signs on the same assembly. For commercial zone signs a vertical organization of information can be recommended.

The sequential organization of similar information requires that the influence zone of individual signs is taken into account so that all signs in a sequence contribute to the same type of information. Inversely, placement of signs with different types of information that alternate consistently, may confuse drivers and not allow them to draw associations between similar signs.

Perception of continuity in the visual field. Perception of continuity in the visual field mostly refers to the perception of crossroad access as a result of the placement of traffic blocking devices. From the driver's point of view, devices for blocking or allowing access to crossroads on the opposite side of the street and through a work zone often appear projected in front or behind work zone barriers along the main street, or near construction equipment. This means that the visual image that the driver receives can be complex and confusing. The placement of devices, in a way that some form of horizontal alignment and continuity of at least one feature of the device is achieved, is necessary. In other words, there is a need for some type of horizontal continuity along the work zone boundaries to clearly mark areas where "pass through" is not allowed, or, inversely, discontinuities in the horizontal alignment, that render accesses to crossroads perceptible.

Depth perception and optical illusions. The perception of depth in the driver's visual field is critical since it gives him or her clues about the side distance from a work zone, from an obstacle, or the beginning of a closed lane. It is also critical, since, based on human clues on absolute distance, the driver may use judgment on how soon to decelerate. In general, when several buildings exist in the proximity of streets, then various building features of known dimensions, such as doors, and windows provide adequate clues to drivers about the distance from obstacles in their visual field. But, when buildings are at a further distance from the street, or in reduced environmental lighting conditions as in nighttime, there may not be adequate context information to help drivers get an accurate estimate of distances from a work zone barrier. In such situations, appropriate placement of

vertical blocking devices may help in conveying accurate information about distances in drivers' visual field. Optical illusions may also be used in work zones when a reduced or increased perception of depth is required. More specifically, placing work zone devices in an aligned configuration, but at an angle in respect to the boundaries of the work zone, may alter a driver's perception of absolute distance from a work zone boundary or obstacle. In addition, the placement of vertical devices, such as barrels at increasing or decreasing distance from each other, may also alter the driver's perception of depth and, respectively, his or her clues on absolute distance from an obstacle. Driving at a close proximity to construction equipment may become the cause of accidents, even if adequate clearance is provided for construction operations, due to reduced or distorted depth perception. In our proposition, the placement of a see-through traffic device, like a wire mesh that provides the assurance of a spatial barrier between construction equipment and drivers, can be recommended.

Low visibility at nighttime. Assuming the level of retro-reflectivity is properly addressed in work zone sign design and placement, then low visibility conditions that require special attention include the following:

1. Vertical changes on road pavement level. Unless if appropriately marked with vertical reflective elements that reach the level of road pavement, drivers will not be able to clearly perceive side distances from vertical changes on road pavement. As an example, at the Lake Austin Boulevard, barrels placed on the top of an elevated feature, and at a short distance from the its edge, do not provide accurate distance information to drivers. Therefore the application of vertical reflective elements that reach the level of road pavement on all elements raised over road's level can be recommended.
2. Tall construction equipment, on the road side. Reflective elements may be needed to call drivers' attention to necessary clearances.
3. Overhead structures, such as temporary scaffolding for bridge constructions. Installation of reflective devices or markings to assure drivers attention to clearances are required.
4. Cross road access information. Night visibility needs to be addressed in reference to the perception of devices that define the boundaries of work zones and help drivers find their way to cross road access. The need for a horizontal alignment and continuity to be achieved with the appropriate placement or design of traffic devices is already addressed in the previous section, and applies to both day and night time. The difference may be in the physical expression of this continuity or discontinuity. Features in devices that allow for the formation of a continuous reflective ribbon, with interruptions only when an access is needed, is therefore desired and part of the developed recommendations.

High levels of illumination in work zone areas/ eye adaptation. High levels of illumination in work zone areas is related to illumination in work zones when construction takes place at night. Two different types of problems are identified:

1. A problem may appear when bright directional light from a construction zone, adjacent to the road, falls within the drivers visual field. This may interfere with the perception of signage and has to be addressed. Further research on ratio's of ambient and incident light on signage as well as strategies to avoid veiling reflections and glare is required.
2. A problem may also appear when the overall levels of diffuse illumination in the part of the road where the construction takes place are very high. When moving from a work-zone to a regular road condition, a certain amount of time is needed for the eye to adjust to a significantly different level of illumination. This time increases with the age of the driver, and certainly needs to be addressed.

Use of pictorial symbol versus text in sign use and design. In the current version of MUTCD code two different types of signs for use in work zones exist a) signs with text information and b) signs with pictorial information. The main advantage of pictorial treatment is that it enables the viewer to instantly grasp the significance of the message and to place it within recognizable parameters. A consideration though in the use of pictorial treatment is related to whether the symbolism of the image is understood by all drivers in the same way.

A second advantage in the use of symbolic pictorial imagery versus text information presents, is that pictorial treatment may have a universal effect when compared to text signs that are subject to language barriers. This is a major issue of consideration in Texas due to the large Hispanic community.

A third advantage is that, because of the instant grasp of information in pictorial treatments, more symbolic analogues can be linked together in one single compound of signs.

Finally a characteristic of work zone signage that is inherently related to the design parameters of the two different types of signage and may suggest the use of symbolic over text signs is the following. In work zone signs with text information, which present a level of color contrast between text (black) and background (any orange hue) not as strong as in other signs, (ie in school signs), text from a distance appears as an arrangement of smaller elements against a non highly contrasting background. Due to this feature alone, work signs with text information are not detected and read as fast as work zone pictorial signs, which, because of the size and shape of the characteristic symbolic image, can be easily detected at high speeds and from long distances. A consideration in this regard is that minimum levels of retro-reflectivity in Federal Highway Administration guidelines, need to be addressed in relation to color contrast.

3.1.3 Recommended Draft Guidelines for Urban Arterial Streets Work Zone Traffic Control

Based on the joint analysis of the identified problems, common traffic control schemes, and principles of human perception, the general draft guideline for traffic control plan on urban arterial streets work zones was developed and represented in the Figure 3.6.

For “Advance Information Zone” and “Secondary Advanced Information Zone”, a new signs that provides advance information on lane closure by indicating road intersections between which construction takes places, another words all necessary information, that a driver, approaching a work zone area, needs to make a decision on what route to follow to avoid traffic delays were developed. Here and further, work zone traffic control sections, named correspondingly with the Figure 3.5. For the design of the “advance information on lane closure between intersections” sign (fig.3.7) , use of text is made mainly for necessary information on road names. This sign will be used in instances where drivers’ early decision to choose an alternative route to avoid traffic congestion / delays due to a work zone is of critical importance. Two different signs have been developed to facilitate drivers with some familiarity with the area, who approach a work zone from the main road along which construction happens (fig.3.7a), or from a crossing streets (fig. 3.7b). The alignment of the schematic plan, representing the location of work zone between intersections, with drivers’ direction will facilitate the drivers’ spatial orientation in relation to the upcoming road closure, and reduce time required for decision making.

The next recommendation related to “Transition Zone” and formulated as to begin necessary lane closure a block upstream of the “Active Roadwork Zone”. The Figures 3.8 and 3.9 shows the initial work zone section for two cases: (1) arterial street intersects with lower significance street (Figure 3.8), and (2) with similar arterial street (Figure 3.9).

Figure 3.10 represent recommended traffic control plan for the “Active Roadwork Zone”. To address the common problem of local accesses, a new signs and directions for sign and traffic device placement are proposed. The proposed new sign on commercial zone information is intended to assist drivers to sort out the information they need by grouping all business’ names in one sign.

In the proposed scheme the placement of currently used blocking devices (cones) in close distance from each other, as indicated in Figure 3.11 is intended to assist drivers to easily perceive work zone boundary definitions in adjacent roads, or roads in opposite directions.

If low profile barriers are foreseen for work zone separation, the application of vertical reflective elements that reach the level of road pavement are recommended (Figure 3.12).

As it was noted, driving at a close proximity to construction equipment may become the cause of accidents, even if adequate clearance is provided for construction operations, due to reduced or distorted depth perception. Figure 3.13 show the recommended placement of a see through device, like a net, that provide the assurance of a spatial barrier between construction equipment and drivers.

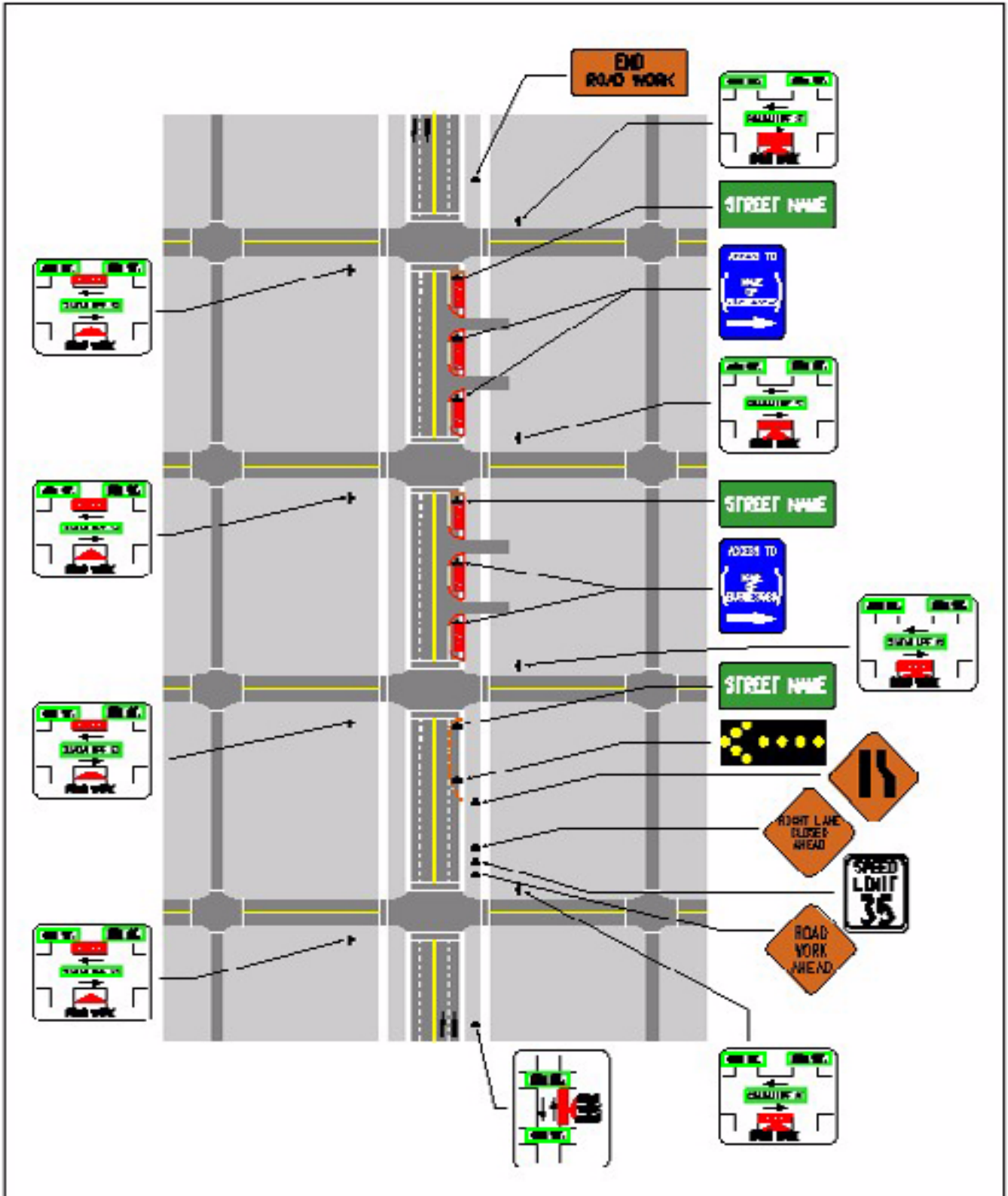
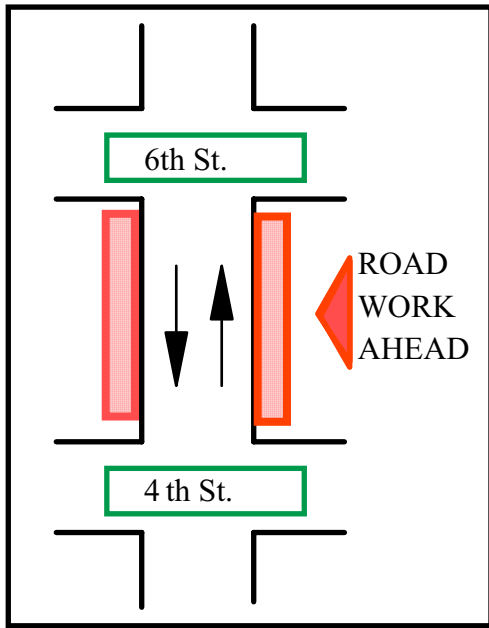
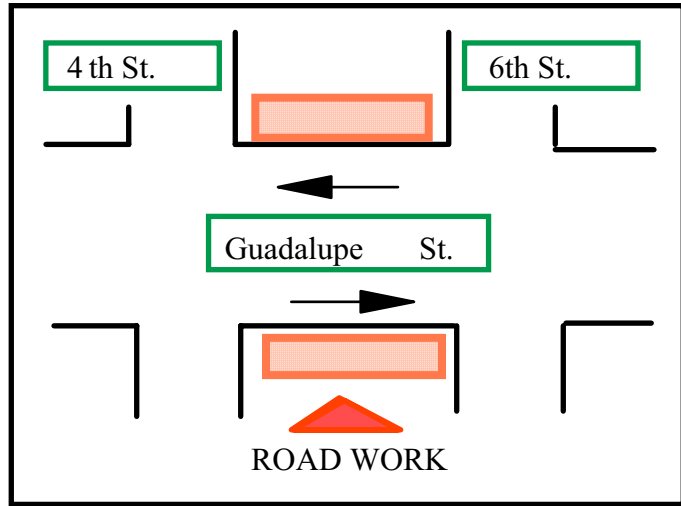


Figure 3.6 General Guidelines for Traffic Control on Urban Arterial Streets Work Zones



a)



b)

Figure 3.7 General Approach for Advance Information Signs Design for:
 a) Main Street, and b) for Crossing Streets

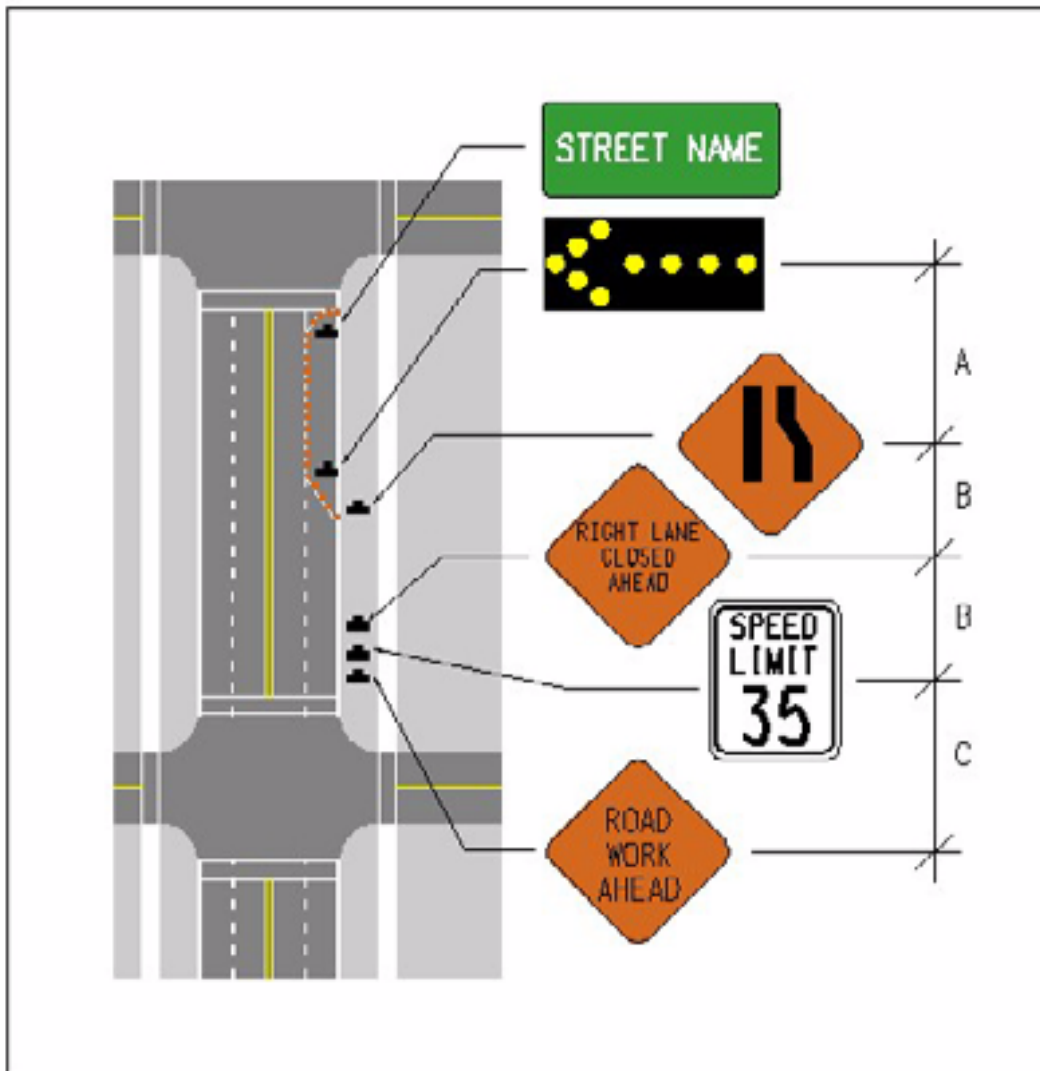


Figure 3.8 Recommended Transition Zone Design in Case of Intersection with Street of Lower Significance

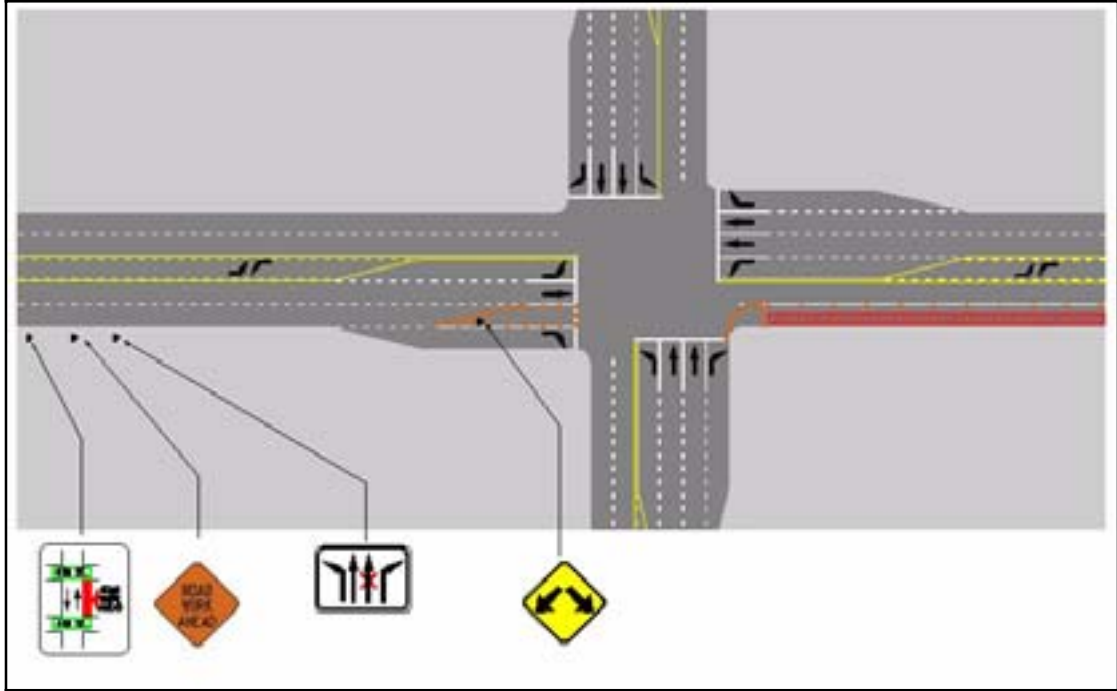


Figure 3.9 Recommended Transition Zone Design in Case of Intersection with Arterial Street

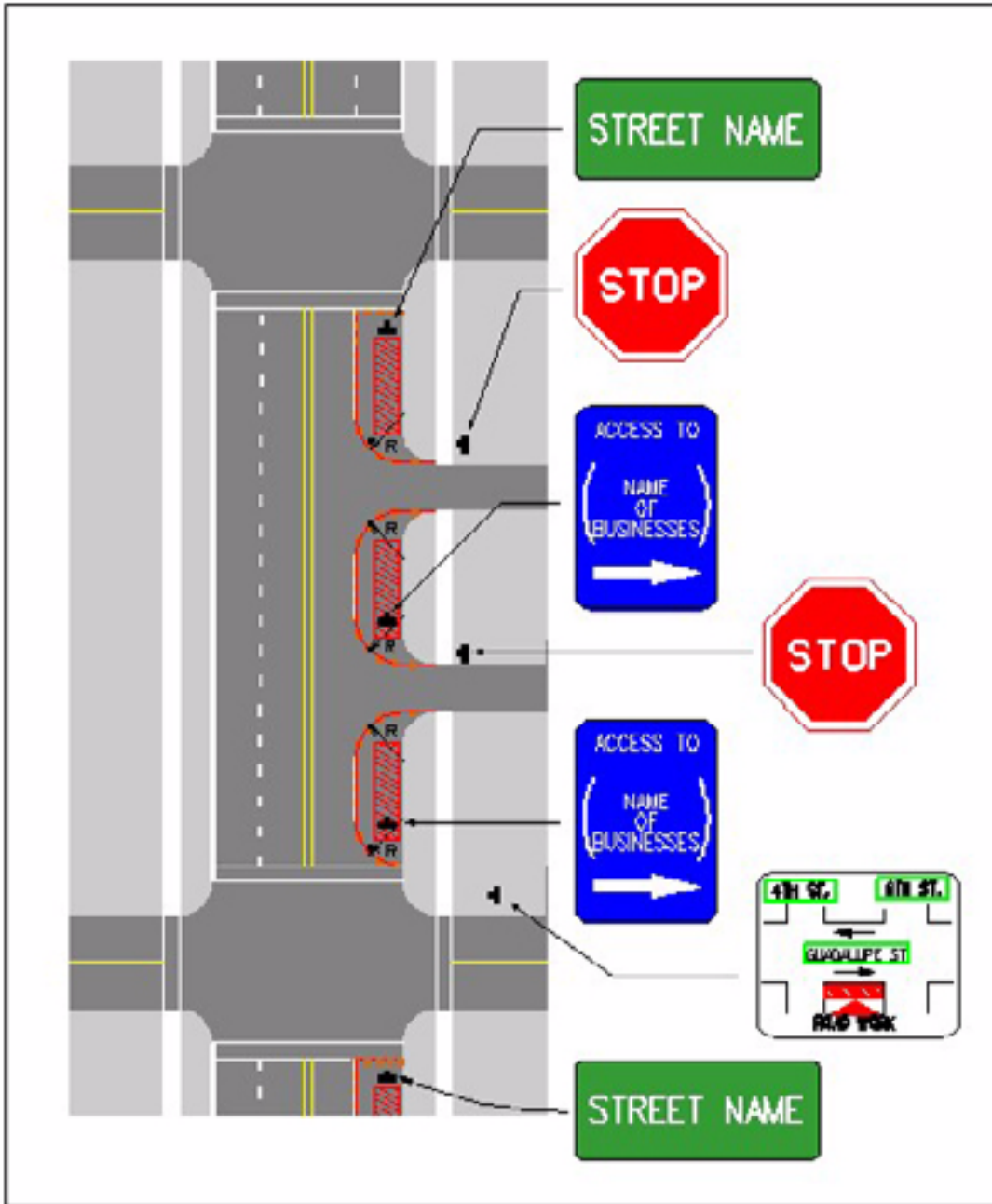


Figure 3.10 Recommended Active Roadwork Zone Design

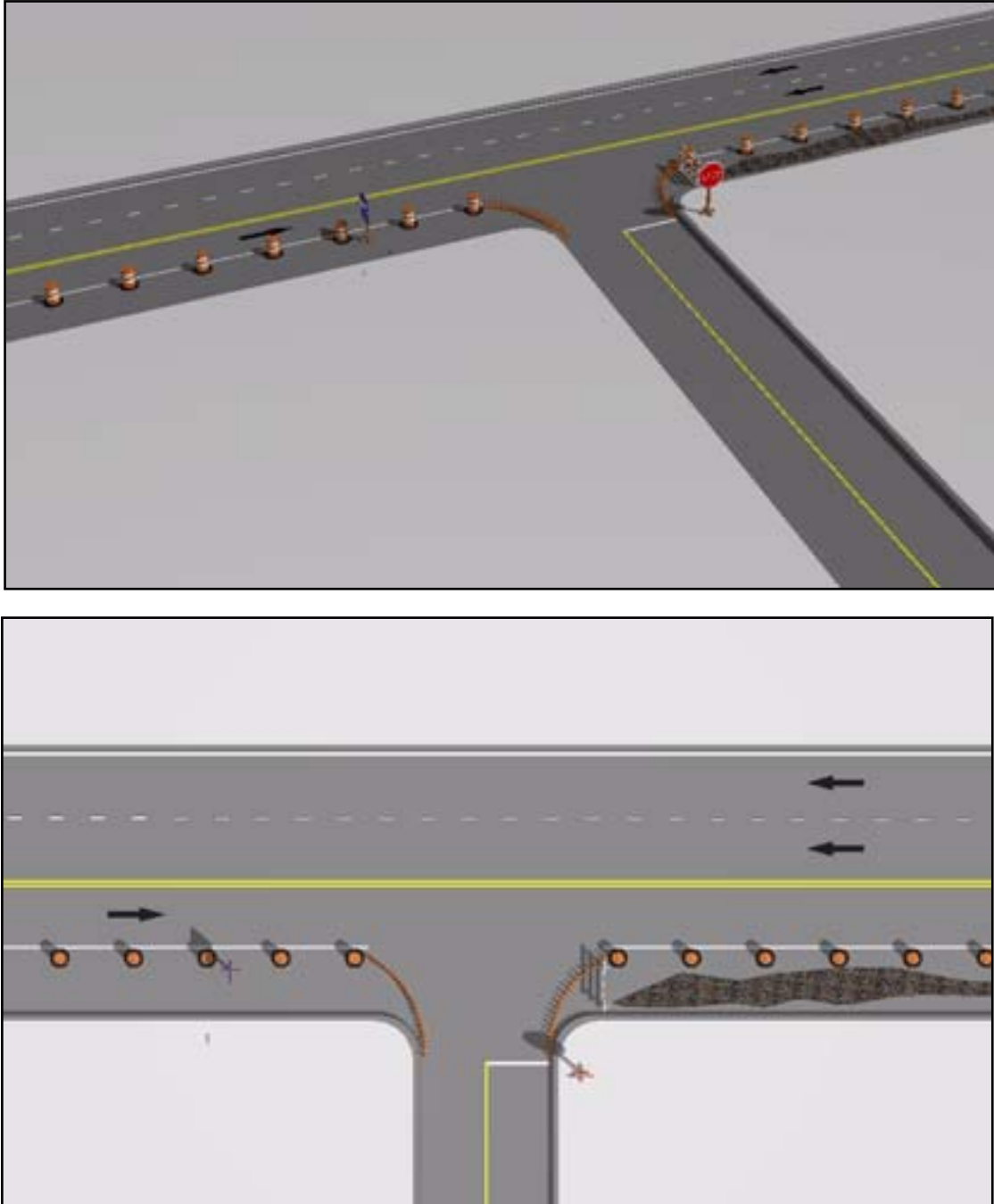


Figure 3.11 Recommended Placement of Blocking Devices on Local Access Roads



Figure 3.12 Recommended Vertical Markings of Low-Profile Barriers



Figure 3.13 Recommended Protection of Traffic when Construction Mechanism is in Close Proximity

3.2 Training Materials

Another solution for work zone traffic control improvements is better training of TxDOT staff involved in the work zone design and activity.

The CTR research team and the TxDOT Training Department staff, formulated training goals for two target groups two target groups identified as (1) inspectors, and (2) engineers or TCP designers. Accordingly, the CTR research team reviewed training materials currently in use by TxDOT with the purpose to determine what can be incorporated from the research findings.

Such problems as unspecified traffic control device placement and mixing, unstable installation, poor assembly of device supports, unused signs in a clear zone, still visible permanent signs or pavement markings, insufficient technical state of the devices, etc. as a very frequent on urban arterial streets work zones. Mostly, such problems can be fixed during the TxDOT regular inspections. With this purpose the research team proposed some additions (Figure 3.14) to the "Quality Guidelines for Work Zone Traffic Control Devices" currently used by TxDOT. This brochure can be used for inspectors training purposes as well as a field booklet to reduce impact of inspector's subjective opinion.

Identified traffic control problems, as well as literature review of accident statistics, described in Chapter 2, are good sources for illustration of importance of different design solutions represented in TxDOT training course "Work Zone Traffic Control – Design and Operations".



Figure 3.14 Recommended Additions to the “Quality Guidelines for Work Zone Traffic Control Devices”

3.3 Second Year Work Plan

Task 5 "Countermeasure Evaluation" is planned for the project second year. Task 5 includes three subtasks: (a) prepare data Collection tools; (b) data collection; and (c) data analysis. Drivers' perception and reactions will be investigated using computer simulations and real traffic experiments, and the effectiveness of proposed recommendations will be determined.

The first step will be to investigate human perception of new signs using computer animation procedures, and to test the efficiency of recommended sign placement and designs. The team will investigate the quantity of errors, signs missed by drivers, difficulties in reading and understanding signs. The general outline of the computer experiments, which will be revised during subtask 5a, is as follows:

I. First set of experiments: Perception of work zone and other signs sequential organization or groupings.

- a) Generate a traffic scene characterized by visual noise and test what subjects remember after exposure for 1.5 minutes to various individual signs when (1) only one sign is related to work zone, and (2) more than one signs refers to work zone.
- b) Conduct similar experiment with various groupings of signs.

II. Second set of experiments: Perception of work zone sign design features.

III. Third set of experiments: Way-finding. Way-finding in zones with numerous control devices and test methods for providing visual continuity.

IV. Fourth set of experiments: Determine the effect of optical illusions caused by the placement of various traffic control devices on the driver's perception.

The second step will be a field investigation of the proposed countermeasure effectiveness. "Before" and "after" field observations on the selected work zones will be reviewed during the second year of the project. "Before" conditions are determined as a work zone designed corresponding to current MUTCD requirements. Following the implementation of the developed recommendations, "after" observations will be conducted. For quantitative descriptions of traffic conditions, an analysis of speed-time history will be undertaken together with the analysis of the driver's psycho-physiological reactions.

Video recording of traffic in different work zone sections and car following test-driving through the work zone using an instrumented vehicle have been selected as the most adequate for the tasks of experimental observations. For the car following test driving, the CTR vehicle was equipped with a digital camcorder, a portable device for driver's electrocardiogram and skin-galvanic reaction registration, and a special device and computer software for registering the vehicle's parameters (speed, acceleration/deceleration, engine revolutions per minute, etc.). Different tests in the laboratory were conducted to identify positions of electrodes on the driver's body to

register the strongest signal. Then, test drives in real traffic were made to determine the effect of vehicle vibration and the driver's movements on the electrocardiogram registration. All necessary adjustments were made. Then several test drives were made. During each test drive, a driver's electrocardiogram (waveform) was registered, as well as a video recording of situations in the driver's field of view and speed-time history.

Therefore, it can be noted that at the present time the CTR research team has the appropriate equipment and methodologies for field observations, as well as a methodology for data analysis. After proposed recommendations are investigated in the lab and all necessary adjustments are made, the field experiments will be conducted.

During the second year the research team based on the results of computer and field experiments will develop the final version of draft guideline for traffic control plan on urban arterial streets work zones. At the same time, the research team will work with TxDOT Training Department to develop training materials regarding urban work zone problems for TCP designers. The proposed guidelines will be recommended as an addendum to the "Reference Guide to Work Zone Traffic Control" as well as the training course "Work Zone Traffic Control - Design and Operations".

The CTR research team will continue accident statistics analysis on Texas urban arterial streets work zones. Currently, the City of Houston's Department of Public Works and Engineering provided data regarding work zones conducted in the Houston metropolitan area during 2000, 2001, and the 2002. The database contains work zone dates, times, duration, types of activity, and lane closure strategy. The CTR researchers reviewed the City of Houston work zone database and selected work zones most adequate for the research goals for accident statistics analysis. The list of the selected work zones with exact locations and dates was submitted to the Houston Police Department, who provided the researchers with data about police activity in the selected areas. At present time, researchers continue identifying from this huge database police activities related to work zone accidents. After selection of appropriate codes, this data will be sent to the Houston Police Department, and they will provide the corresponding police records.

The accident data for the previous 2/3 years on the corresponding streets will be collected from the Texas Department of Public Safety.

In addition, accident statistics before and during a work zone will be analyzed using information from major automobile insurance companies' database. This method allows the research team to consider heavy accidents as fatal and injury (DPS data), as well as small property damage accidents (insurance data).

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Appendix A
Observed Work Zones in Austin

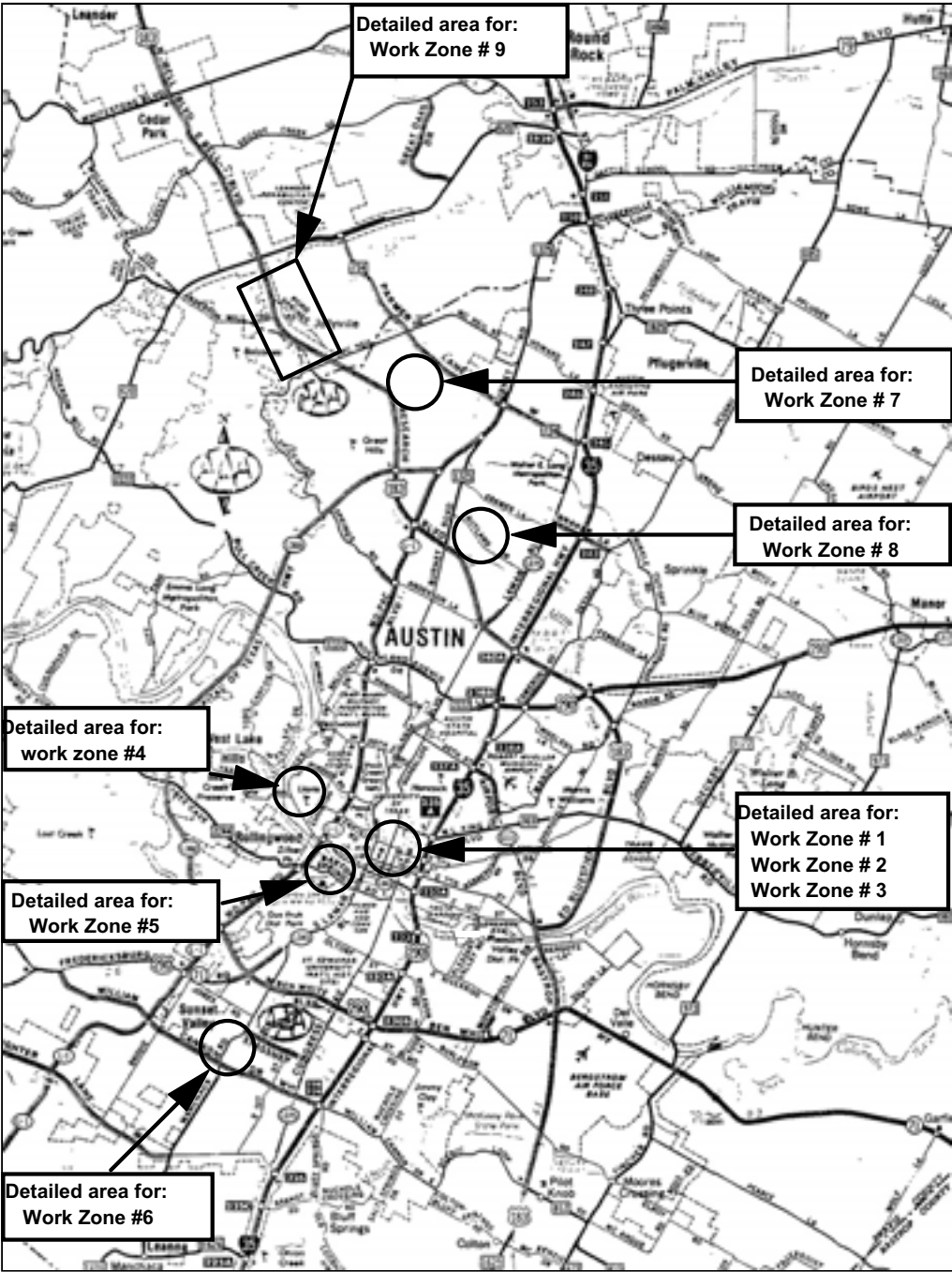


Figure A.1 Austin Metropolitan Area Map with Work Zone Locations



Figure A.2 Detailed Area for Work Zone # 1 (600 Guadalupe St., Austin).

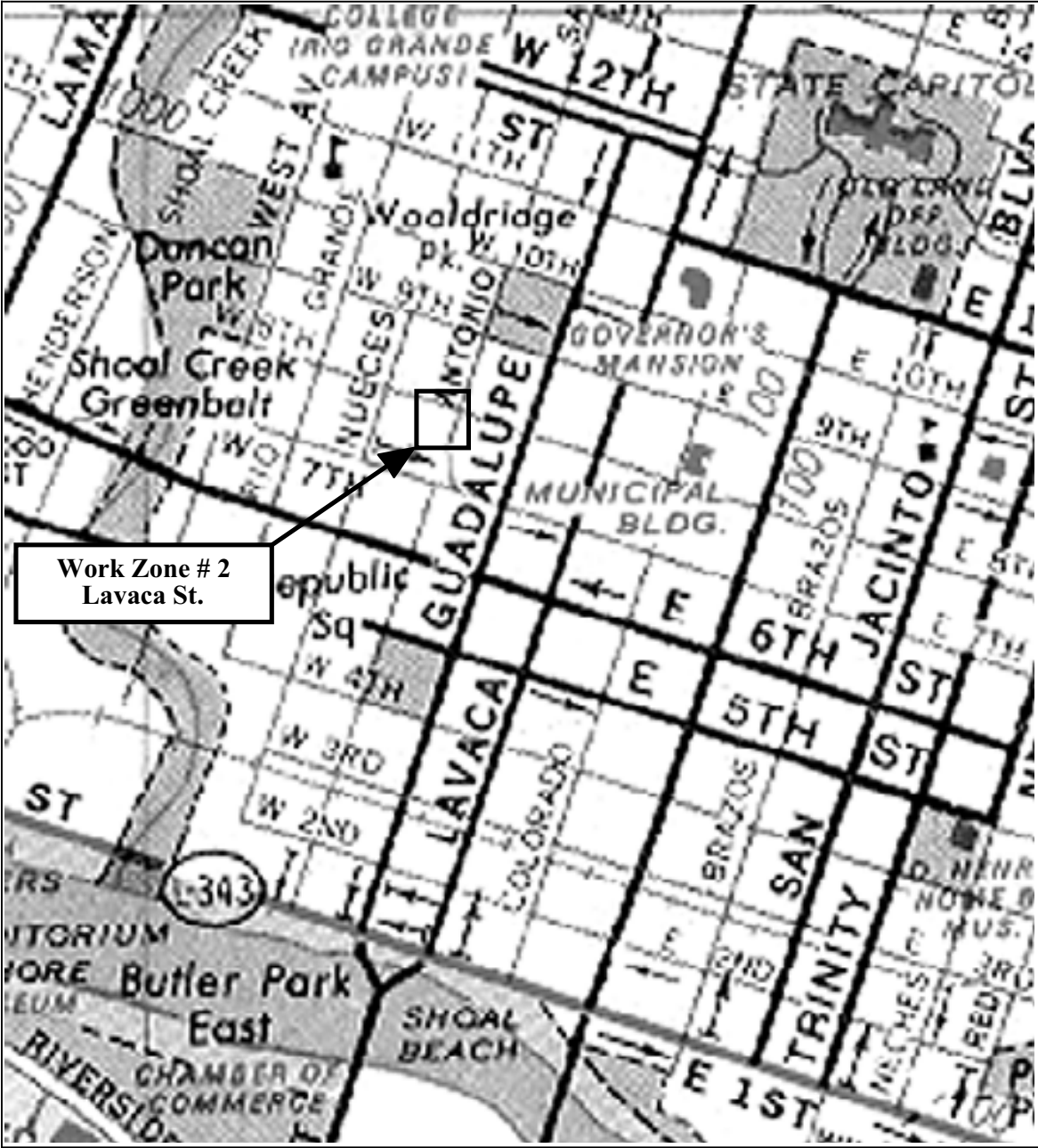


Figure A.3 Detailed Area for Work Zone # 2 (Lavaca St., Austin).

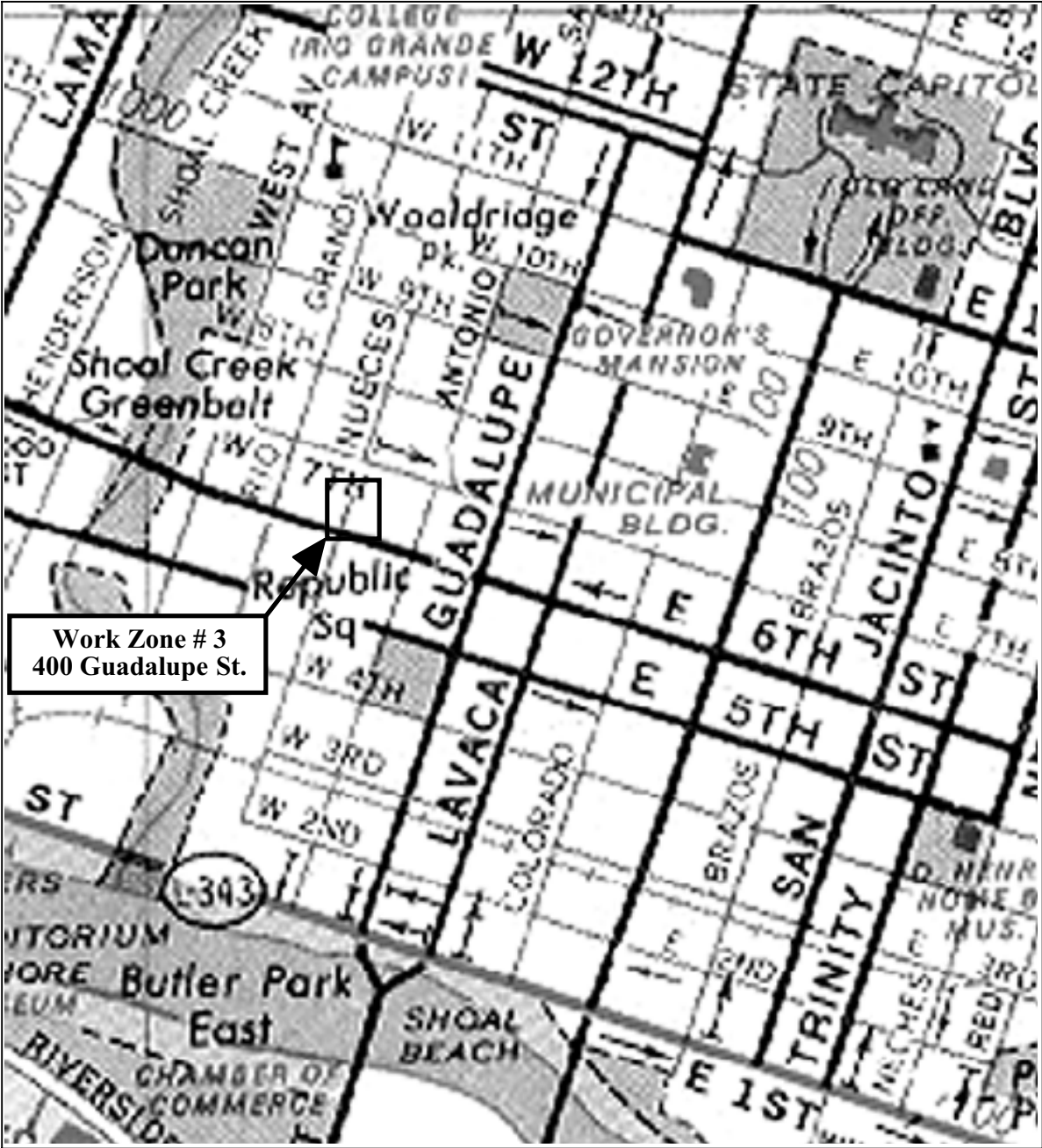


Figure A.4 Detailed Area for Work Zone # 3 (400 Guadalupe St., Austin)

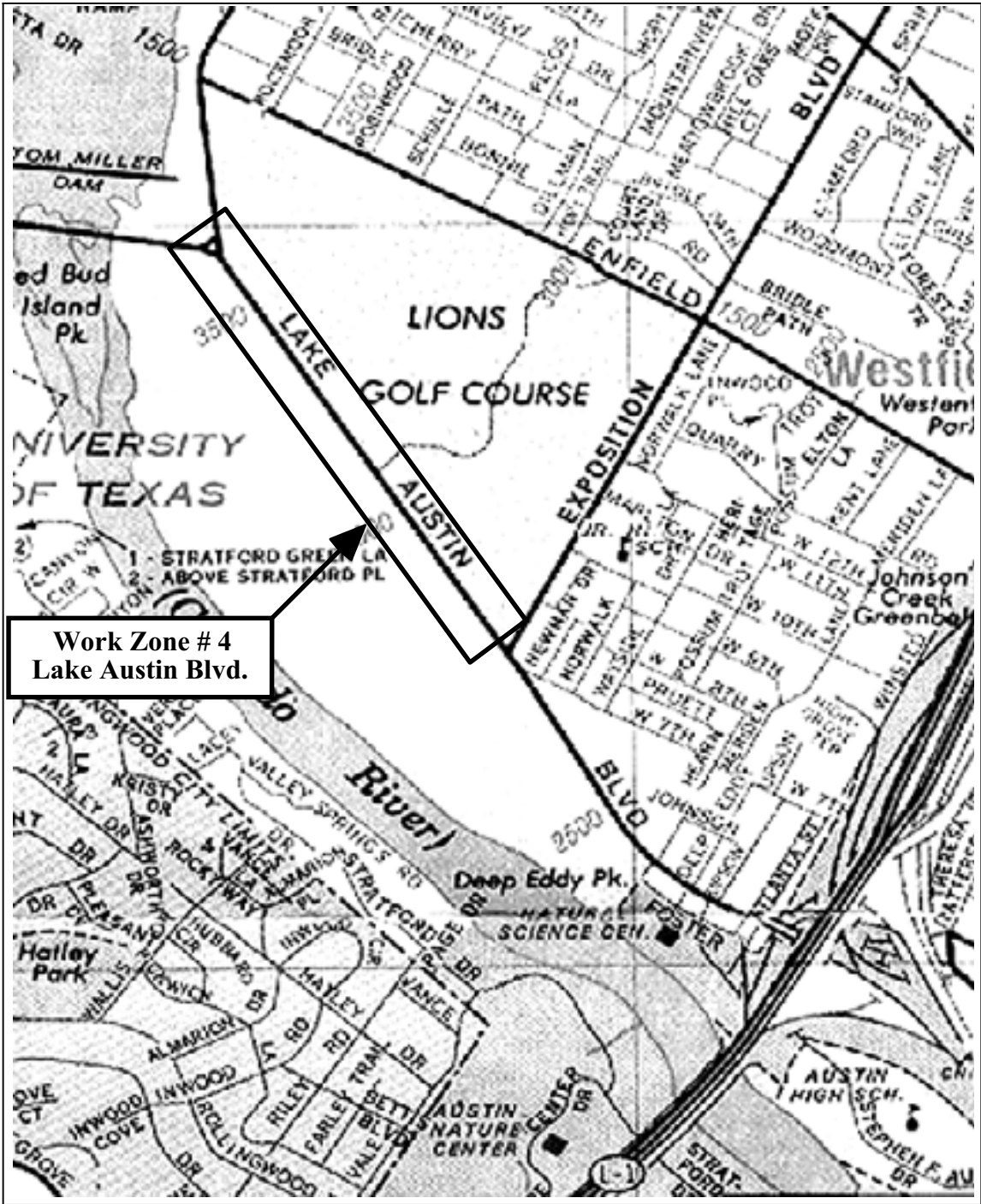


Figure A.5 Detailed Area for Work Zone # 4 (Lake Austin Blvd., Austin)



Figure A.6 Detailed Area for Work Zone # 5 (Barton Springs Rd., Austin)

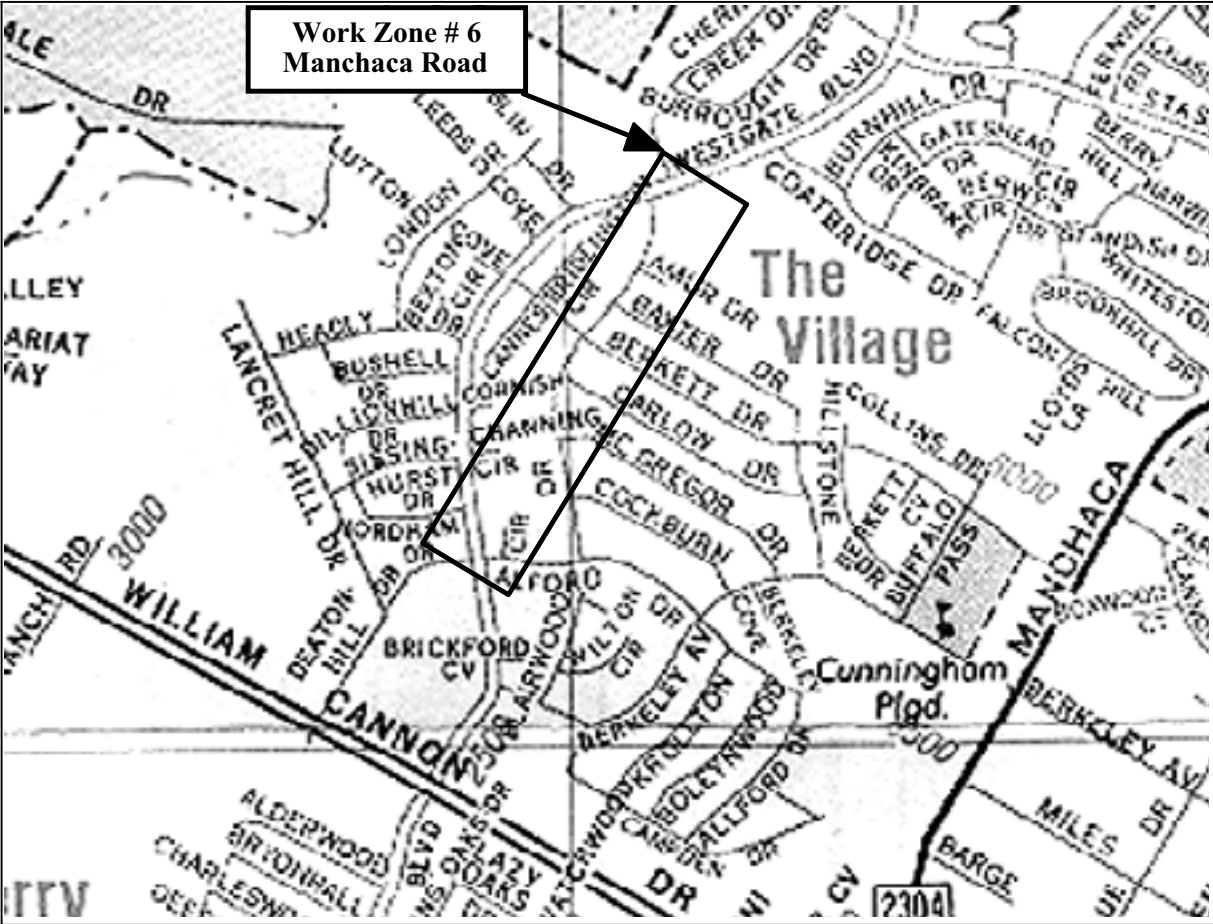


Figure A.7 Detailed Area for Work Zone # 6 (Manchaca Rd., Austin)

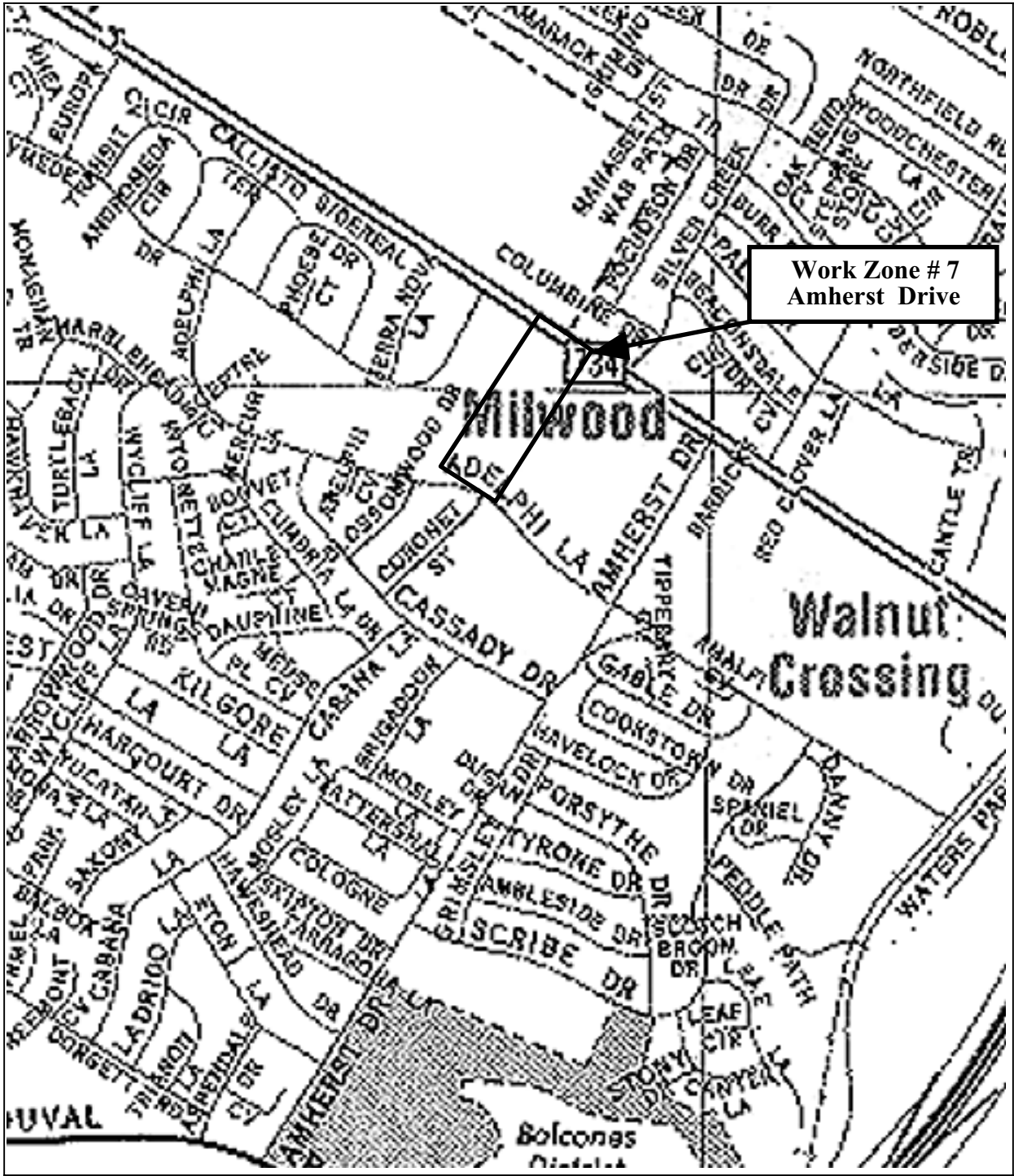


Figure A.8 Detailed Area for Work Zone # 7 (Amherst Dr., Austin)



Figure A.9 Detailed Area for Work Zone # 8 (Rutland Dr., Austin)

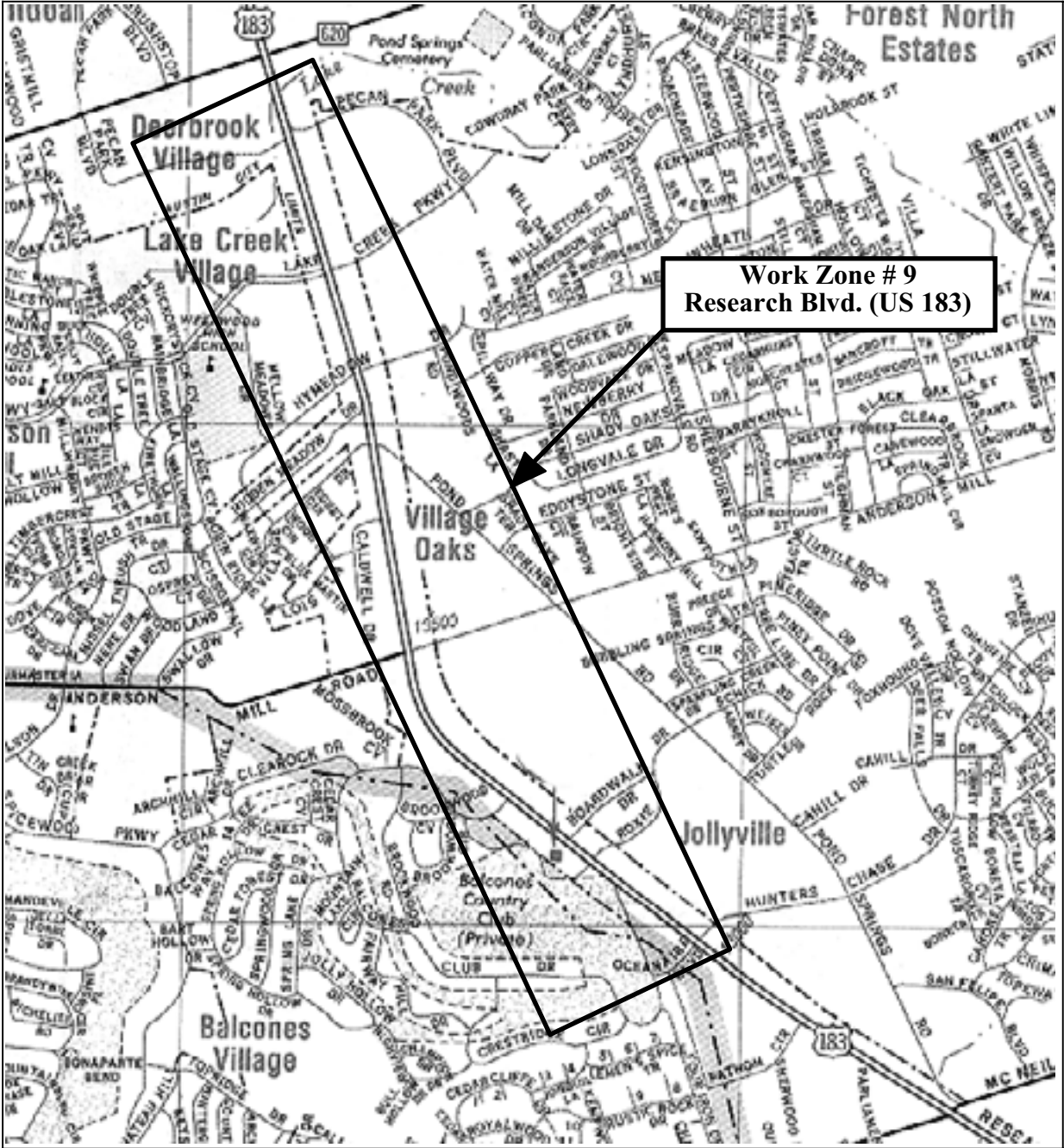


Figure A.10 Detailed Area for Work Zone # 9 (Research Blvd., Austin)

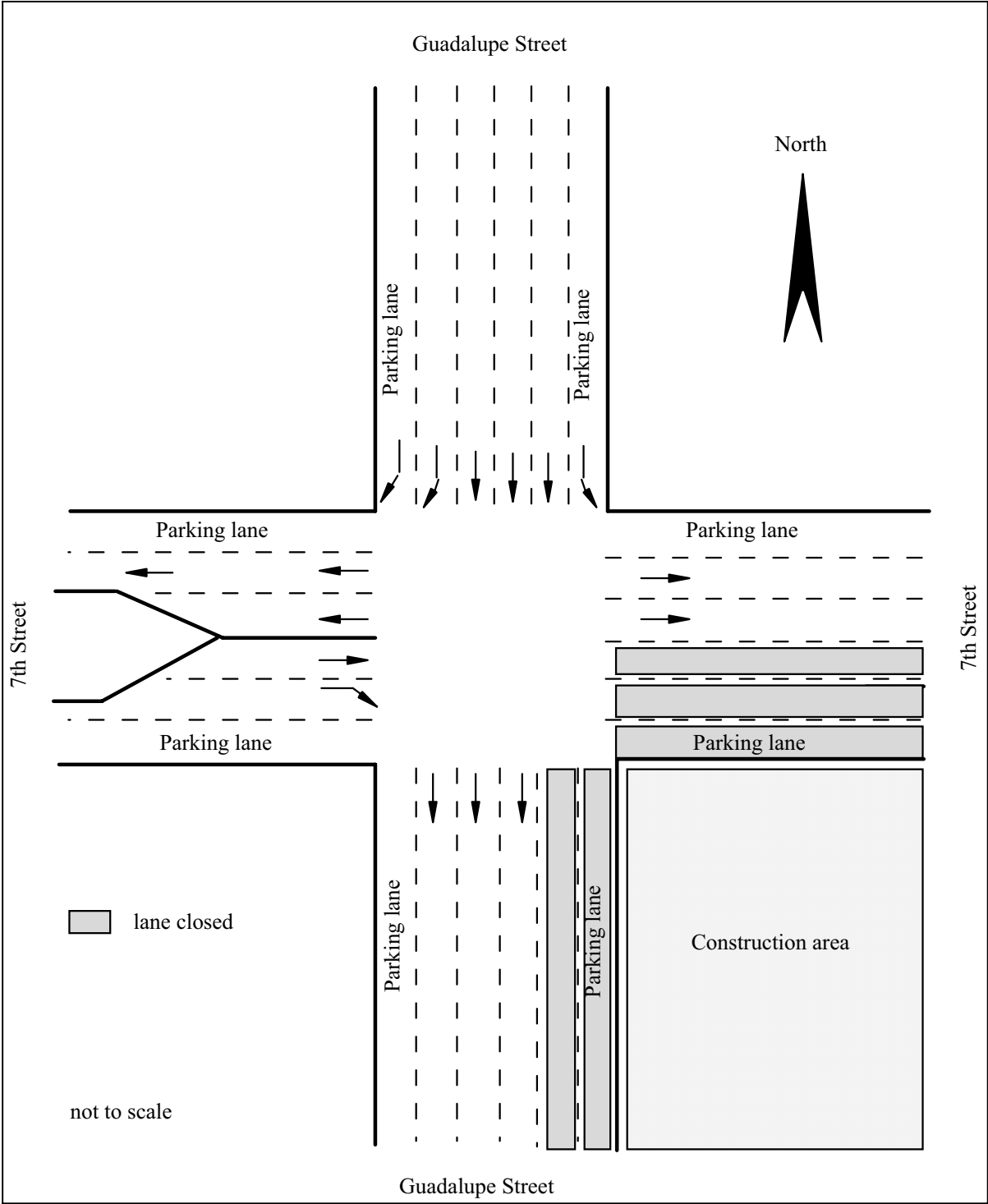


Figure A.11 Lane Closure Strategy on Work Zone # 1 (600 Guadalupe St., Austin)

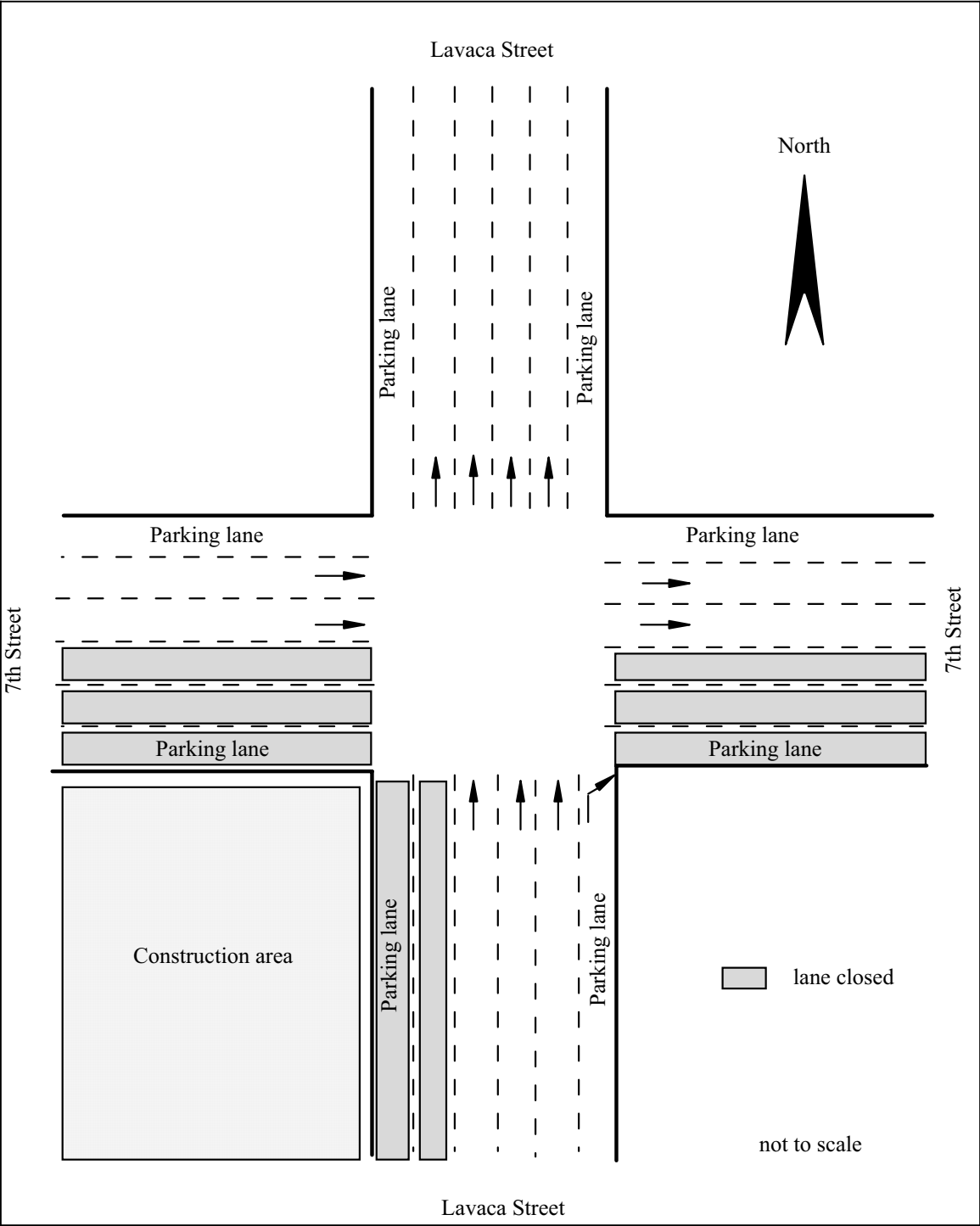


Figure A.12 Lane Closure Strategy on Work Zone # 2 (Lavaca St., Austin)

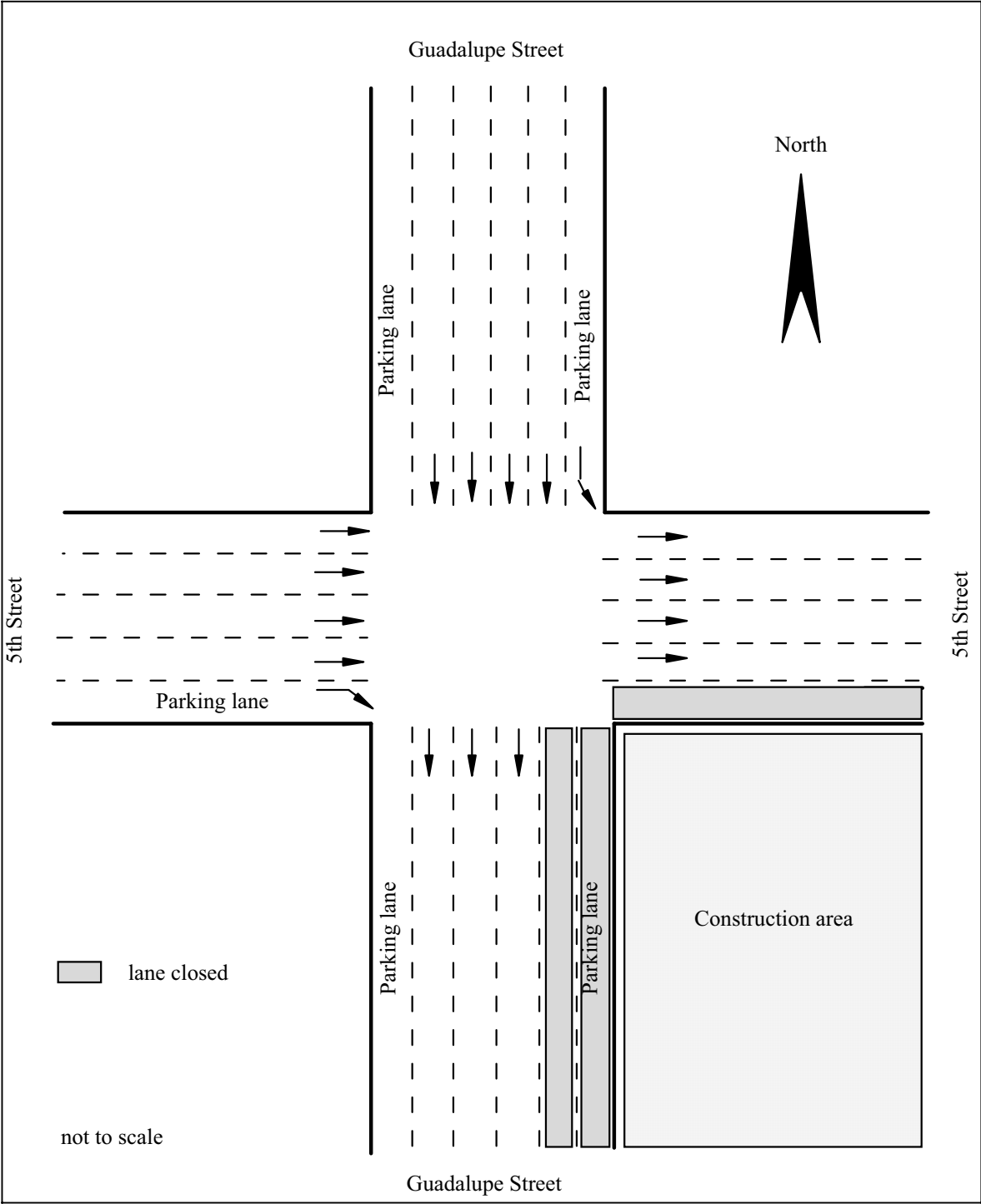


Figure A.13 Lane Closure Strategy on Work Zone # 3 (400 Guadalupe St., Austin)

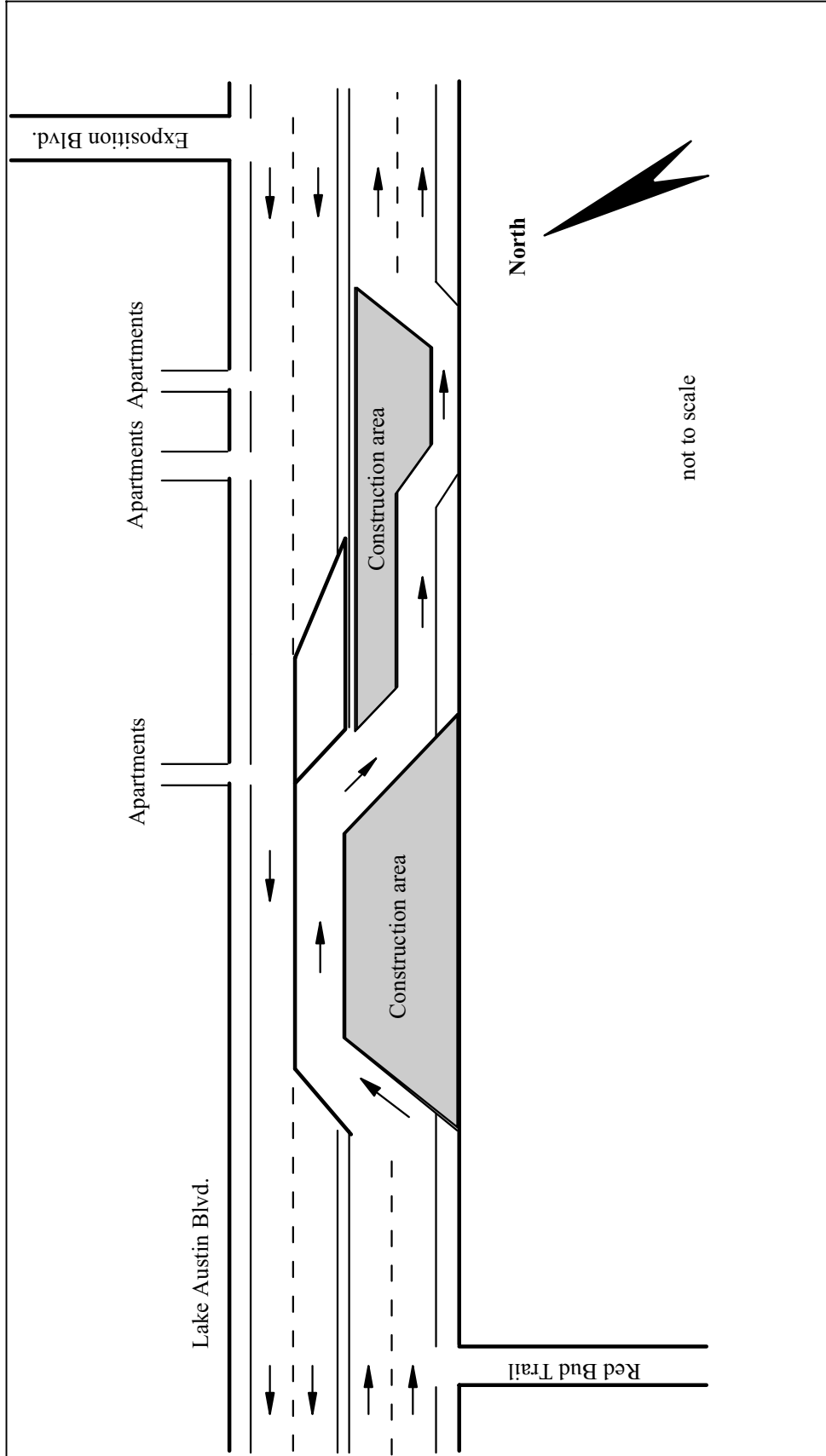


Figure A.14 Lane Closure Strategy on Work Zone #4
(Lake Austin Blvd., Austin)

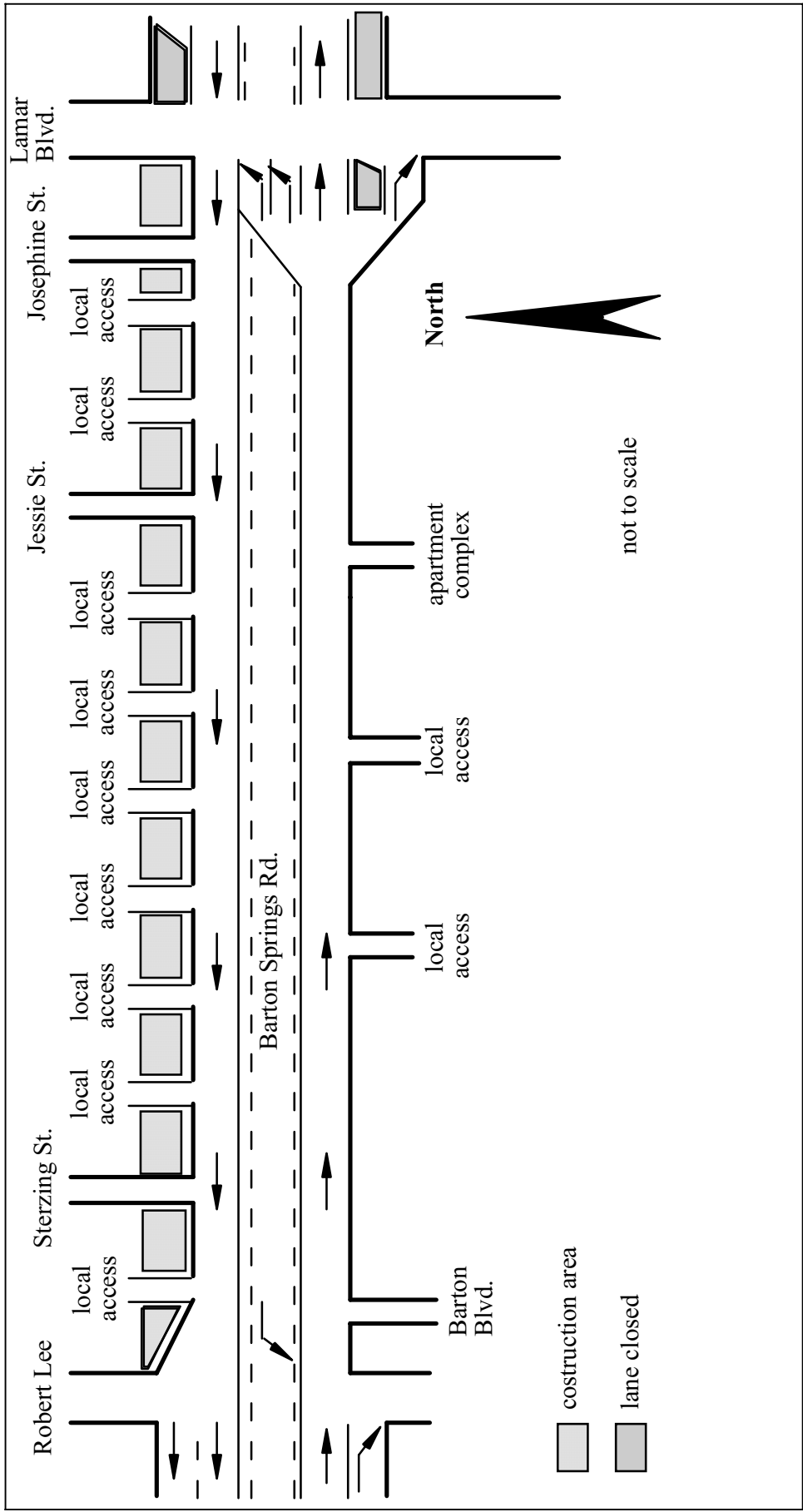


Figure A.15 Lane Closure Strategy on Work Zone # 5
(Barton Springs Rd., Austin)

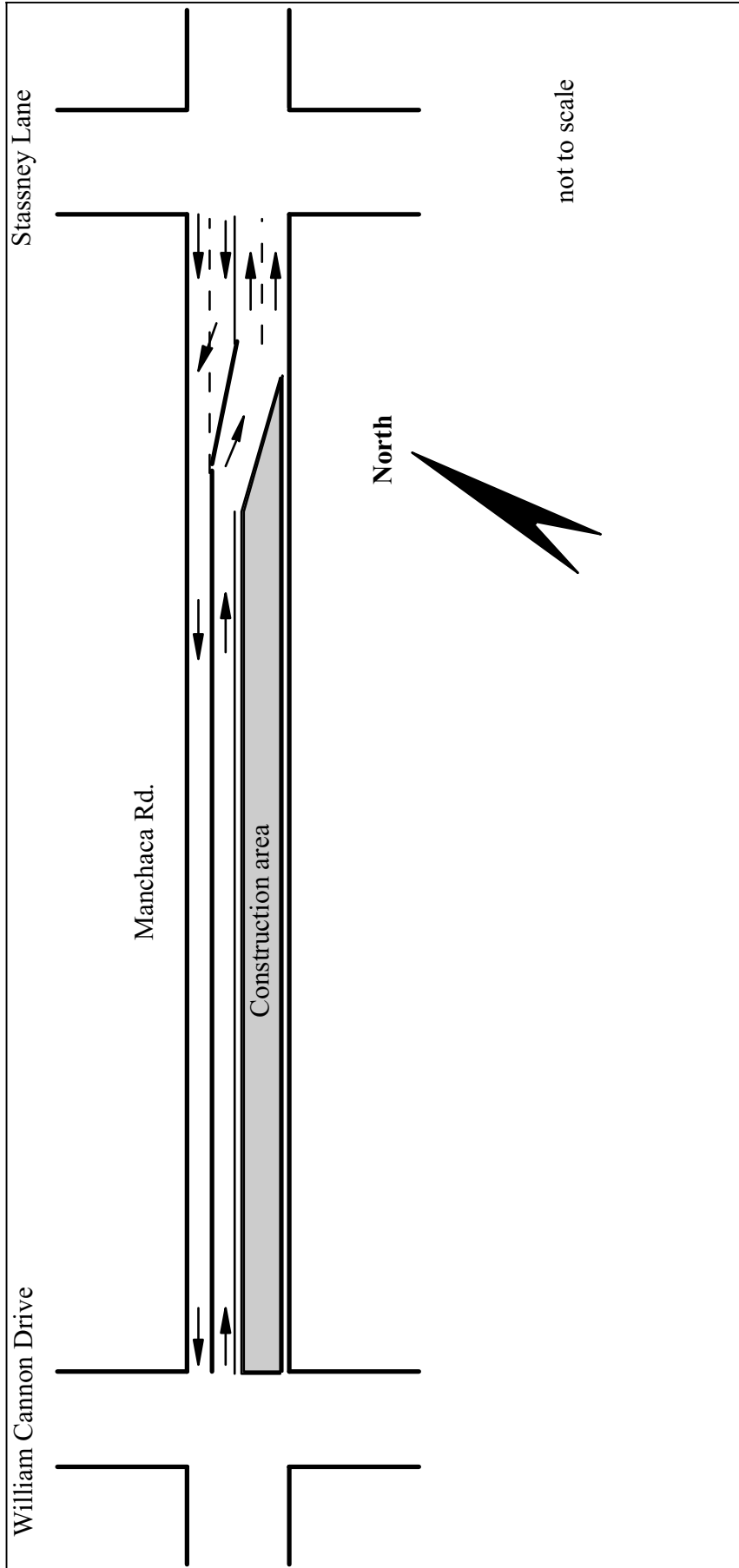


Figure A.16 Lane Closure Strategy on Work Zone # 6 (Manchaca Rd., Austin)

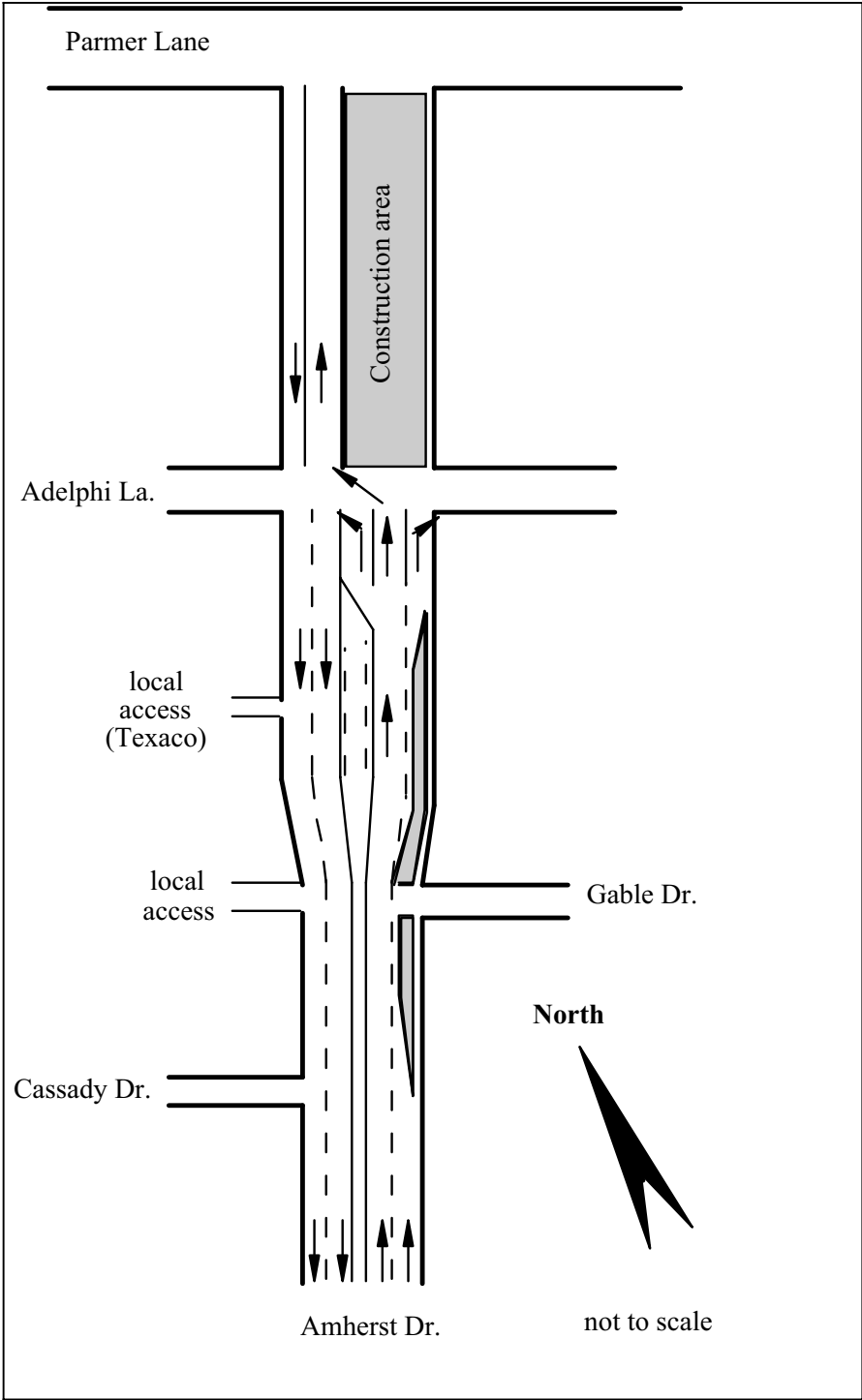


Figure A.17 Lane Closure Strategy on Work Zone # 7 (Amherst Dr., Austin)

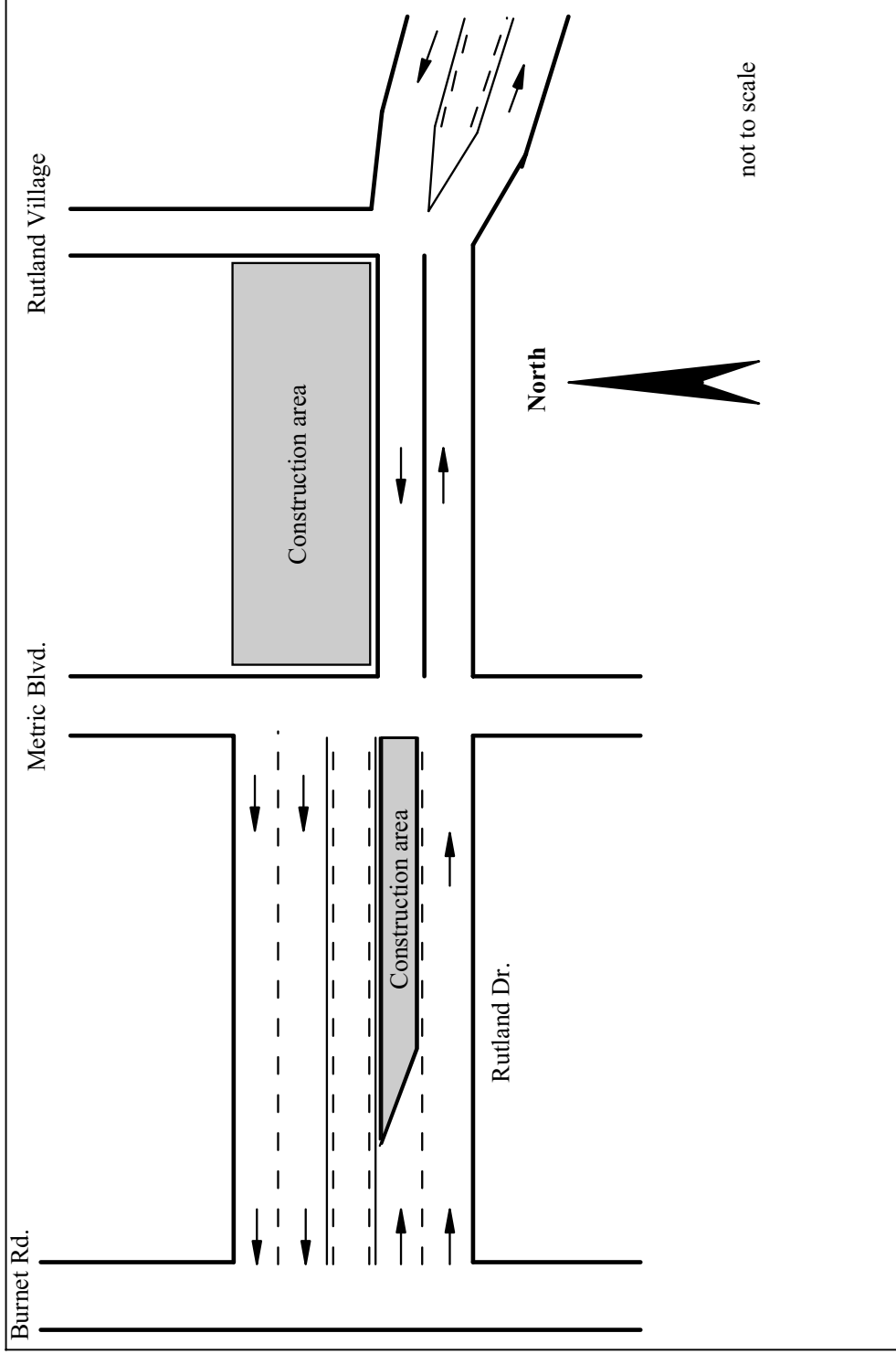


Figure A.18 Lane Closure Strategy on Work Zone # 8
(Rutland Dr., Austin)

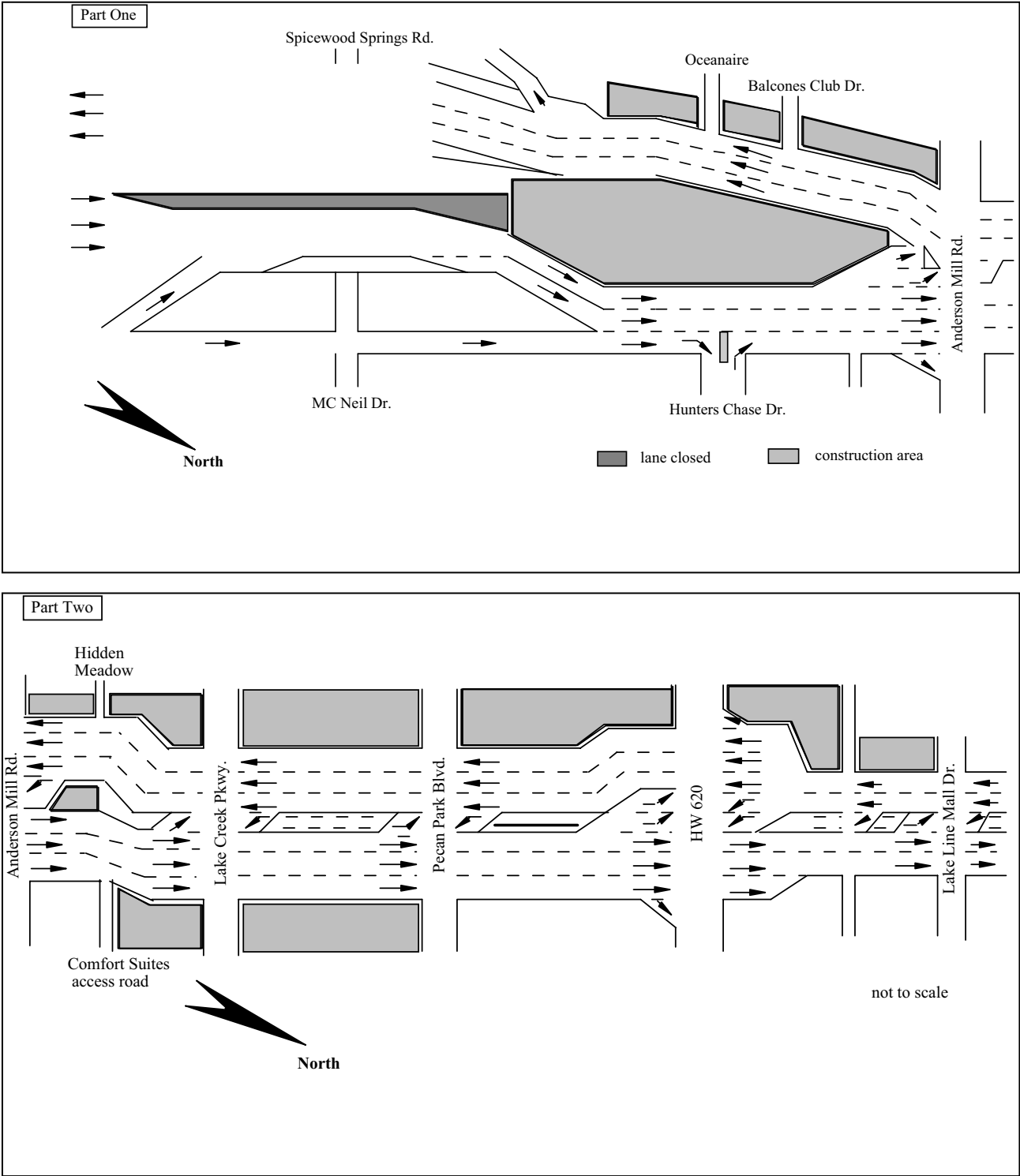


Figure A.19 Lane Closure Strategy on Work Zone #9 (Research Blvd., Austin)



Photo A.1 Austin, Work Zone #1, 600 Guadalupe St.: General view



Photo A.2 Austin, Work Zone #1, 600 Guadalupe St.: General view of work zone section on Guadalupe St.



*Photo A.3 Austin, Work Zone #1, 600 Guadalupe St.:
General view of work zone on 7th Street*



*Photo A.4 Austin, Work Zone #2, Lavaca St.:
General view*



*Photo A.5 Austin, Work Zone #3, 400 Guadalupe St.:
General view of work zone section on Guadalupe St., block 500*



*Photo A.6 Austin, Work Zone #3, 400 Guadalupe St.:
General view of work zone section on Guadalupe St., block 400*



*Photo A.7 Austin, Work Zone #3, 400 Guadalupe St.:
General view of work zone section on 5th Street*



*Photo A.8 Austin, Work Zone #4, Lake Austin Blvd.:
Work zone initial section (westbound)*



*Photo A.9 Austin, Work Zone #4, Lake Austin Blvd.:
General view of the main construction area*



*Photo A.10 Austin, Work Zone #4, Lake Austin Blvd.:
General view of the main construction area from eastbound*



*Photo A.11 Austin, Work Zone #4, Lake Austin Blvd.:
Work zone initial section (eastbound)*



*Photo A.12 Austin, Work Zone #5, Barton Springs Rd.:
View of west end of work zone*



*Photo A.13 Austin, Work Zone #5, Barton Springs Rd.:
View of east end of work zone*



*Photo A.14 Austin, Work Zone #5, Barton Springs Rd.:
View of the main construction activity section*



*Photo A.15 Austin, Work Zone #5, Barton Springs Rd.:
View of the main construction activity section*



*Photo A.16 Austin, Work Zone #6, Manchaca Rd.:
View of northwest end of work zone*



*Photo A.17 Austin, Work Zone #6, Manchaca Rd.:
View of the main construction activity section*



*Photo A.18 Austin, Work Zone #7, Amherst Dr.:
View of the southeast end of work zone*



*Photo A.19 Austin, Work Zone #7, Amherst Dr.:
General view of work zone*



*Photo A.20 Austin, Work Zone #8, Rutland Dr.:
View of the east end of work zone*



*Photo A.21 Austin, Work Zone #8, Rutland Dr.:
View of the west end of work zone*



*Photo A.22 Austin, Work Zone #8, Rutland Dr.:
View of the main construction activity section*



*Photo A.23 Austin, Work Zone #9, Research Blvd.:
View of northbound work zone initial section*



*Photo A.24 Austin, Work Zone #9, Research Blvd.:
Initial section of northbound detour*



*Photo A.25 Austin, Work Zone #9, Research Blvd.:
Northbound view of Research Blvd. and Anderson Mill Rd. intersection*



*Photo A.26 Austin, Work Zone #9, Research Blvd.:
Northbound view of work zone between Anderson Mill Rd. and Lake Creek Pkwy.*



*Photo A.27 Austin, Work Zone #9, Research Blvd.:
Northbound view between Anderson Mill Rd. and Lake Creek Pkwy.*



*Photo A.28 Austin, Work Zone #9, Research Blvd.:
Northbound view of Research Blvd. and HW 620 intersection*



*Photo A.29 Austin, Work Zone #9, Research Blvd.:
Southbound view of Research Blvd. and HW 620 intersection*



*Photo A.30 Austin, Work Zone #9, Research Blvd.:
Southbound view between Lake Creek Pkwy. and Anderson Mill Rd.*



*Photo A.31 Austin, Work Zone #9, Research Blvd.:
Southbound view between Anderson Mill Rd. and Balcones Club Dr.*



*Photo A.32 Austin, Work Zone #9, Research Blvd.:
Southbound view between Balcones Club Dr. and Oceanaire*



*Photo A.33 Austin, Work Zone #9, Research Blvd.:
View of work zone south end*

Appendix B

Observed Work Zones in San Antonio

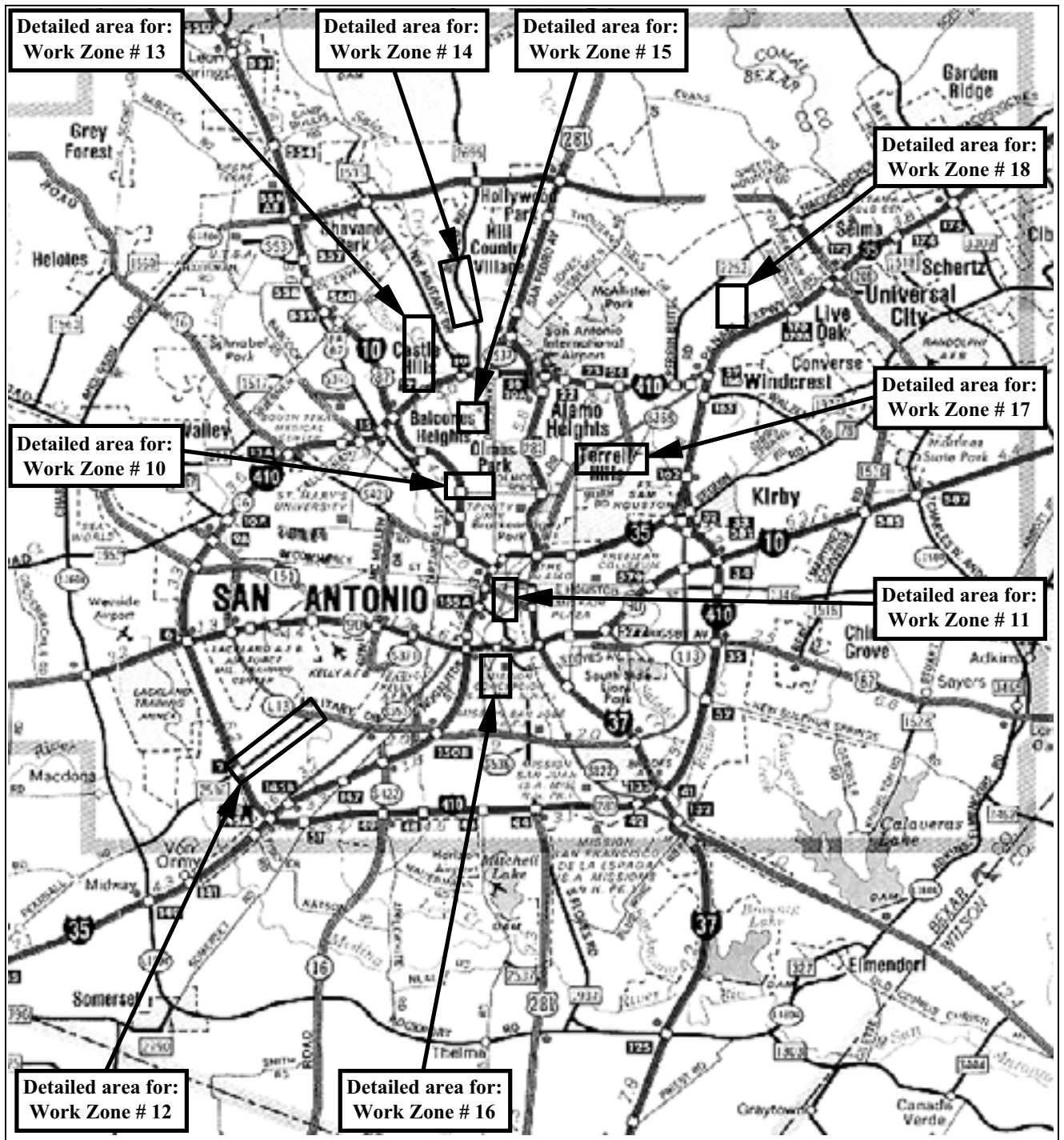


Figure B.1 San Antonio Metropolitan Area Map with Work Zone Locations

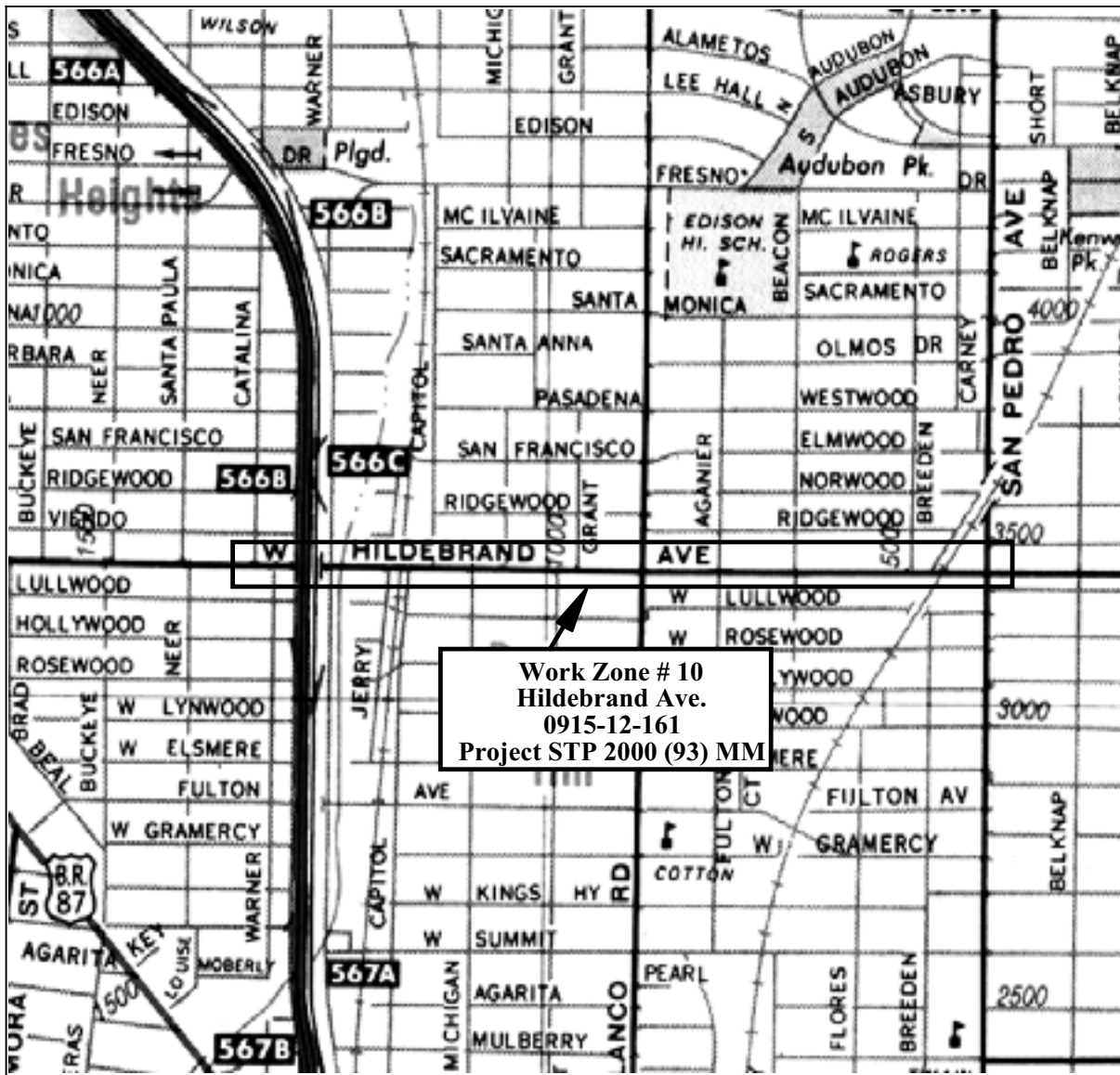


Figure B.2 Detailed Area for Work Zone # 10 (Hildebrand Ave., San Antonio)

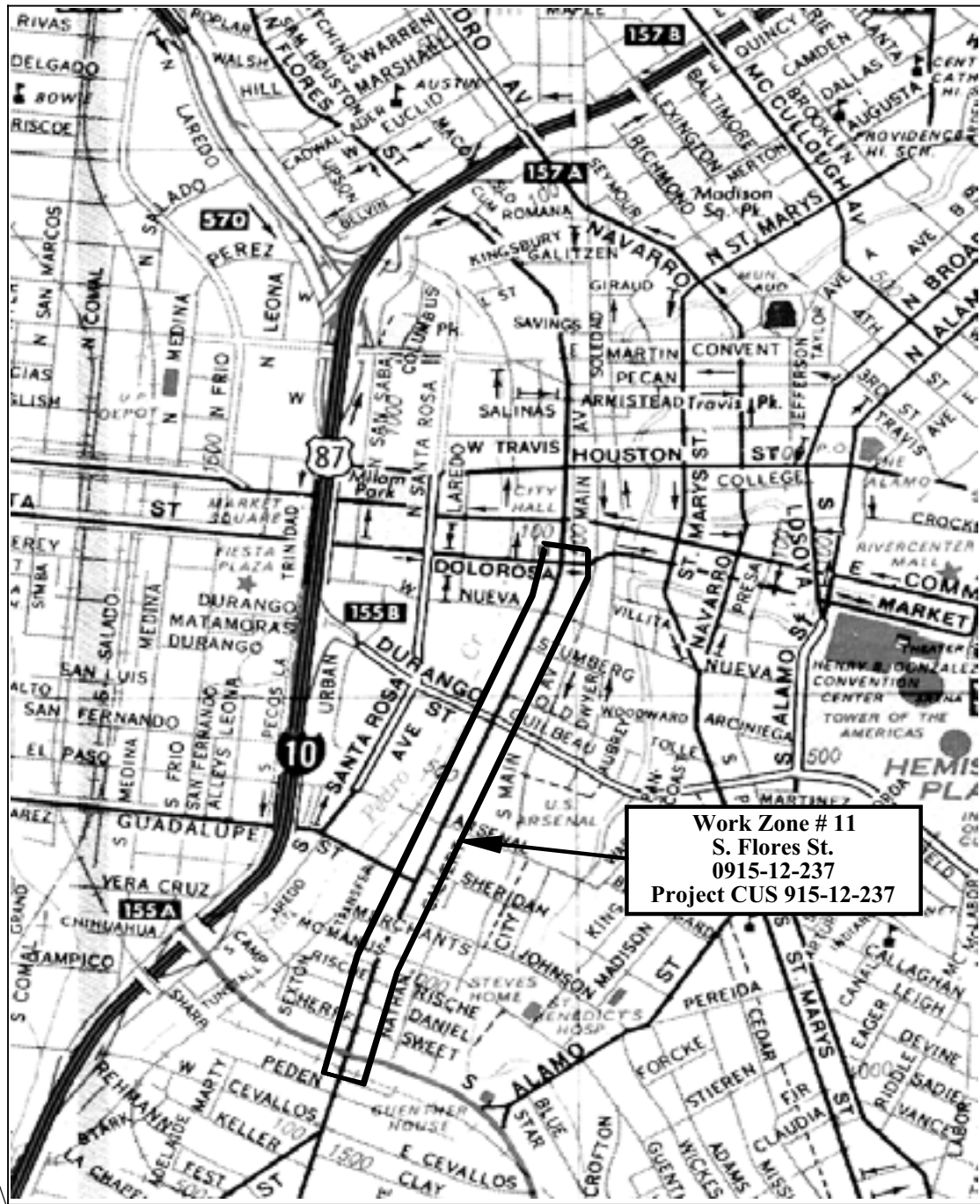


Figure B.3 Detailed Area for Work Zone # 11 (S. Flores St., San Antonio)

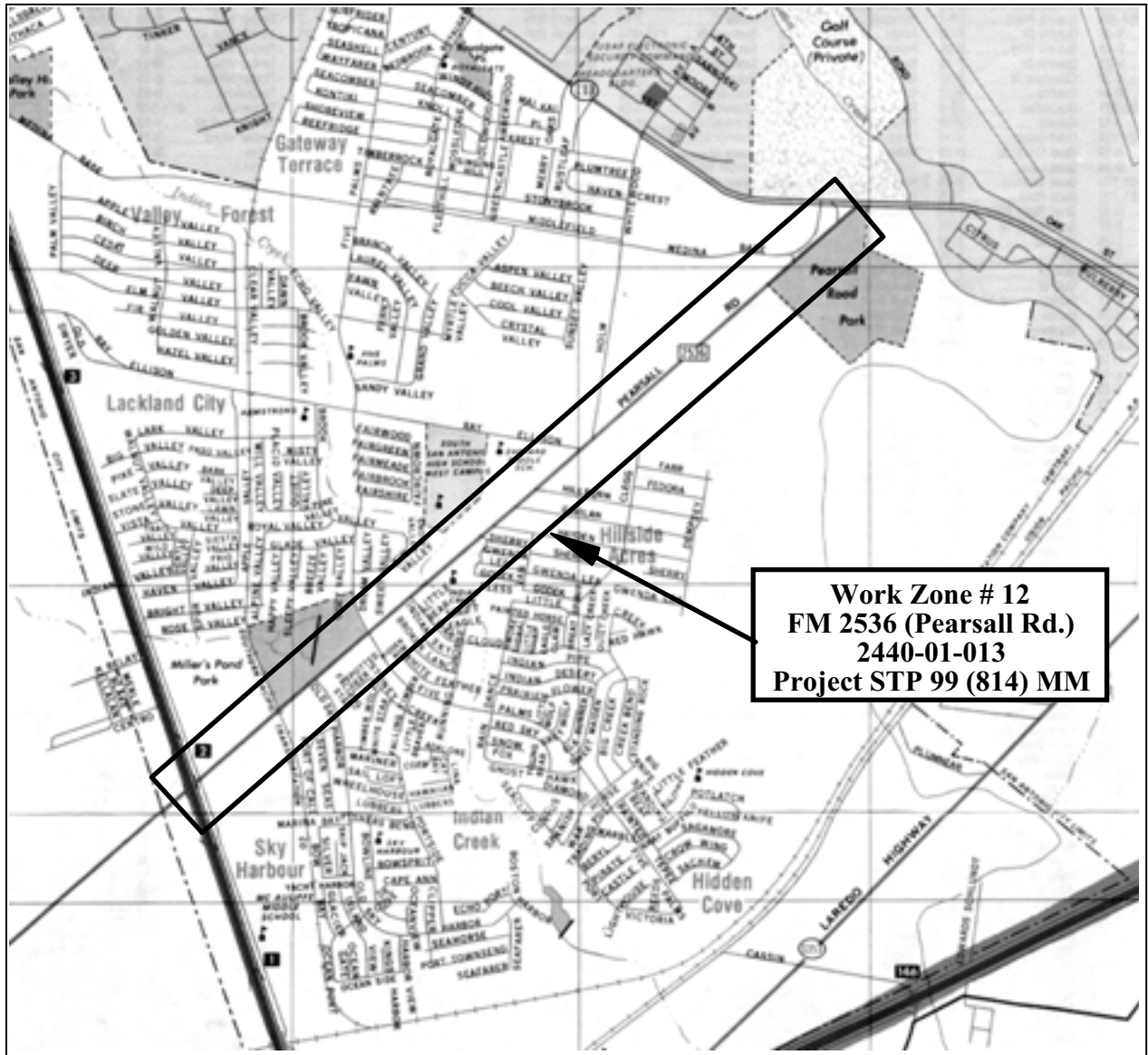


Figure B.4 Detailed Area for Work Zone # 12 (FM 2536, San Antonio)

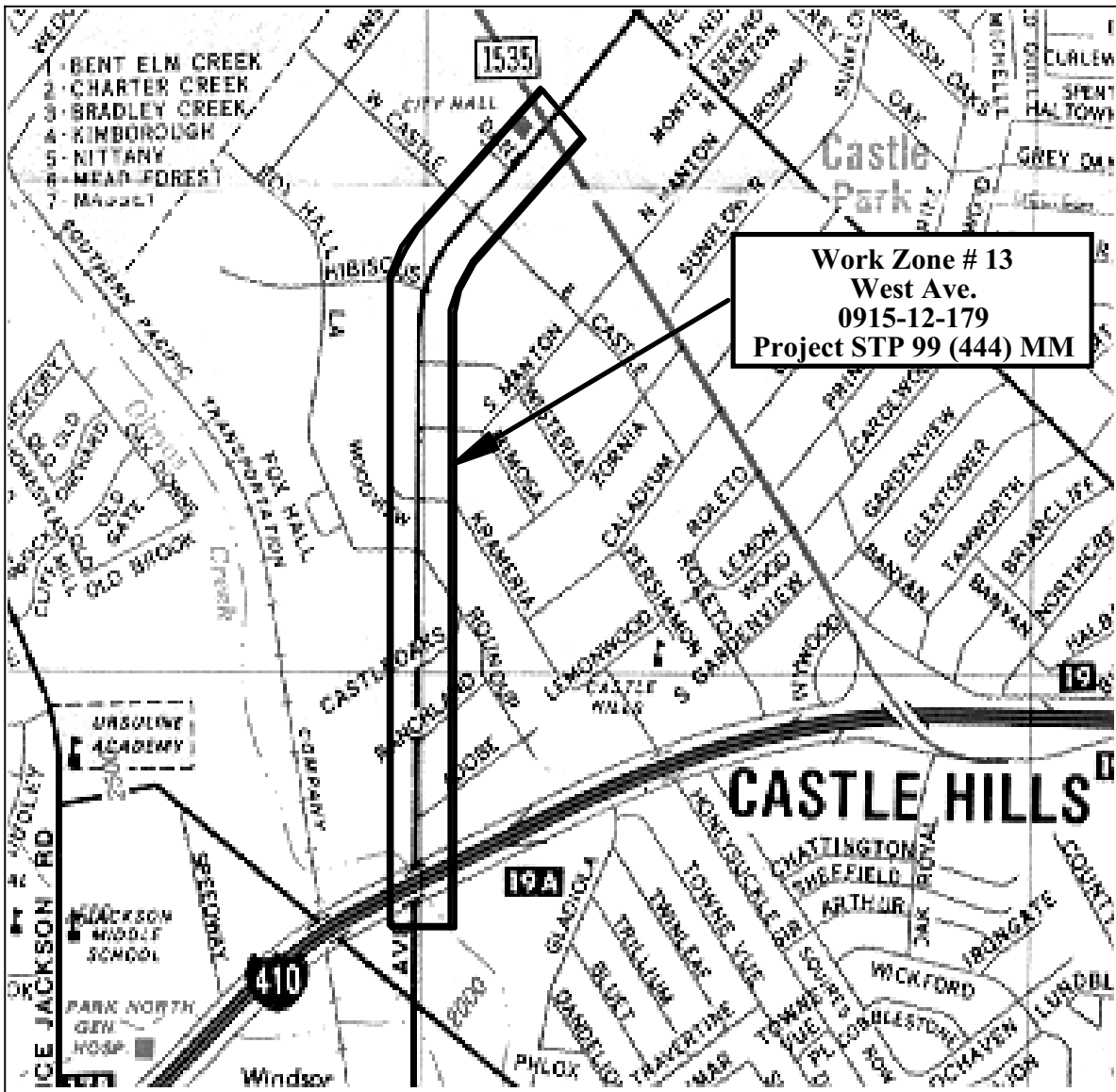


Figure B.5 Detailed Area for Work Zone # 13 (West Ave., San Antonio)

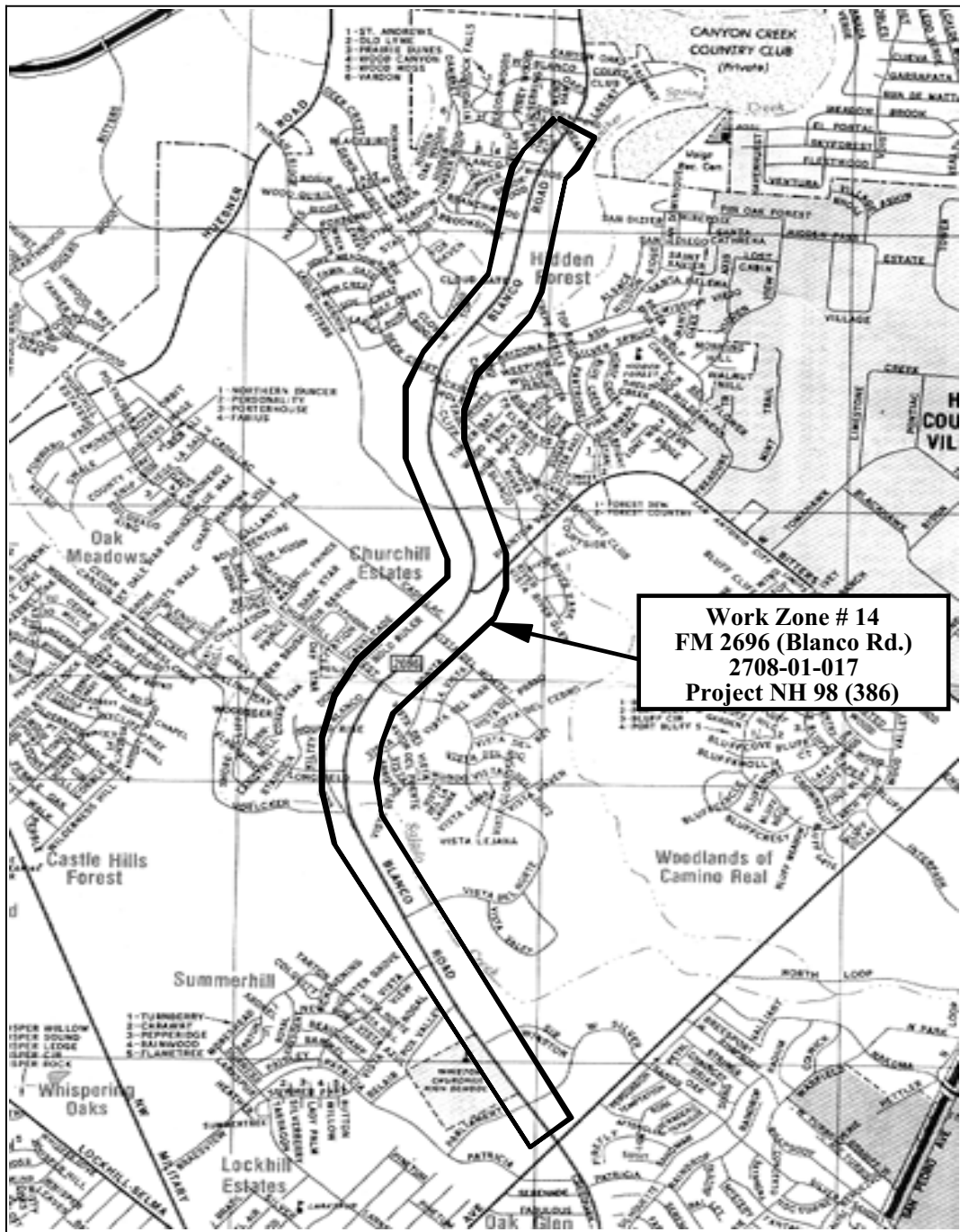
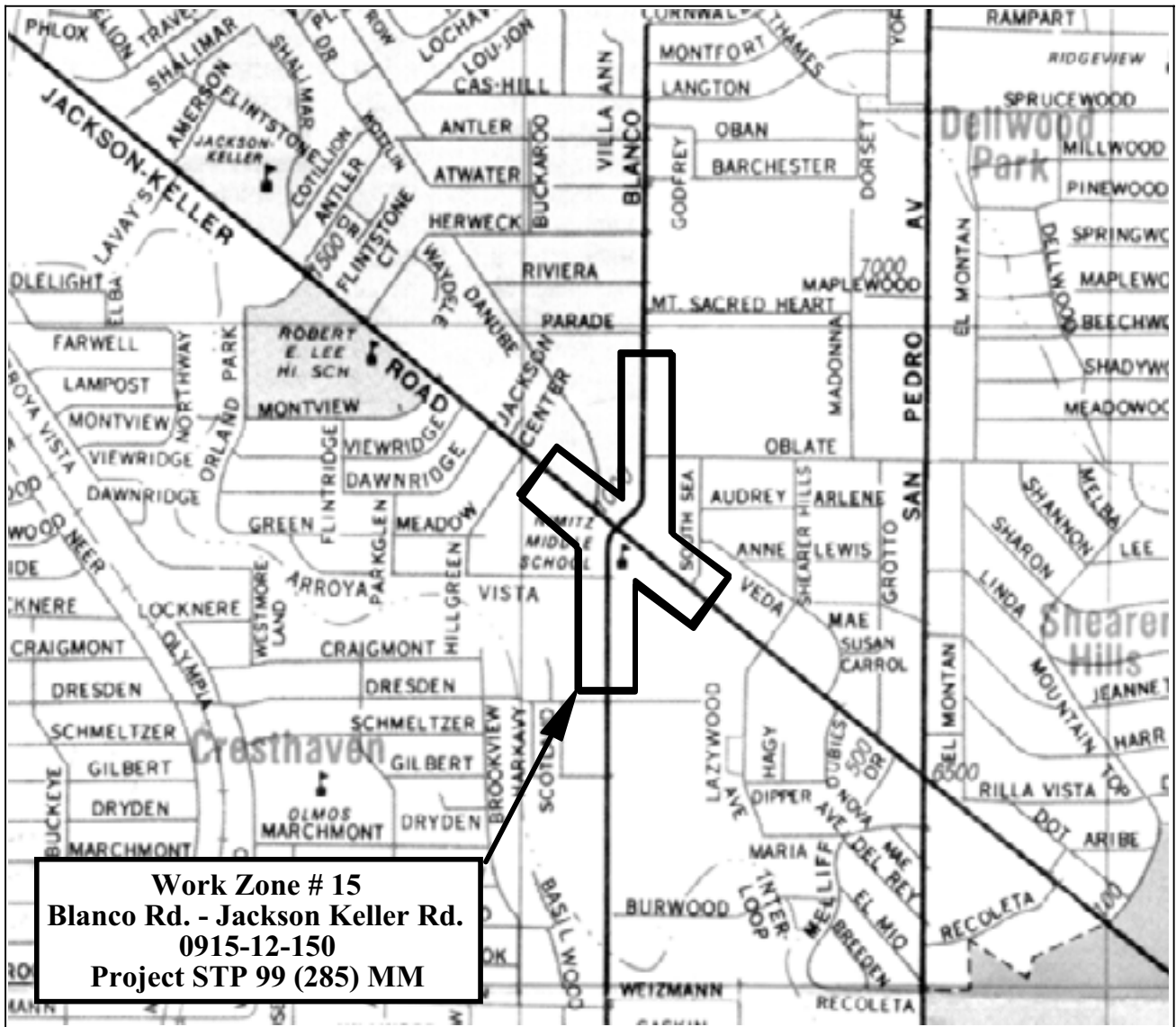


Figure B.6 Detailed Area for Work Zone # 14 (FM 2696, San Antonio)



*Figure B.7 Detailed Area for Work Zone # 15
(Intersection of Blanco Rd. and Jackson Keller Rd., San Antonio)*

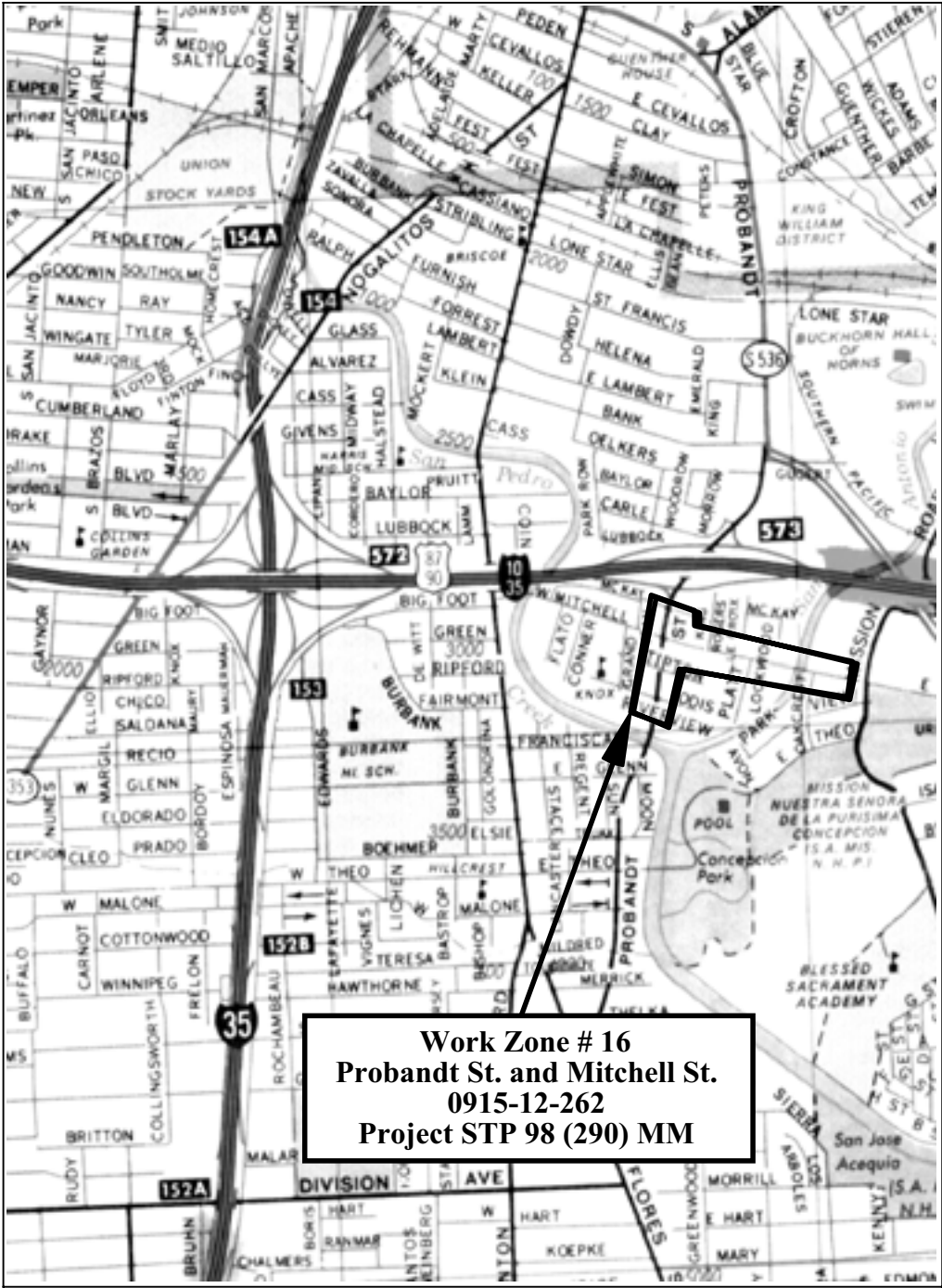


Figure B.8 Detailed Area for Work Zone # 16 (Probandt St. and Mitchell St., San Antonio)

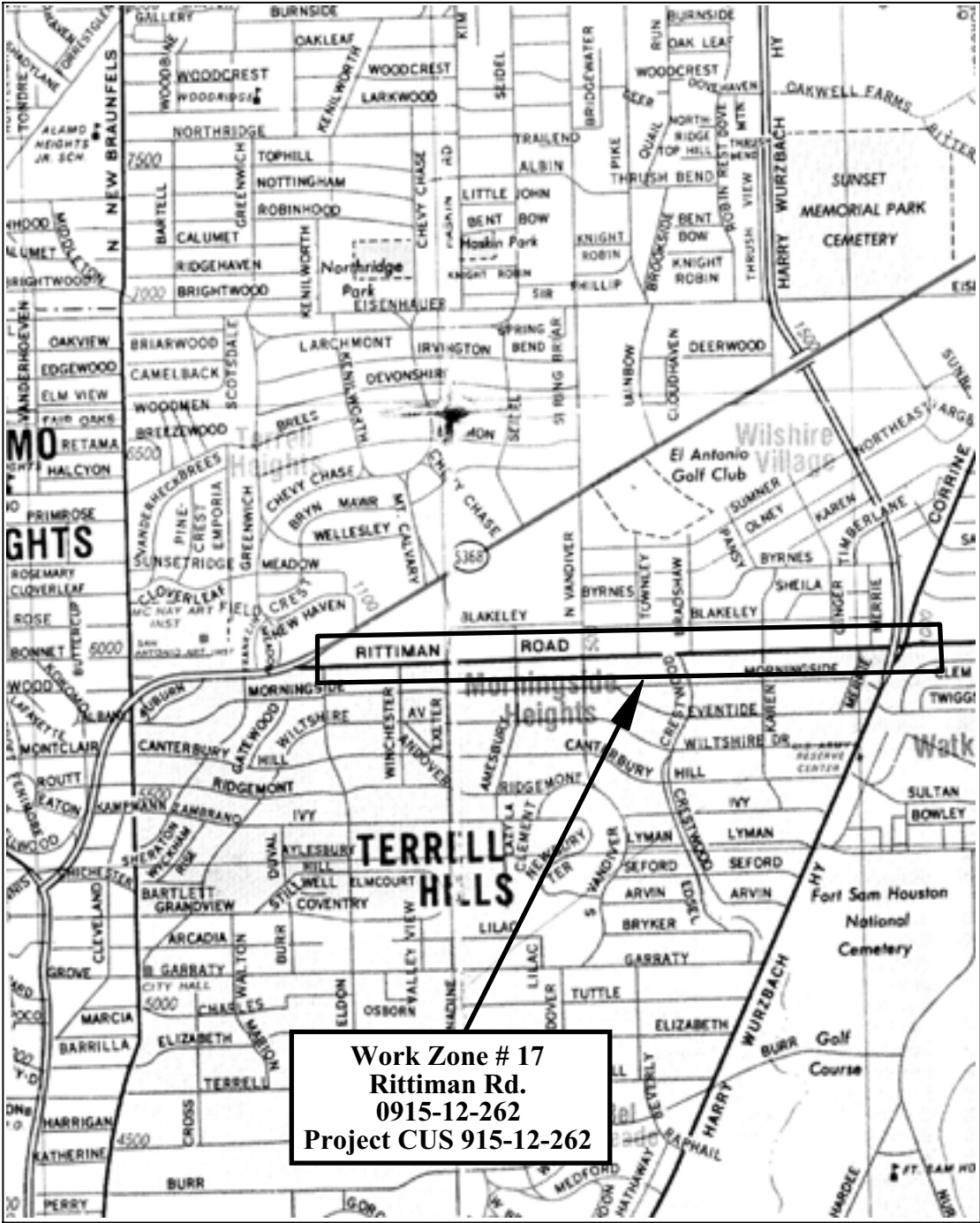


Figure B.9 Detailed Area for Work Zone # 17 (Rittiman Rd., San Antonio)

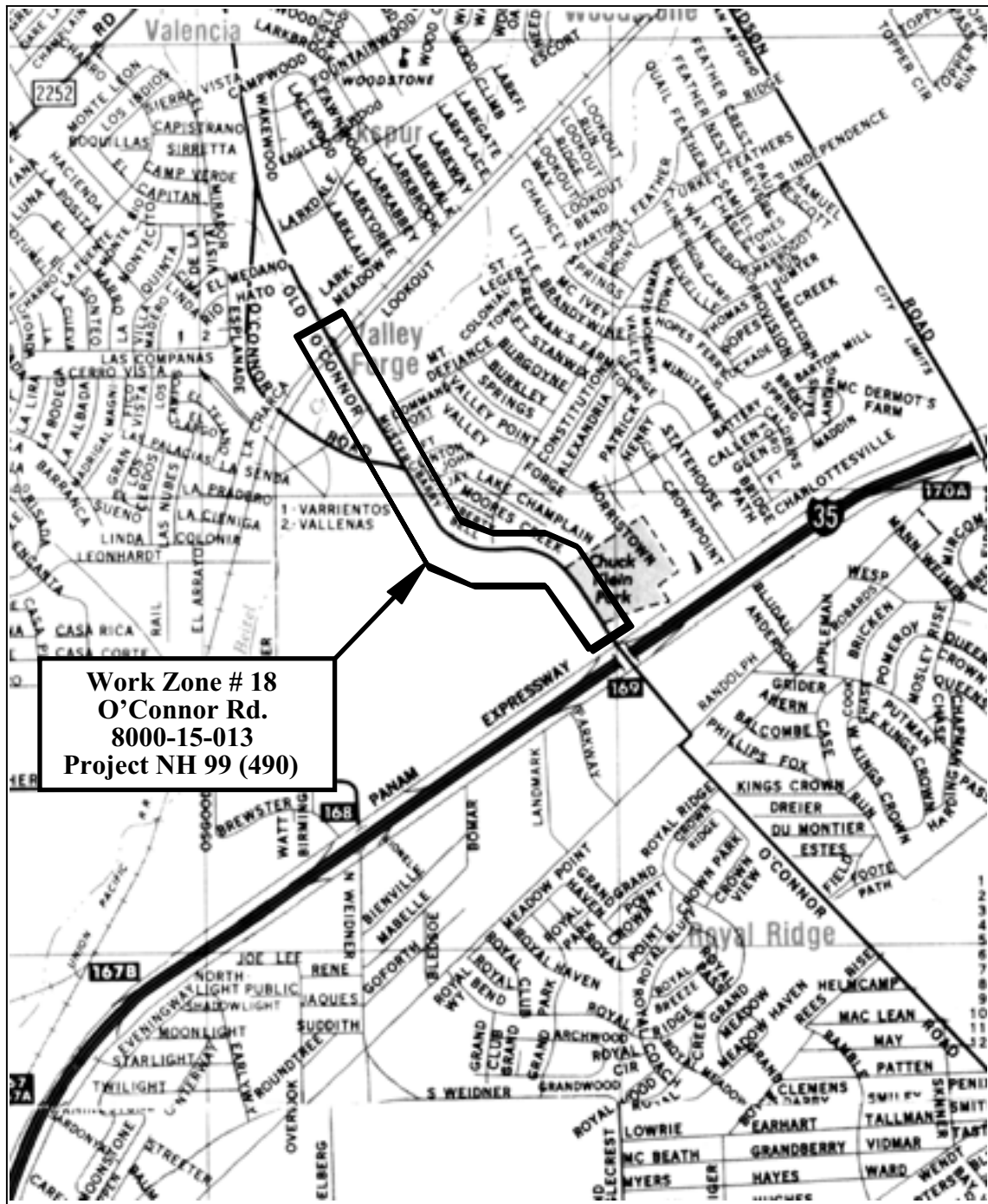


Figure B.10 Detailed Area for Work Zone # 18 (O'Connor Rd., San Antonio)

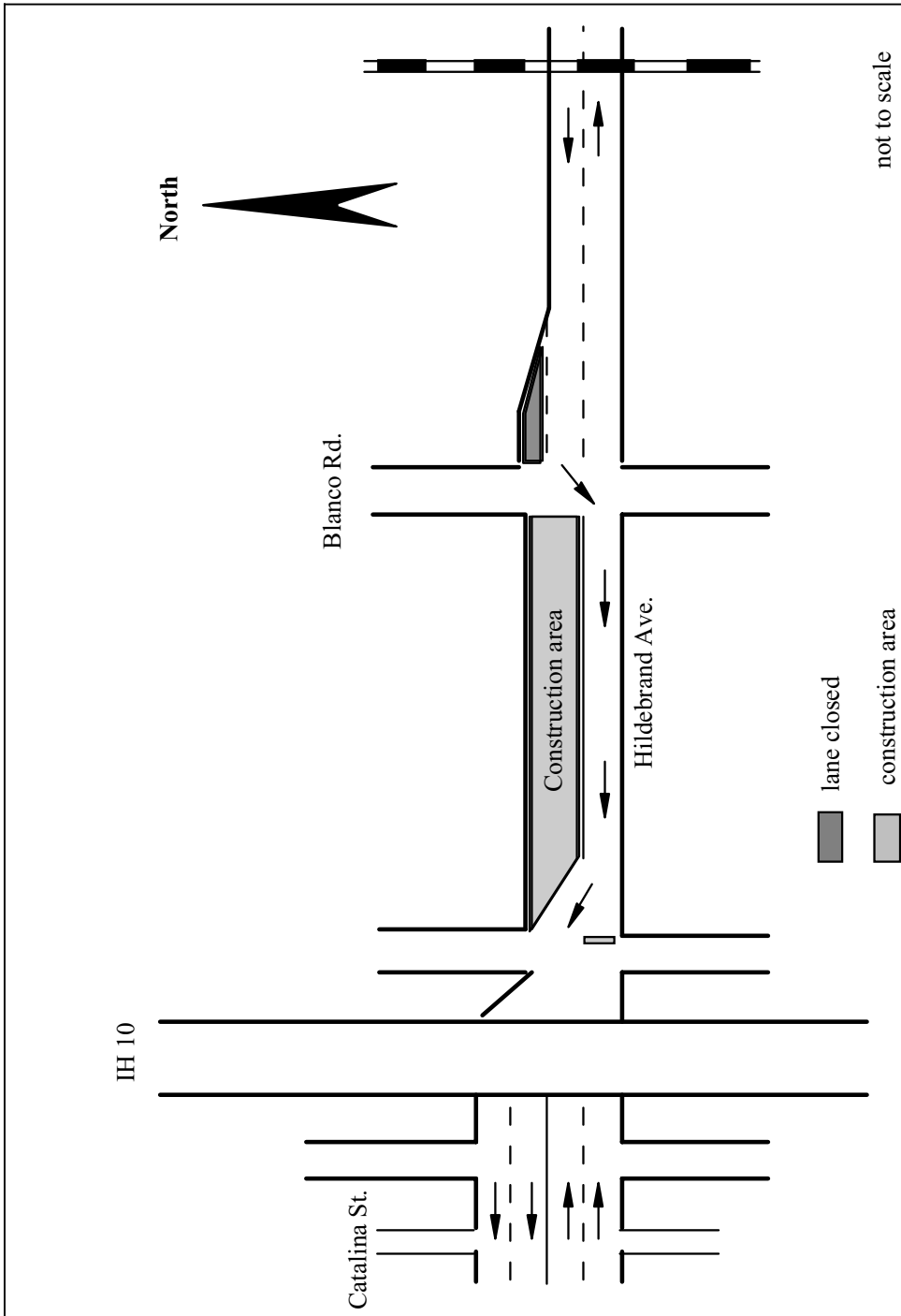


Figure B.11 Lane Closure Strategy on Work Zone # 10 (Hildebrand Ave., San Antonio)

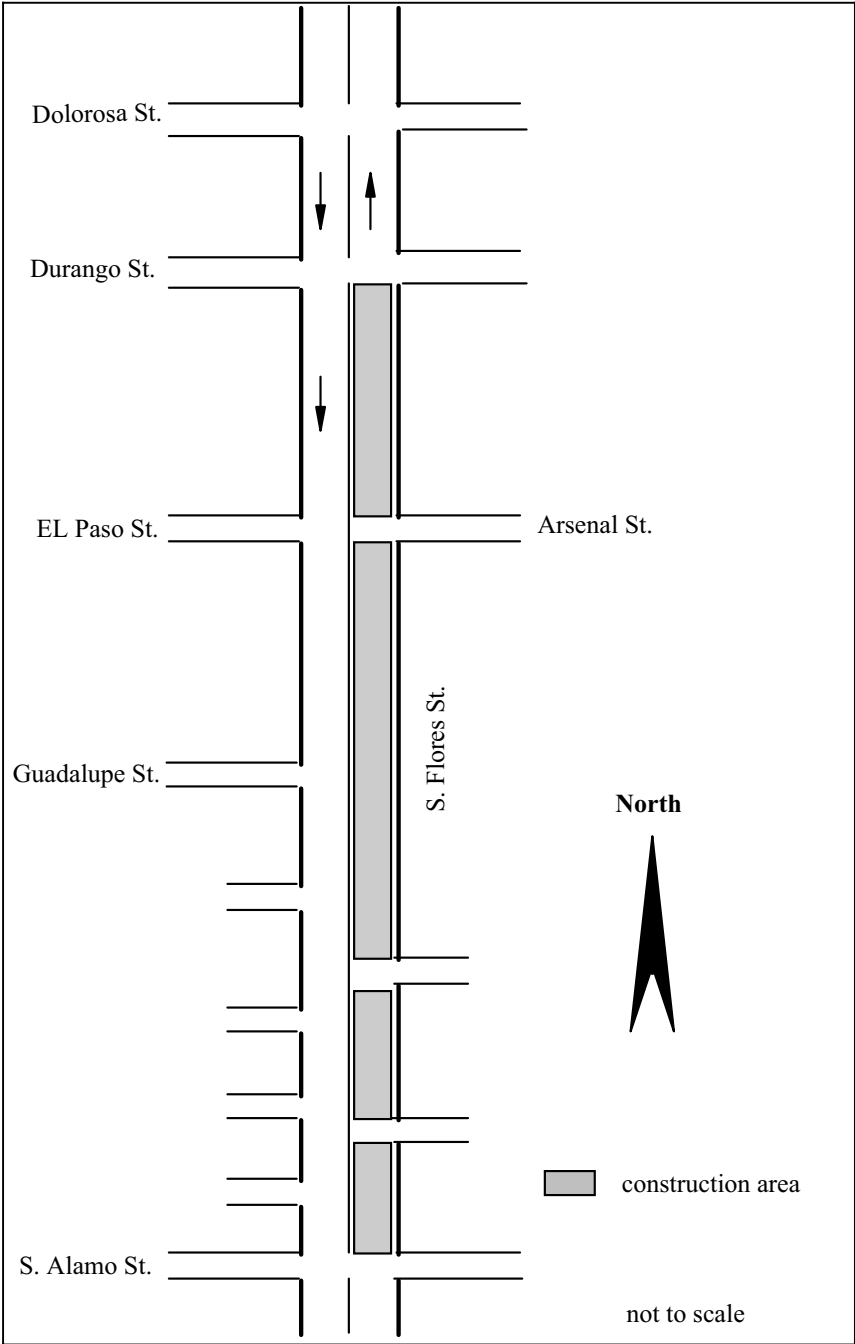


Figure B.12 Lane Closure Strategy on Work Zone #11 (S. Flores St., San Antonio)

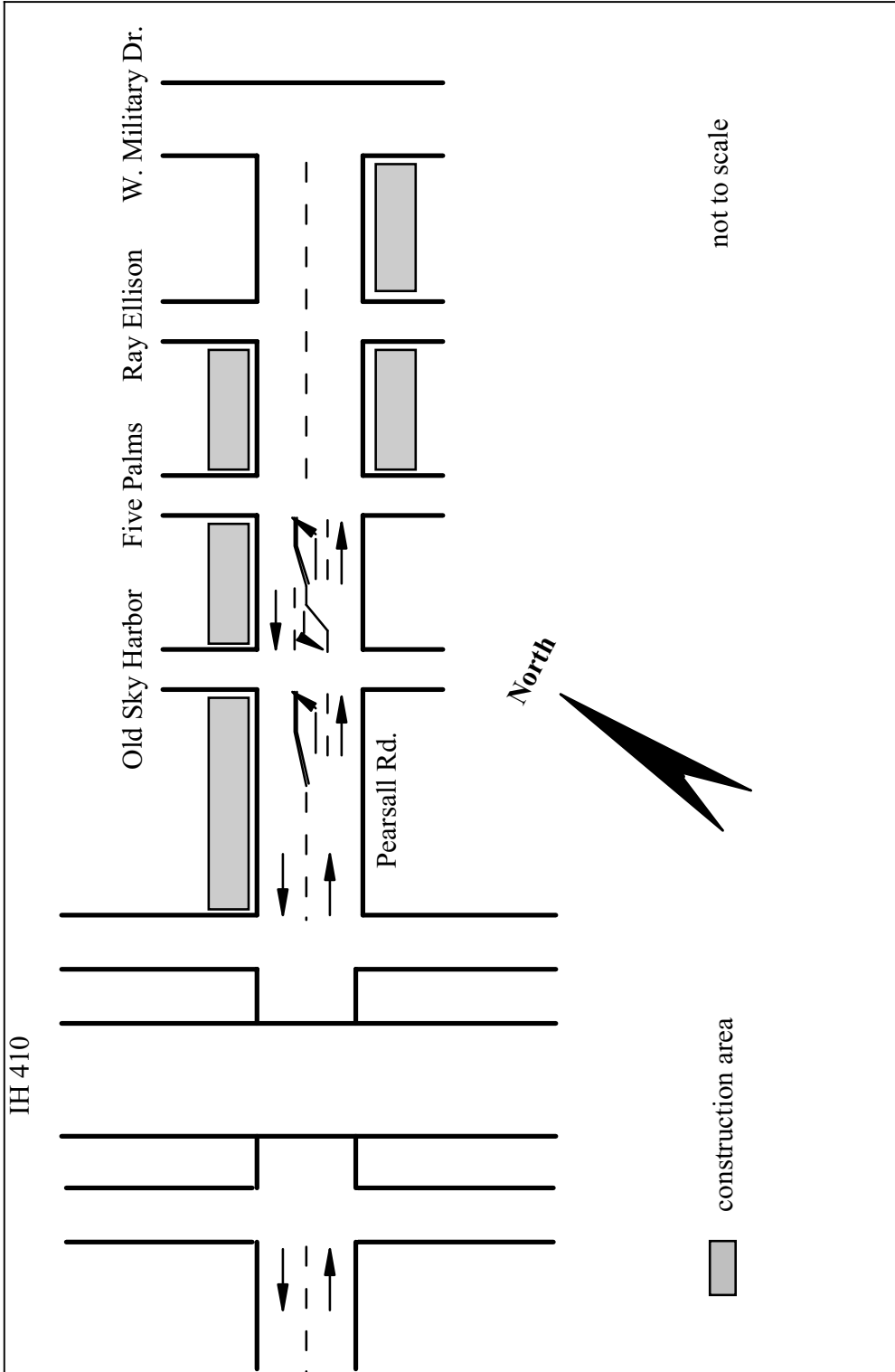


Figure B.13 Lane Closure Strategy on Work Zone # 12
(FM 2536, San Antonio)

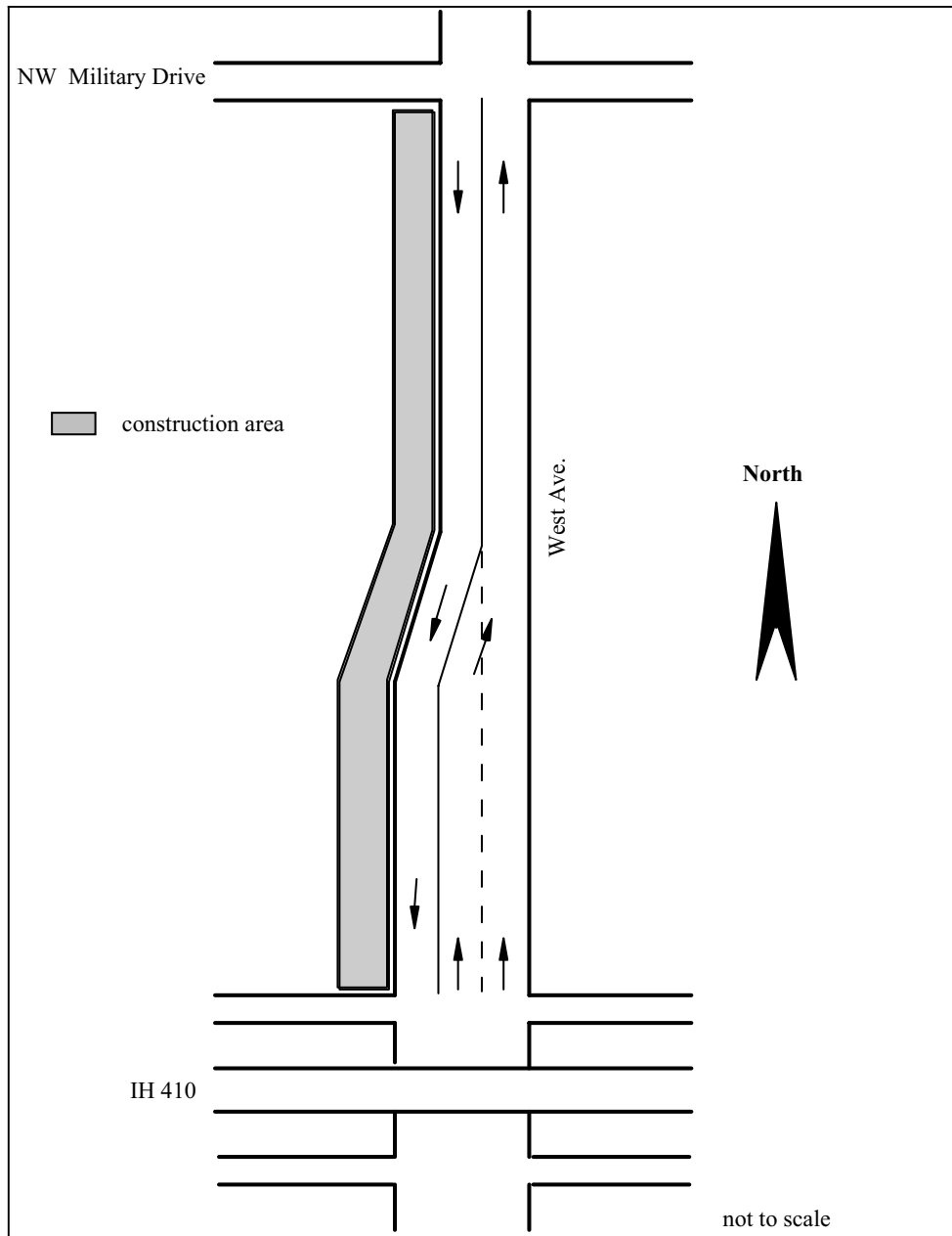


Figure B.14 Lane Closure Strategy on Work Zone # 13
(West Ave., San Antonio)

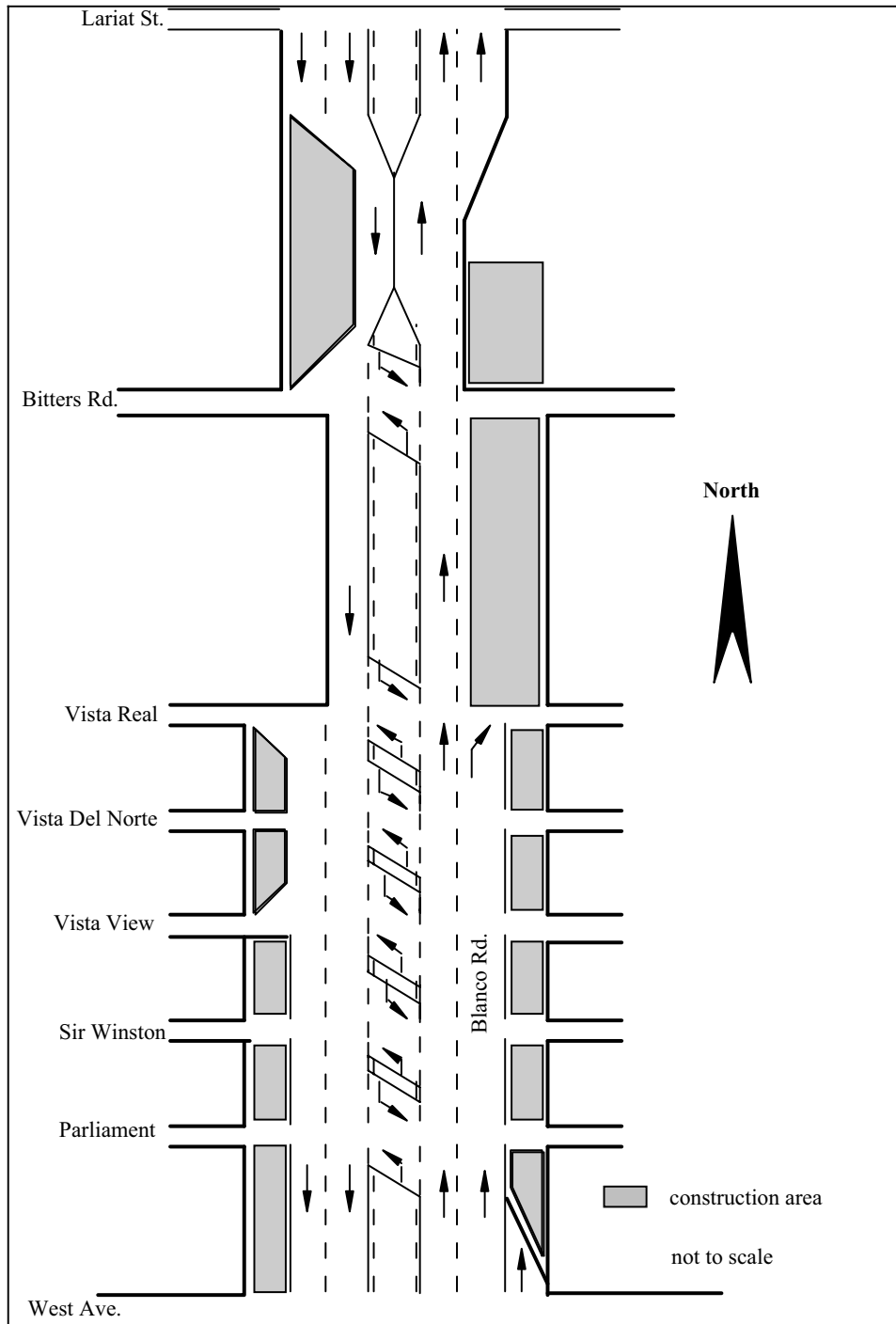
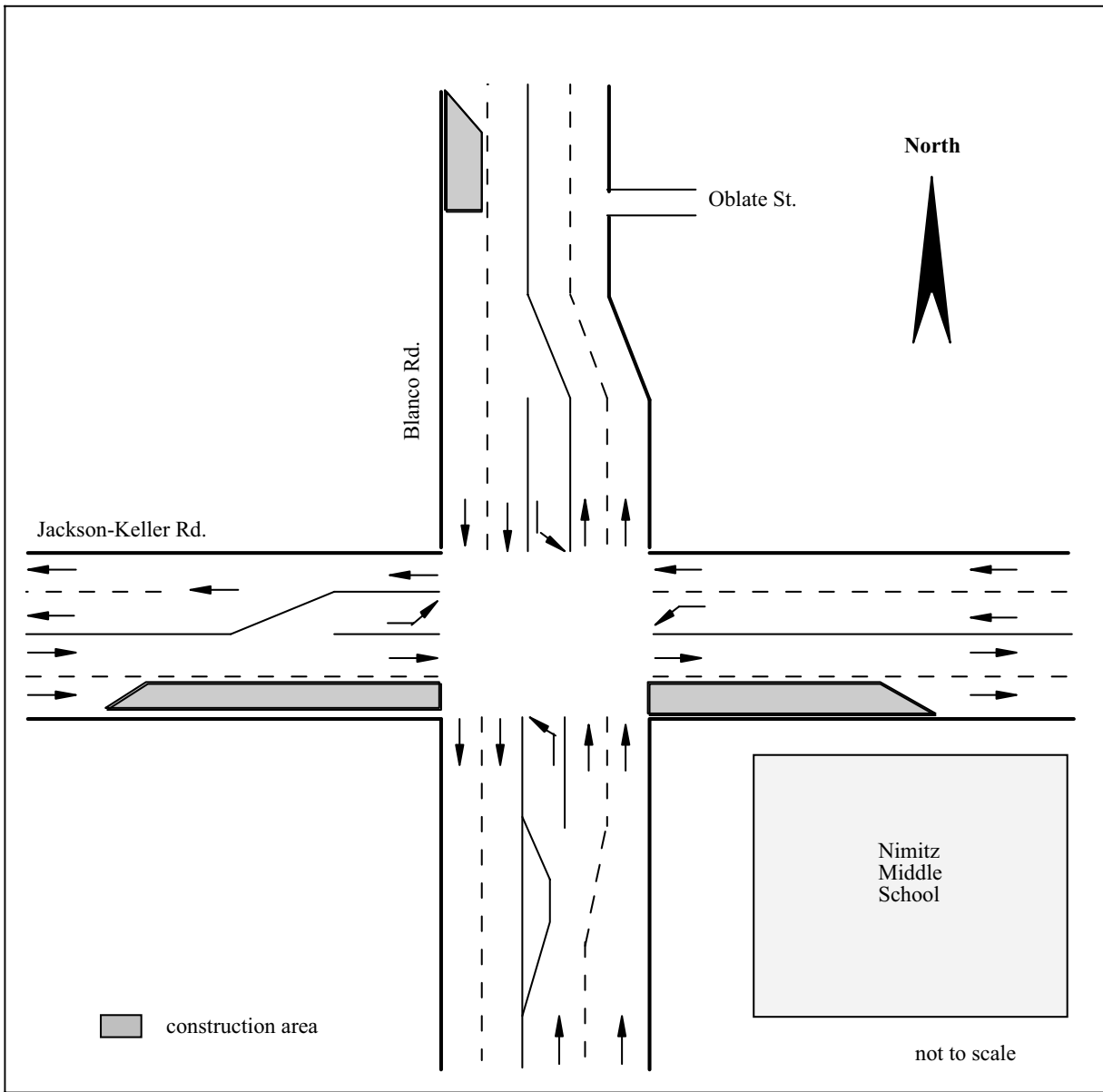


Figure B.15 Lane Closure Strategy on Work Zone #14
(FM 2696, San Antonio)



*Figure B.16 Lane Closure Strategy on Work Zone # 15
(Intersection of Blanco Rd. and Jackson Keller Rd., San Antonio)*

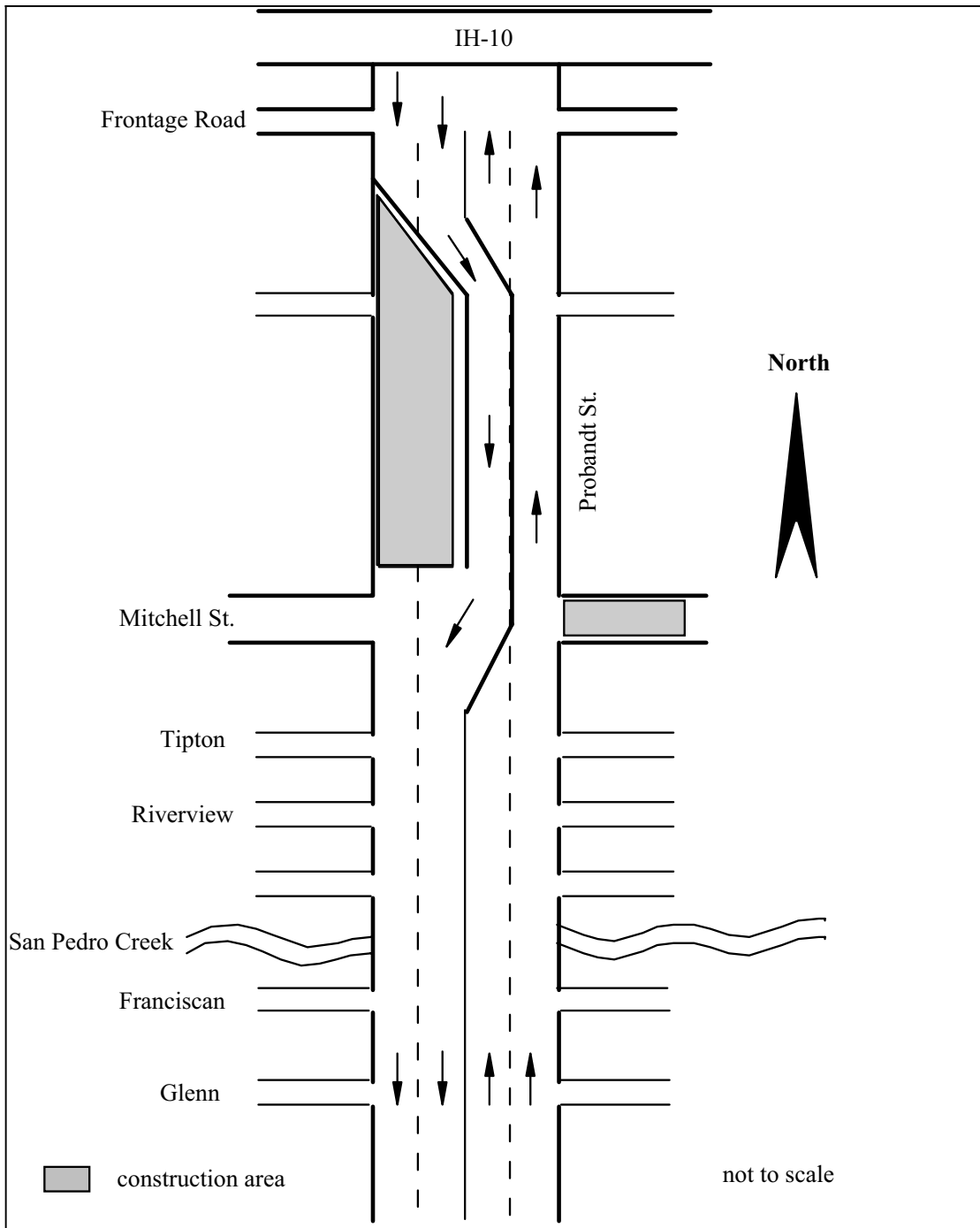


Figure B.17 Lane Closure Strategy on Work Zone # 16
(Probandt St. and Mitchell St., San Antonio)

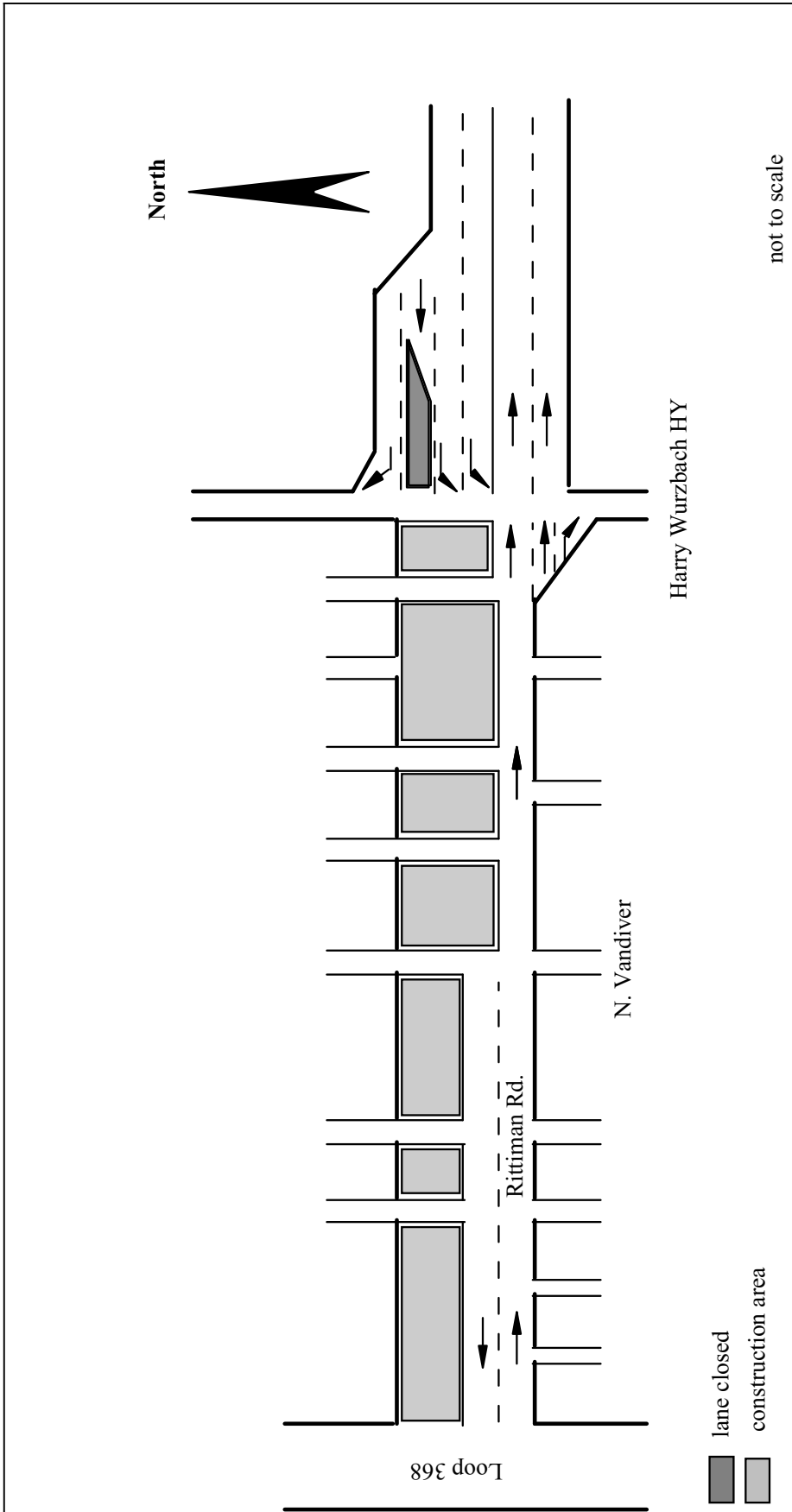


Figure B.18 Lane Closure Strategy on Work Zone # 17
(Rittiman Rd., San Antonio)

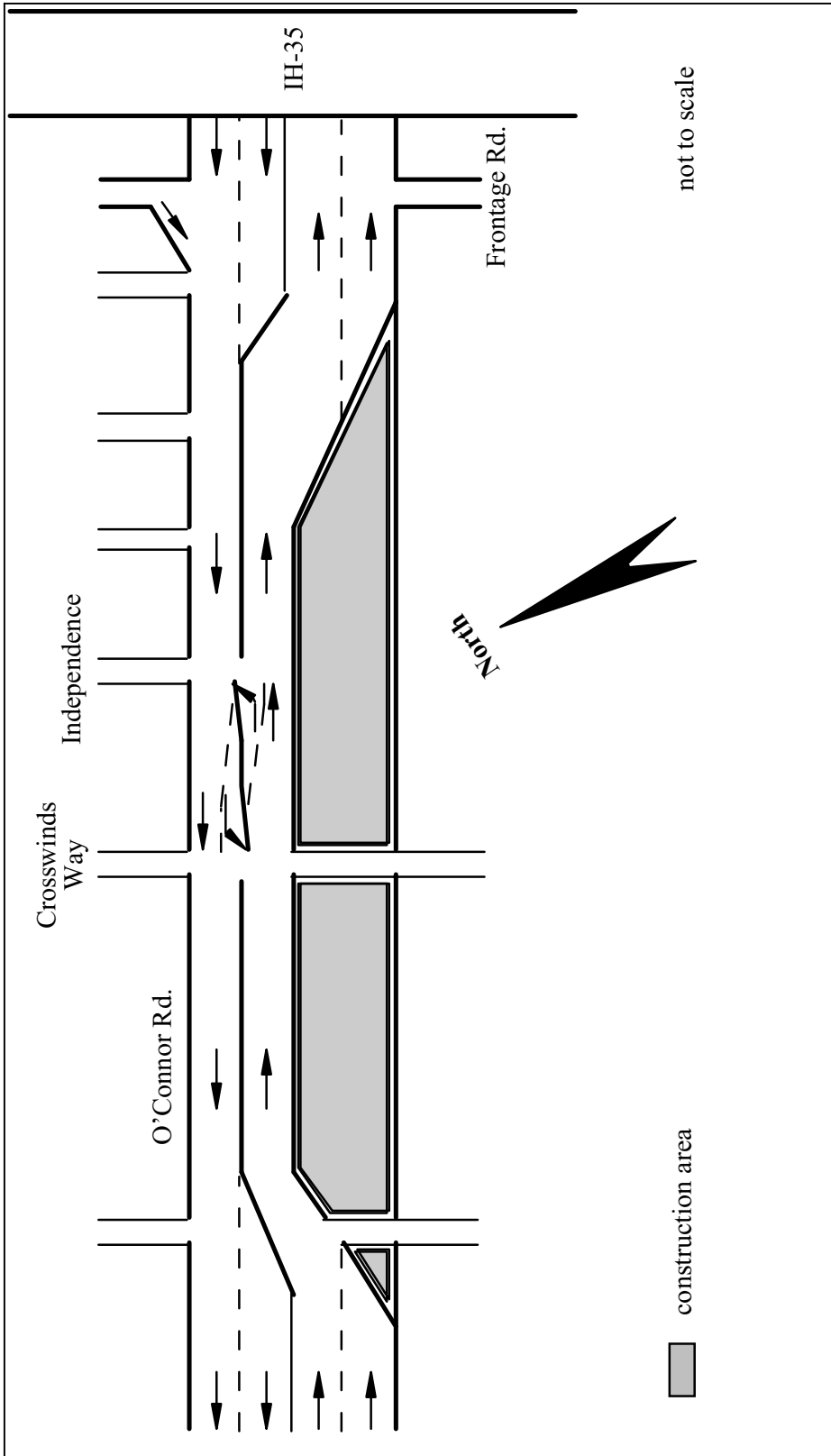


Figure B.19 Lane Closure Strategy on Work Zone # 18
(O'Connor Rd., San Antonio)



*Photo B.1 San Antonio, Work Zone #10, Hildebrand Ave.:
Work zone view from Blanco Rd.*



*Photo B.2 San Antonio, Work Zone #11, S. Flores St.:
General view of the work zone*



*Photo B.3 San Antonio, Work Zone #12, FM 2536:
View of the initial work zone section at intersection with IH 410*



*Photo B.4 San Antonio, Work Zone #12, FM 2536:
View of work zone section between IH 410 and Five Palms Rd.*



*Photo B.5 San Antonio, Work Zone #12, FM 2536:
View of work zone section between IH 410 and Five Palms Rd.*



*Photo B.6 San Antonio, Work Zone #12, FM 2536:
View of work zone section between Five Palms Rd. and W. Military Dr.*



*Photo B.7 San Antonio, Work Zone #12, FM 2536:
View of work zone section between Five Palms Rd. and W. Military Dr.*



*Photo B.8 San Antonio, Work Zone #13, West Ave.:
View of work zone initial section at NW Military Dr.*



*Photo B.9 San Antonio, Work Zone #13, West Ave.:
General view of work zone*



*Photo B.10 San Antonio, Work Zone #14, FM 2696:
Work zone view between West Ave. and Vista Real*



*Photo B.11 San Antonio, Work Zone #14, FM 2696:
Work zone view between Vista Real and Bitters Rd.*



*Photo B.12 San Antonio, Work Zone #14, FM 2696:
Work zone view between Bitters Rd. and Lariat St.*



Photo B.13 San Antonio, Work Zone #15, Blanco–Jackson Keller Intersection: Southbound approach (Blanco Rd.), facing south



Photo B.14 San Antonio, Work Zone #15, Blanco–Jackson Keller Intersection: Northbound approach (Blanco Rd.), facing south



Photo B.15 San Antonio, Work Zone #15, Blanco–Jackson Keller Intersection: Eastbound approach (Jackson Keller Rd.), facing west



Photo B.16 San Antonio, Work Zone #15, Blanco–Jackson Keller Intersection: Westbound approach (Jackson Keller Rd.), facing east



*Photo B.17 San Antonio, Work Zone #16, Probandt and Mitchell St.:
General view of work zone on Probandt St.*



*Photo B.18 San Antonio, Work Zone #16, Probandt and Mitchell St.:
General view of work zone on Mitchell St.*



*Photo B.19 San Antonio, Work Zone #17, Rittiman Rd.:
View of work zone initial section at Harry Wurzbach*



*Photo B.20 San Antonio, Work Zone #17, Rittiman Rd.:
Work zone view between Harry Wurzbach and N. Vandiver*



*Photo B.21 San Antonio, Work Zone #17, Rittiman Rd.:
Two-way road to one-way road transition section at N. Vandiver intersection*



*Photo B.22 San Antonio, Work Zone #17, Rittiman Rd.:
Work zone view between N. Vandiver and Loop 368*



*Photo B.23 San Antonio, Work Zone #18, O'Connor Rd.:
View of work zone northwest initial section*



*Photo B.24 San Antonio, Work Zone #18, O'Connor Rd.:
View of work zone northwest initial section*



*Photo B.25 San Antonio, Work Zone #18, O'Connor Rd.:
View of work zone main section, facing southeast*



*Photo B.26 San Antonio, Work Zone #18, O'Connor Rd.:
View of work zone main section, facing northwest*



*Photo B.27 San Antonio, Work Zone #18, O'Connor Rd.:
View of work zone southeast initial section (at IH 35)*



*Photo B.28 San Antonio, Work Zone #18, O'Connor Rd.:
View of work zone southeast initial section (at IH 35)*

Appendix C

Samples of Identified Traffic Control Problems



Photo C.1 Insufficient condition of sign. Sign fastened to support with nails.



Photo C.2 Damaged edge line channelizer



Photo C.3 Damaged plastic drum



Photo C.4 Barricade installed backside to traffic and too close to arrow board



Photo C.5 Construction mechanism too close to traffic



Photo C.6 Pavement drop off



Photo C.7 Insufficient barricade assembling



Photo C.8 Sign and barricade do not have the required 10-foot buffer space



Photo C.9 Damaged barricade



Photo C.10 Overlapping barricades installation



Photo C.11 Typical barricade's reflective sheeting damage



Photo C.12 Old pavement stripes were not completely removed



Photo C.13 Small radius curve on the busy local access road



Photo C.14 Insufficient signs installation



Photo C.15 Second sign hidden by previous. Second sign is unnecessary.



Photo C.16 Commercial signs create visual noise for work signs perception



Photo C.17 Typical damage of chevrons



Photo C.18 Example of Pavement Drop-Off and Excessive Distance between Drums



Photo C.19 Sign support did not meet the minimum mounting height



Photo C.20 Damaged sign



Photo C.21 A plywood "Keep Right" sign not approved to be attached to a plastic drum

Appendix D
Questionnaire

For traffic control plan designers

District: _____

Area office: _____

Position: _____

Experience: _____

During observation of traffic operations on the urban work zones several problems were identified. Please rate problems stated below on how significant the particular problem is for insuring work zone traffic safety.
Rate 1, 2, 3 with 1 most significant.

Problems	Significance
1. Lack of necessary information	
2. Information overload	
3. Confusing signs	
4. Insufficient advance information	
5. Traffic control plan utilizing non effective control devices	
6. Traffic control plan does not follow MUTCD	
7. Insufficient work zone separation from main traffic	
8. Lack of lateral clearance zone	
9. Lack of pedestrian ways	
10. Construction machines working too close to traffic	
11. Insufficient protection of pavement drop-off	
12. Commercial displays affect road sign perception	
13. Lighting of local businesses disturb work zone sign visibility	
14. Inappropriate work zone night illumination.	
15. Low-profile barriers reduce lane capacity	
16. Insufficient visibility of low-profile barrier	
17. Numerous local driveways	
18. Small radius local driveways permit turns at slow speeds only	
Other:	

Are problems on urban work zones mostly caused by:	
A. Site limitations.	
B. Contractor inability to follow original traffic control plan	
C. Traffic control plan inadequacy	
D. MUTCD requirements do not recognize specifics of urban work zones	
Other:	

We appreciate any additional comments regarding traffic control on urban work zones and your views on safety improvements.

For inspectors	
District:	
Area office:	
Position:	
Experience:	
Please rate problems stated below on how often you encounter them in your practice on the urban work zones and how significant the particular problem is for insuring work zone traffic safety. Rate 1 through 3 with 1 most frequent or most significant.	
Problems	Frequency
I. Control device installations not following MUTCD requirements:	
I-a. Unspecified traffic control device mixing	
I-b Unspecified device placement (not meeting the minimum mounting height, lack of lateral clearance, etc.)	
I-c. Permanent signs are still visible	
I-d. Permanent pavement markings are still visible	
I-e. Unstable device installation	
I-f. Sign support not assembled properly	
I-g. Barricade not assembled properly	
I-h. Signs not in use remain in a clear zone	
I-i. Other:	
II. Poor physical condition of control devices:	
Please specify the kind of control device (signs, drums, barricades, chevrons, cones, edge line channelizers, vertical panels, pavement markings, any other or all devices)	
III. Insufficient traffic control plans:	
III-a. Lack of necessary information	
III-b. Information overload	
III-c. Confusing signs	
III-d. Insufficient advance information	
III-e. Traffic control plan utilizing non effective control devices	
III-f. Traffic control plan does not follow MUTCD	
III-g. Other:	
IV. Other:	
IV-a. Insufficient work zone separation from main traffic	
IV-b. Lack of lateral clearance zone	
IV-c. Lack of pedestrian ways	
IV-d. Construction machines working too close to traffic	
IV-e. Insufficient protection of pavement drop-off	
IV-f. Commercial displays affect road sign perception	
IV-g. Lighting of local businesses disturb work zone sign visibility	
IV-h. Inappropriate work zone night illumination.	
IV-i. Low-profile barriers reduce lane capacity	
IV-j. Insufficient visibility of low-profile barrier	
IV-k. Numerous local driveways	
IV-l. Small radius local driveways permit turns at slow speeds only	
IV-m. Other:	
V. Are problems on urban work zones mostly caused by:	
V-a. Site limitations.	
V-b. Contractor inability to follow original traffic control plan	
V-c. Traffic control plan inadequacy	
V-d. MUTCD requirements do not recognize specifics of urban work zones	
V-e. Other:	
We appreciate any additional comments regarding traffic control on urban work zones and your views on safety improvements.	