TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-91/1107-3		

4. Title and Subtitle	5. Report Date
Mobility Impacts from Improvements to an Arterial Street	September 1990
	6. Performing Organization Code
7. Author(s) Kay Fitzpatrick, Bruce Rymer, and Thomas Urbanik II	8. Performing Organization Report No. Research Report 1107-3
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843	10. Work Unit No. 11. Contract or Grant No. Study No. 2/3-8/10-88-1107
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation; Transportation Planning Division P.O. Box 5051 Austin, Texas 77863	13. Type of Report and Period Covered Final - September 1987 August 1990 14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with DOT, FHWA.

Research Study Title: The Role of the Arterial Street System in Urban Mobility

16. Abstract

The Texas State Department of Highways and Public Transportation is exploring methods of providing additional roadway capacity for major traffic movements. One method identified is to increase the capacity of the arterial street system. Streets with the potential of serving an enhanced role could be improved to operate at high speeds and a high level of service yet would not be required to satisfy the strict access control and right-of-way needs of a freeway. Strategic arterial was the term selected to describe this new street category. The mobility impacts from improvements to an existing arterial street (US 90A in Houston) and to conceptual corridors were evaluated using computer simulation. Transyt-7F was the computer program used to evaluate the case study improvements that ranged from a do-nothing alternative to providing grade separations at all major intersections. For the conceptual corridor, improvements evaluated included prohibiting left turns, changing the orientation of a grade-separated structure, and modifying the number of signals per mile. The primary measure of effectiveness used to describe the mobility impacts was average through speed. At-grade improvements (e.g., adding lanes or prohibiting left turns) to the existing arterial showed limited increases in through speed due to the highly congested nature of the case study area in the year 2000. Grade-separated improvements were needed to cause significant increases in travel speeds.

17. Key Words	18. Distribution Statement
Strategic arterial, principal arterial, super street, operations, mobility impacts, computer simulation, Transyt-7F	No restrictions. This document is available to the public through the National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	90	

Form DOT F 1700.7 (8-69)

MOBILITY IMPACTS FROM IMPROVEMENTS TO AN ARTERIAL STREET

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Research Report 1107-3

Research Study No. 2/3-8/10-88-1107
The Role of the Arterial Street System
in Urban Mobility

Sponsored by

Texas State Department of Highways and Public Transportation
in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843-3135

September 1990

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

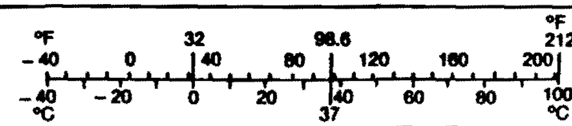
Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	2.54	centimetres	cm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
AREA				
in^2	square inches	645.2	centimetres squared	cm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
MASS (weight)				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
VOLUME				
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

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

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

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
AREA				
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac
MASS (weight)				
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
VOLUME				
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
TEMPERATURE (exact)				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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

* SI is the symbol for the International System of Measurements

ABSTRACT

The Texas State Department of Highways and Public Transportation is exploring methods of providing additional roadway capacity for major traffic movements. One method identified is to increase the capacity of the arterial street system. Streets with the potential of serving an enhanced role could be improved to operate at high speeds and a high level of service yet would not be required to satisfy the strict access control and right-of-way needs of a freeway. Strategic arterial was the term selected to describe this new street category. The mobility impacts from improvements to an existing arterial street (US 90A in Houston) and to conceptual corridors were evaluated using computer simulation. Transyt-7F was the computer program used to evaluate the case study improvements that ranged from a do-nothing alternative to providing grade separations at all major intersections. For the conceptual corridor, improvements evaluated included prohibiting left turns, changing the orientation of a grade-separated structure, and modifying the number of signals per mile. The primary measure of effectiveness used to describe the mobility impacts was average through speed. At-grade improvements (e.g., adding lanes or prohibiting left turns) to the existing arterial showed limited increases in through speed due to the highly congested nature of the case study area in the year 2000. Grade-separated improvements were needed to cause significant increases in travel speeds.

KEY WORDS: Strategic arterial, principal arterial, super street, operations, mobility impacts, computer simulation, Transyt-7F

IMPLEMENTATION STATEMENT

The Texas State Department of Highways and Public Transportation is investigating methods to provide additional roadway capacity for major traffic movements. One area being examined to provide increased mobility in urban areas is the arterial street system.

This report demonstrates, through the use of computer simulation, the impacts on mobility various improvements have on an existing arterial street and on conceptual corridors. The findings from the simulations assist in characterizing a new class of roads, defined as strategic arterials. These arterials would have high speeds and a high level of service but would not be required to satisfy the strict access control and right-of-way needs of a freeway.

DISCLAIMER

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

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

In an effort to improve urban mobility, the Texas State Department of Highways and Public Transportation is exploring methods of providing additional roadway capacity for major traffic movements. In large urban areas, the backbone of the highway and street network is the freeways and arterial streets. The previous report on "An Enhanced Role for the Arterial Street System in Texas Cities" [1] found that the freeway systems in Texas handle higher percentages of the daily vehicle-miles traveled than other U.S. cities studied and that the percentages of vehicle-miles traveled on principal arterials is less than in the other U.S. cities studied. This implies that arterial streets in Texas, if properly developed, can be expected to serve higher trip volumes and therefore reduce demands on the freeway system. The report also found that the arterial streets in Texas tend to lack continuity. In the study, an arterial was considered "continuous" if it had a cross section of at least four lanes over a minimum distance of four miles. Roadway inventory data suggested that 85 percent of the arterial lane-miles in Dallas, 60 percent of the lane-miles in Houston, and 35 percent of the lane-miles in Fort Worth conform to this definition of continuous. The report concluded that a feasible means of providing additional roadway capacity for major traffic movements in the large urban areas of Texas is by increasing the capacity of the arterial street system.

Increasing the capacity of the overall arterial street system begins with identifying those streets that could serve an enhanced role. These streets would be improved to operate at high speeds and a high level of service but would not be required to satisfy the strict access control and right-of-way needs of a freeway. The identified streets may be in several different roadside development stages. Simplest in terms of construction and control of access would be if the street will be on a new alignment. Identifying an arterial street in an area that will experience development could preserve the corridor to serve the enhanced role when development reaches the area. An arterial in an existing, heavily-developed area may also be identified as needing to serve an enhanced role. While it may be difficult to upgrade this arterial because of narrow right-of-way and existing heavy traffic flow, the upgrade may be required to improve mobility for a region. Completing a missing roadway segment along a route could elevate two previously unconnected roads into an arterial that could then serve an enhanced role.

At-grade improvements such as adding through or turn lanes, prohibiting left turns, and access management can result in noticeable improvements as measured by increased capacity and speed. However, using grade separations at selected intersections may be necessary to achieve the enhanced arterial streets' objectives of high speeds and a high level of service. Conditions existing along the arterial would assist in identifying the types of improvements needed to upgrade the arterial.

1.2 REPORT OBJECTIVES

The major objective of this report is to define the mobility impacts on an existing arterial street from upgrading the arterial using selected at-grade and grade-separation improvements. A computer simulation program (Transyt-7F) was used to evaluate different improvements on an arterial street located in southwest Houston. The improvements ranged from a do-nothing alternative to providing grade-separated structures at all major intersections along the arterial. In order to place the case study corridor in an appropriate overall framework, the mobility impacts from selected improvements on conceptual corridors were evaluated first.

While investigating the role an enhanced arterial street system could serve, discussions occurred concerning where this improved street best fits within the existing functional classification scheme. Was this type of street more like a freeway and should it be known as a "junior freeway" or should it be known as a "super street" to indicate that it is providing service at a super efficient level? An additional objective of this report was to define and characterize this new category of streets which functions between existing principal arterials and freeways. The term "strategic arterial" was selected to describe this new street category.

CHAPTER 2

FUNCTIONAL CLASSIFICATION

2.1 GREEN BOOK STREET CLASSIFICATION SYSTEM

2.1.1 Background

The American Association of State Highway and Transportation Officials' (AASHTO) A Policy on the Geometric Design of Highways and Streets (commonly referred to as the Green Book) [2] indicates that the functional classification or the grouping of highways by the character of service they provide was developed for transportation planning purposes. The two major considerations in classifying highway and street networks functionally are access and mobility. The conflict between serving through movement and providing access to a dispersed pattern of trip origins and destinations necessitates the different functional classes. Access limitations are necessary on arterials to enhance their primary function of mobility. Conversely, the primary function of local roads and streets is to provide access (implementation of which causes a limitation of mobility). The extent of access control is a significant factor in defining the functional class of a street or highway. Figure 1 illustrates the relationship of a functional classified system to access and mobility.

2.1.2 Functional Highway Systems in Urbanized Areas

The Green Book [2] functional highway systems for urbanized areas are urban principal arterials, minor arterials, collectors, and local streets. This study is concerned with principal arterials whose primary function is movement.

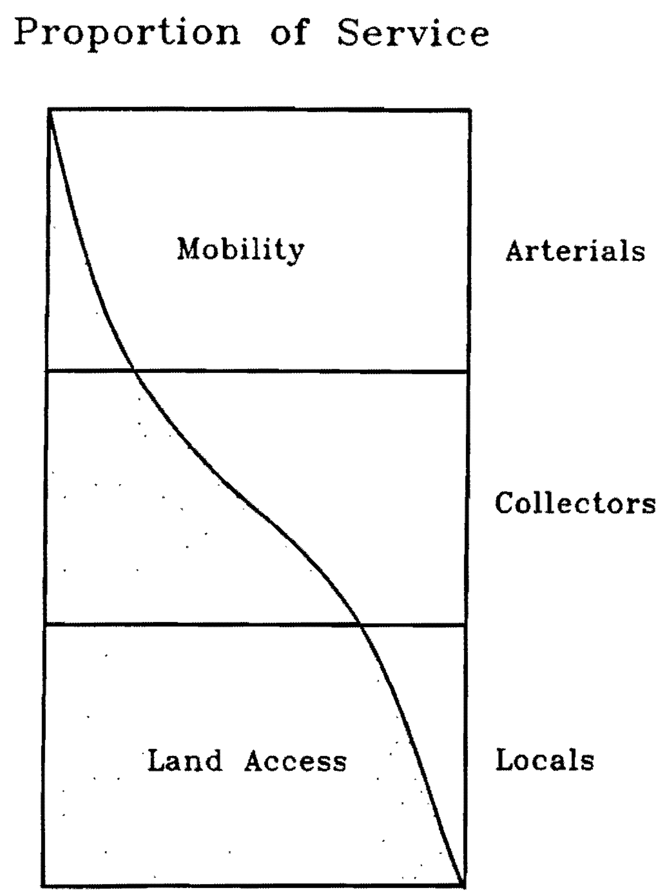

Figure 1. Green Book's relationship of functional classified system to access and mobility. [2]

The principal arterial system carries most of the trips entering and leaving the urban area, as well as most of the through movements bypassing the city. Because of the nature of the travel served by the principal arterial system, almost all partially and fully controlled access facilities are part of this functional class. However, this system is not restricted to controlled-access routes. To preserve the identification of controlled-access facilities, the Green Book [2] stratifies the principal arterial system as follows: (1) interstate, (2) other freeways and expressways, and (3) other principal arterial (with partial or no control of access). Access is subordinate to mobility of major traffic movements. Access is purely incidental to the primary functional responsibility of this class of roads.

2.2 PROPOSED FUNCTIONAL CLASSIFICATION SYSTEM

Since emphasis is currently being placed on improving mobility on existing urban streets, new classes or descriptions of roads are being discussed to describe a street with a high level of mobility that does not fulfill the strict requirements of a freeway in terms of access control or right-of-way needs. Names being used include super streets, junior expressways, strategic arterials, and others. The system as presented in the Green Book does not provide a category that adequately describes the type of arterial currently being discussed.

A proposed functional classification is shown in Figure 2. Freeways, with the requirements of grade separation and total control of access, are shown in their own class. The next class is arterial streets which has a primary function of providing mobility but with access control that is not as restrictive as freeways. The remaining two groups are still collector and local streets.

The proposed arterial class is subdivided into three subclasses: strategic arterials, principal arterials, and minor arterials. The majority of the existing arterials currently categorized as a principal arterial would continue to be placed in that subclass. Roads in the new strategic arterial class would have stricter access control requirements than the principal arterial subclass but not as extensive as the freeway requirements. An occasional at-grade intersection could be consistent with the goals of the strategic arterial class.

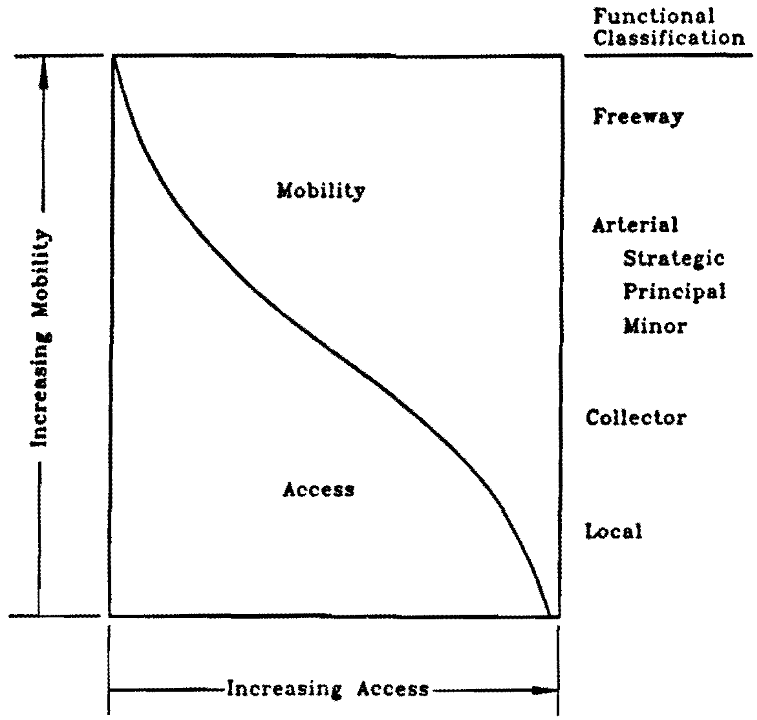

Figure 2. Proposed classification.

CHAPTER 3

TRANSYT-7F

3.1 TRANSYT-7F PROGRAM

The tool selected for evaluating various scenarios and improvements to a case study area is the Transyt-7F computer program [3]. Transyt-7F was selected because it is a flexible signal optimization and evaluation program. It is capable of modeling traffic networks with intersection traffic control ranging from stop signs to complex signal timing plans. The program is deterministic (produces the same results whenever the same inputs are used) and macroscopic (models based on platoon of vehicles instead of individual vehicles). It optimizes the traffic signal system based on minimizing delay and stops at the intersections.

Transyt-7F analyzes and optimizes single intersections as well as multiple intersections in a corridor or network. Transyt-7F follows a link/node format with the nodes representing intersections and the links representing turn bays or travel lanes between intersections. The detailed geometric and operational information required by the program includes lane usage, capacity, and length; traffic volume; free flow speed (or the speed limit); and signal phasing information. Transyt-7F uses this information in the search for an optimal system wide cycle length. Once the optimal cycle length is determined, intersection delay is recalculated and queues are determined. This information is then used to determine average travel time on the links (arterial segments) between the intersections.

3.2 TRANSYT-7F MEASURES OF EFFECTIVENESS

Transyt-7F produces several measures of effectiveness which are useful for analyzing improvement strategies. Transyt-7F calculates the measures for each individual intersection and also generates a summary of the system wide measures of effectiveness. The system wide measures used for comparison purposes in the case study are:

- total uniform delay (veh-hr/hr)
- total random/saturation delay (veh-hr/hr)
- total system delay (veh-hr/hr)
- total travel time (veh-hr/hr)
- average system speed or average through speed (mph)
- total stops (percent of veh/hr)
- cycle length (sec)

Average through speed (speed of the through vehicles on the major street) is the primary measure of effectiveness used in the evaluations in this study.

Delay (veh-hr/hr) represents the indirect cost to motorists in terms of time lost and the direct cost in terms of fuel consumed during idling. Excessive delay at signalized intersections reflects the inefficiency of the signal timing. The total system delay value includes the delay due to uniform arrivals of vehicles and the delay due to random arrivals and saturated conditions (periods of high demand). In periods of high demand, the random/saturation delay component can be much higher then the uniform delay. High random/saturation delay is an indicator that there are traffic flow problems and the motorist's mobility has been adversely affected.

Total travel time (veh-hr/hr) for a system includes both the time the motorist spends moving and the time spent delayed at each intersection. Travel time for a link is determined by multiplying the time spent on the link (including delay) by the link volume. Total travel time is the summation of travel times for all links.

Average system speed (mph) is an indication of the overall quality of flow in the network. It is the ratio of total travel distance to total travel time. Total travel distance (veh-mi/hr) is the summation of the distances traveled by each vehicle. (It is calculated by summing the products of the number of vehicles on a link in a hour multiplied by the link's length.) Total travel distance is constant for a given network and set of traffic volumes.

Links in the data set with zero distance are excluded by Transyt-7F from the calculation of the average system speed. Cross street link lengths and the turn bay lengths were assumed to be zero in the simulation runs so that the calculated average through speed would represent the through vehicles on the major road. This allows for a comparison of the program's computed speed with the speed that drivers on US 90A in the case study may actually experience. The calculation of the average through speed for through traffic on US 90A would also allow an evaluation of the quality of flow along the arterial.

Total stops (percent of veh/hr) is an estimate of the total number of stops which occurred in the system during the simulated hour. The percentage of stops is based on an empirical relationship developed by the original authors of the Transyt-7F program at the Transport and Road Research Laboratory [4]. The percentage of stops decreases as the calculated delay decreases. Percentages larger than 60 percent may indicate congestion problems, while percentages lower than 40 percent may indicate reasonably well progressed traffic.

Optimal cycle length (sec) is another gauge of how well the signal system is performing. Cycle length is the amount of time during which all movements at a signalized intersection are accommodated. Excessively long cycle lengths could be an indicator of potential operational problems.

CHAPTER 4

STRATEGIC ARTERIAL STREETS CHARACTERISTICS

4.1 STRATEGIC ARTERIAL STREET CONCEPT

Due to the demands for increased urban mobility, the arterial street system is being examined to determine how improved service can be obtained from the streets. Goals include achieving high operating speeds and a high level of service for long trip lengths. The improved arterials are named strategic arterials to differentiate the characteristics of these new streets from those of existing principal arterials. Table 1 lists characteristics of a strategic arterial along with characteristics of roads within other functional classifications. This table is adapted from *Transportation and Land Development* [5]. It illustrates how a strategic arterial fits within the existing classification scheme of roads.

4.2 GENERAL CHARACTERISTICS

As discussed in a previous report on the enhanced roles for arterial streets [1], the general characteristics of a strategic arterial should support its primary function of traffic movement. To support this function the arterial should have the following characteristics:

- Part of a system of regional, high-capacity arterial streets
- Continuity throughout the urban area from one facility to another of the same functional class or higher (strategic arterial or freeway)
- High design speed and operational flexibility
- Grade separations where applicable
- Long, uniform signal spacing

Table 1. Functional route classification.

Classification	Function	Continuity	Spacing (miles)	Direct Land Access	Minimum Roadway Intersection Spacing	Operating Speed (mph)	Parking	Comments
Freeway and Expressway	Traffic Movement	Continuous	4	None	1 mile	45 - 65	Prohibited	Provides high speed mobility
Strategic Arterial	Traffic Movement	Continuous	2 - 4	Rare	1/2 - 1 mile	45 - 55	Prohibited	
Primary Arterial	Intercommunity and intrametro area traffic movement	Continuous	1 - 2	Limited	1/2 mile	35 - 45 in fully developed areas	Prohibited	Backbone of street system
Secondary Arterial	Primary -- intercommunity, intrametro area, traffic movement Secondary -- land access	Continuous	1/2 - 1	Restricted -- some movements may be prohibited; spacing of driveways controlled	1/4 mile	30 - 35	Generally prohibited	
Collector	Primary -- collect/distribute traffic between local streets and arterial system Secondary -- land access Tertiary -- inter-neighborhood traffic movement	Not necessarily continuous; should not extend across arterials	1/2 or less	Safety controls; limited regulation	300 feet	25 - 30	Limited	Through traffic should be discouraged
Local	Land access	None	As needed	Safety controls only	300 feet	25	Permitted	Through traffic should be discouraged

Source: Adapted from Reference 5

- Signalization improvements to facilitate progressive movement through the system
- Mid-block cross-section incorporating a non-traversable median and peripheral buffer strips
- Management of unsignalized median and peripheral access
- Pedestrian grade separations as needed
- No parking along street
- Consideration of transit loading and unloading areas
- Turn bays with adequate length for deceleration and storage when turning is permitted

Access management criteria should be developed and implemented in order to preserve the movement function of the arterial. Limiting access on a roadway can result in increased speed and capacity within the corridor. The access management criteria should include standards for the location, spacing, and design of access (public and private) which may be constructed between signalized intersections. The major roadway could also be designed with non-traversable medians which can be landscaped to enhance delineation.

Left-turn bays should be required wherever there is an opening in the median. Turn bays should be of sufficient length to allow deceleration to occur after the vehicle leaves the through traffic lane plus storage to accommodate turning vehicles. The speed differential between the through traffic and the traffic entering the turn bay should be a maximum of 10 mph. The turn lane should be designed to store all vehicles in the design peak hour with no more than a 10 percent probability of overload. Effective accommodations of left turning movements is an important concern in improving the traffic flow on an arterial.

Right-turn bays should be required at all arterial intersections, public and private, signalized and unsignalized. The turn bay should be designed so as to limit the speed differential between the turning vehicle and through vehicles to 10 mph or less. Intersections of two arterials should provide channelization of right turn lanes.

4.3 CONSIDERATIONS WHILE REVIEWING POTENTIAL DESIGNS

4.3.1 Overview

When an area is experiencing increased development and traffic, the decision to install a signal or to build a grade-separated structure is typically made based on the operations at the subject intersection. A better solution to an operational or safety problem may be found if the operations along the corridor (or within the network that includes the subject intersection) are evaluated, especially when considering the implementation of a strategic arterial street system. For example, choosing the most simple geometric design in grade separating a route from a cross street will improve the operation at the subject intersection, but maximum realization of the structure's benefits may require the design to favor the cross street rather than the route. The addition of a signal at an intersection may satisfy a development's needs, but may adversely affect the operations along a corridor. Moving the signal to another location within the development may provide better opportunity for progression or improved operations along the corridor while still providing satisfactory access to the development.

Traffic engineers must consider several items when recommending and implementing improvements. Obvious improvements, while providing an adequate solution to a problem at an intersection, may not be the best improvement for the corridor or network. This section will discuss several general concepts (direction of grade separation, grade separating the most congested intersections along an arterial, number of signalized intersections per mile, prohibiting left turns) for consideration when reviewing improvements that will modify an arterial street to serve an enhanced role. Other items for consideration when selecting improvements include access control, number of continuous lanes, distance that the lanes are continuous, and developing a balance street system.

4.3.2 Location and Orientation of Grade-Separated Structures

Location and orientation of grade-separated structures could be key issues when developing a strategic arterial. An intersection may derive benefits from a grade separation, but an analysis of the entire corridor may reveal that the congestion is only moved to an intersection that is not able to handle the increased traffic or that improvements elsewhere on the corridor may provide the greatest benefits. The orientation of the structure specifies which through traffic has the advantage of not passing through signals. The orientation may need to favor a particular route to meet strategic arterial goals or may need to favor a route due to high through volumes.

Six conditions (see Figure 3) were analyzed using the Transyt-7F computer program to illustrate the effects that location and/or orientation of grade-separated structures have on travel speed and delay. The conceptual arterial is one-mile long with five intersections

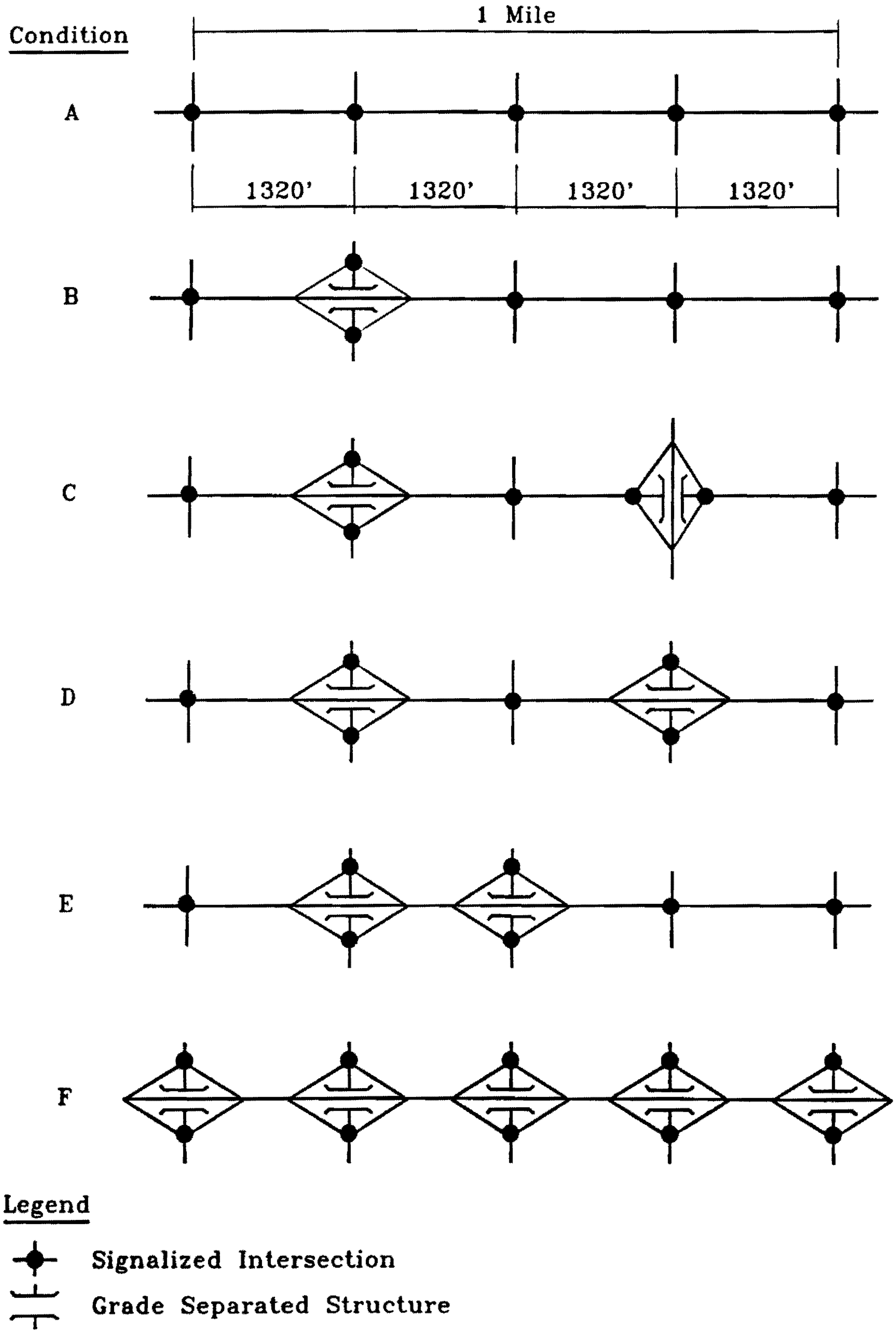

Figure 3. Five Conditions for grade separation analysis.

spaced 1/4 mile apart. Each intersection was assumed to have similar traffic volume (20,000 ADT on each street or 1,000 veh/hr approach volume with 20 percent of the approach vehicles turning left and 20 percent turning right). Each approach consisted of two through lanes, a left-turn bay, and a right-turn bay. Signal phasing included leading left turns, 3 seconds change interval times, and no all-red time. The signals at the grade separations were modeled as compressed diamonds and the free flow speed was 45 mph.

Condition A represents an at-grade corridor. It has five at-grade intersections within the one mile length. Condition B reflects the situation when one of the five at-grade intersections is grade separated.

Two intersections in Condition C are grade separated. One intersection has the grade separation oriented along the major street (the through traffic on the major street passes the cross street on a structure, while the major street's turning maneuvers exit the major street using ramps and then interact with the cross street traffic at a diamond intersection). The other intersection has the grade separation oriented along the cross street.

Condition D and E also have two grade-separated intersections but both intersections are oriented along the major street. Condition D has the grade-separated intersections separated by an at-grade intersection. Condition E does not have an at-grade intersection between the two grade-separated intersections. A grade-separated structure is present at each intersection in Condition F.

The evaluation of the different orientations of the grade-separated structure began with a review of the delay to drivers on the major road. Figure 4 shows the different types of intersection design (at-grade, grade separation favoring the major road, and grade separation favoring the cross street) and the respective delay to the major street traffic. Drivers experience 12.0 veh-hr/hr of delay at an at-grade intersection. When the intersection is upgraded with a grade-separated structure, the major road drivers experience 9.0 veh-hr/hr of delay if the structure favors the cross street and 7.0 veh-hr/hr of delay (to exiting traffic) if the structure favors the major road. When the structure favors the cross street, all major road traffic is forced through signals whereas when the structure favors the major road, only the major road's turning vehicles travel through a signal.

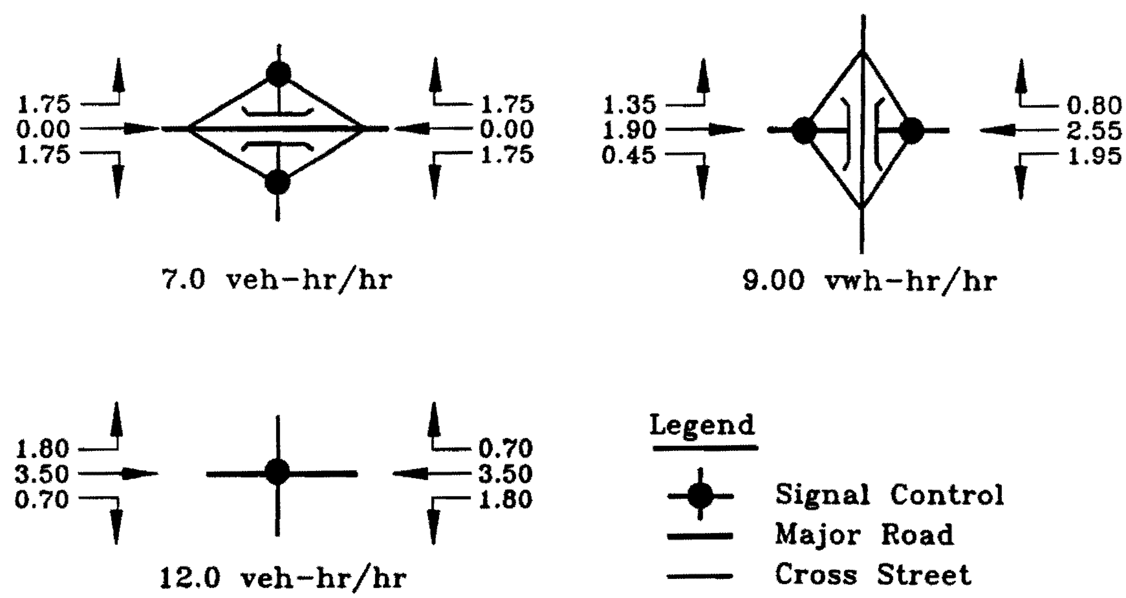

Figure 4. Delay values for major road vehicles for different intersection types.

The overall system performance for each Condition is listed in Table 2. Delay is reported for the major street through vehicles and for all vehicles (through and turning vehicles) on the major street. The delay for the through drivers decreased more than the delay for all drivers on the major street. The through drivers are able to achieve higher speeds due to being able to bypass the signals. Average through speed represents the average speed that the through vehicles experience for each Condition. While the increase in speed may not be dramatic, it does illustrate that benefits do exist for drivers when a grade separation is implemented. The extent of the benefit is highly dependant upon the actual volume and geometric conditions existing along a corridor.

Table 2. Location and orientation of grade-separated structure simulation results.

Condition	Total Delay for Major Street Vehicles (veh-hr/hr)		Average Through Speed (mph)
	Through Vehicles	Through and Turning Vehicles	
A	32	59	23
B	30	58	24
C	27	57	25
D	22	52	27
E	22	52	27
F	0	35	45

The presence of grade-separated structures does increase the speed along the major road (see Table 2), but the speed is not constant throughout the length of the corridor. As shown in Figure 5, the speed for the through traffic on the major road increases prior to a grade-separated structure, but decreases significantly upon approaching the next signalized intersection. When a designer considers recommending a grade-separated structure, an

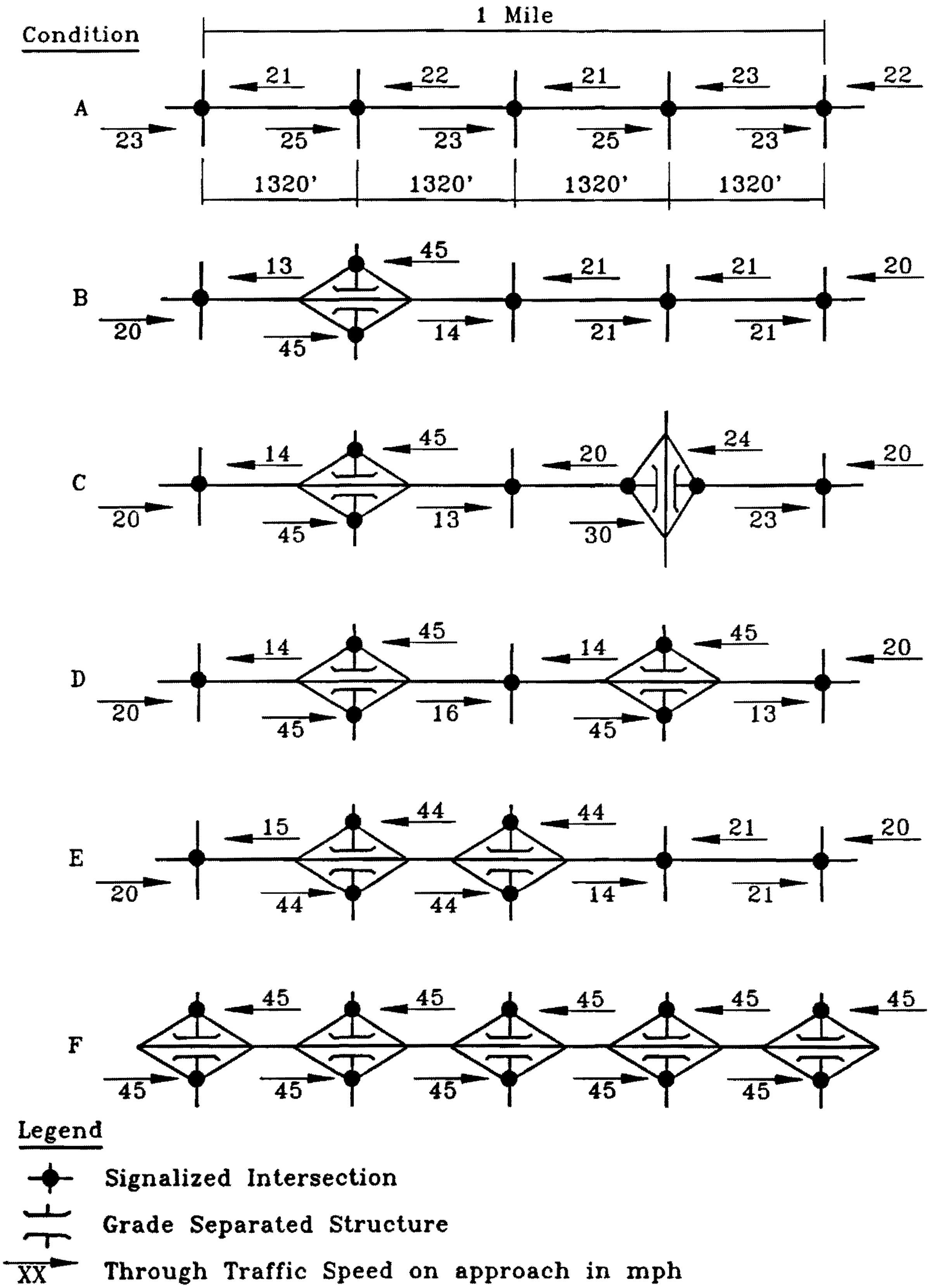

Figure 5. Through traffic speeds for different Conditions.

analysis of the effects on neighboring intersections should be included. When an at-grade intersection is not between two structures (Condition E), drivers are able to maintain the higher speed for a greater distance. This is also likely to be a safer condition.

Condition F presents the effects of total grade separation along the arterial. Delay to the through traffic is small, and the speed along the arterial is 45 mph. The delay accumulates only to the arterial turning traffic as it exits the arterial and enters the at-grade signalized portion of the corridor. Conditions A and F represent operational extremes for an arterial; Condition A, being totally at grade, has a through speed which is approximately half of the through speed for the grade-separated system in Condition F.

This series of simulations is not an extensive analysis, and only general conclusions can be drawn from these conceptual scenarios. Grade separations can impact the delay and speed on an arterial system. They allow commuters to go over (or under) stop-and-go conditions at an intersection, which decreases delay and travel time; however, the speed cannot increase substantially if signalized at-grade intersections are near. Benefits may also be realized if an intersection has high volumes on a particular approach. This analysis only considered equal volumes on each approach to illustrate the effects different grade-separation orientations have on major road traffic.

4.3.3 Grade Separating a Congested Intersection

When the congestion at a specific intersection is much greater than neighboring intersections, grade separating the most congested intersection may improve the traffic flow along an arterial to an acceptable level. Figure 6 shows two Conditions used to illustrate the effects of improving the most congested intersection on an arterial. The conceptual arterial is one-mile long with five intersections spaced 1/4 mile apart. The arterial has an ADT of 30,000 with approach volumes of 1,500 veh/hr with 10 percent of the approach traffic turning right and 10 percent turning left. Six through lanes and left and right turn bays exist along the arterial. All cross streets except the second intersection have two through lanes, a shared right turn lane, and a left turn bay per approach. The ADT along each cross street at these intersections is 15,000 (750 veh/hr approach volume with 20 percent of the approach vehicles turning left and 20 percent turning right). The second intersection represents an intersection of two major streets. The cross street has a cross section and approach volumes similar to the arterial (see Figure 6).

Signal phasing included leading left turns, 3 seconds change interval times, and no all-red time. The signals at the grade separations were modeled as compressed diamonds and the free flow speed was 45 mph.

Condition A has each intersection at grade and is used as the basis for comparison. Condition B has the intersection with the major road (the second intersection) grade separated; this Condition illustrates the effects that grade separating the most congested intersection along an arterial have on delay and average travel time. The results are summarized in Table 3. Grade separation of the most congested intersection has decreased the delay to the arterial through traffic resulting in a minor increase in the overall speed.

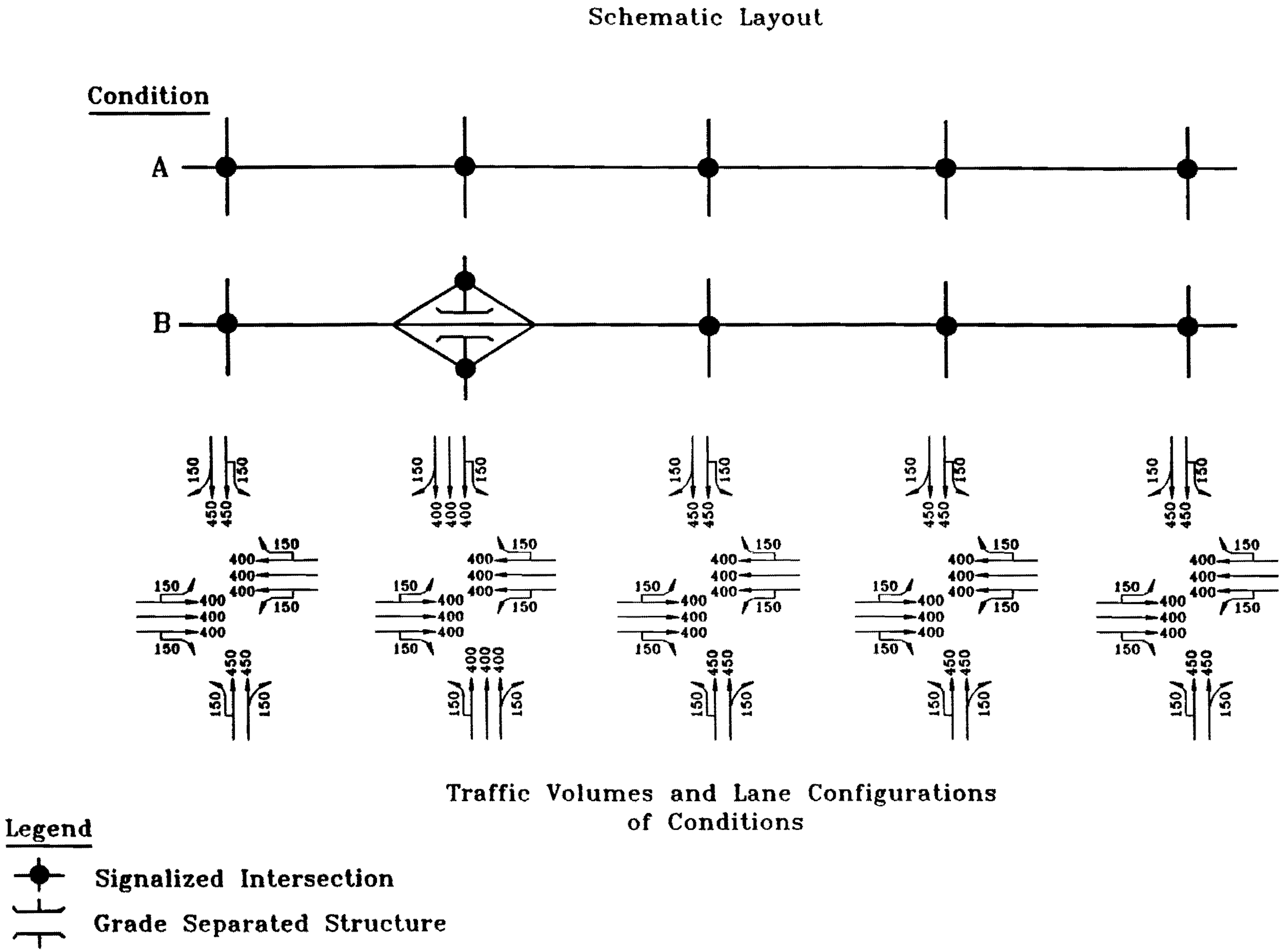

Figure 6. Conditions to illustrate effects of improving the most congested intersection.

Table 3. Grade separating a congested intersection simulation results.

Condition	Total Delay for Major Street Through Vehicles (veh-hr/hr)	Average Through Speed (mph)
A	57	24
B	47	27

In conclusion, grade separating the most congested intersection caused a decrease in the arterial delay, but the separation had only a minor impact on the average through speed from one end of the arterial to the other.

4.3.4 Number of Signals Per Mile

Transyt-7F was used to illustrate the effects of additional signals on average travel speed. Intuitively, the average travel speed should decrease with the increasing number of signalized intersections and the simulation runs support this concept. The runs also illustrated the magnitude of speed reduction that can be expected when signals are added. Average travel speed of the major road traffic was selected as the measure of comparison since drivers easily relate to the value.

The initial simulation runs began with each signalized intersection having equal volume and with equal spacing between signalized intersections. Figure 7 shows the volumes and intersection geometry for the "equal volume, equal spacing, 2 intersections per mile" simulation run. Traffic volumes were selected to avoid congestion at an intersection affecting the results. A four-phase timing plan with protected and permissive lefts was assumed.

A significant influence on the resulting average travel speed was the value used for "free flow speed" in the program. The following different values were used in the simulation runs: 55, 45 and 30 mph. The distance between intersections was held constant. The runs began with using 2 signalized intersections per mile (intersections spaced 5,280 ft apart) and were increased by 1 signalized intersection up to 7 signalized intersections per mile (intersections spaced 880 ft apart). An additional run of 16 signalized intersections per mile (intersections spaced 352 ft apart) to simulate downtown conditions was also made.

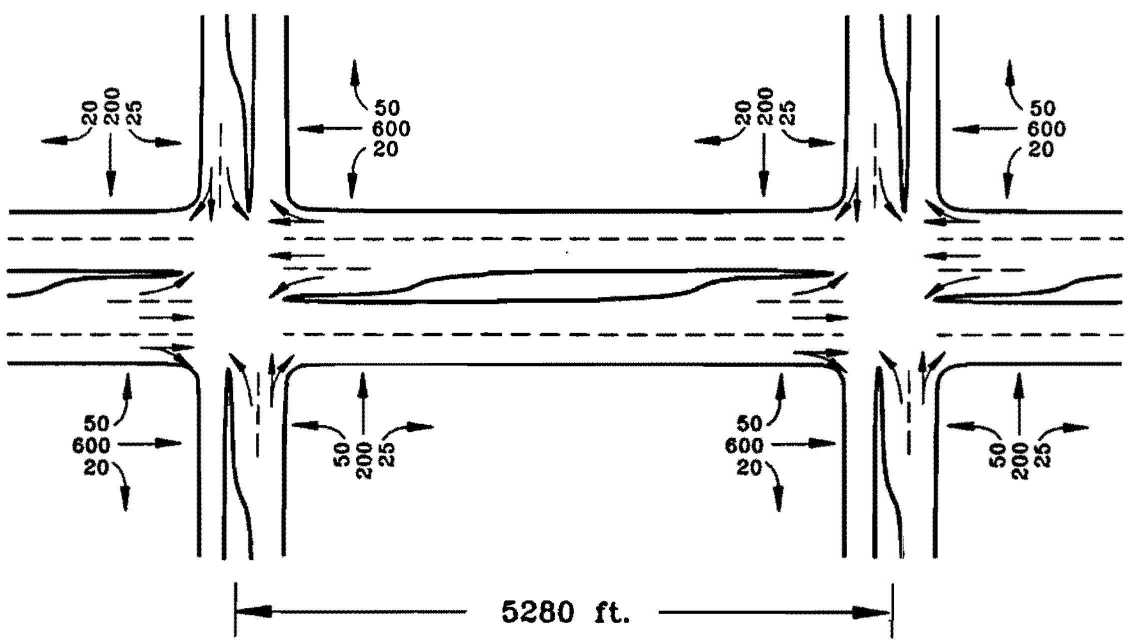

Figure 7. Volume and intersection geometry for equal volume, equal spacing, 2 intersection per mile simulation run.

Figure 8 illustrates the results from the set of runs showing the effects of different free flow speed values. The average travel speeds of the corridor vehicles are influenced by the free flow speeds when the intersections are spaced a mile apart but are not noticeably influenced when several signalized intersections per mile are present.

The results from these simulation runs are conceptual in nature. For example, intersections are not evenly spaced with exactly the same volume of traffic at each intersection. The results do illustrate, however, that there are consequences in adding signalized intersections to a corridor. For each new signal installed, the flow and speed of the corridor traffic is affected. When installing a signal at an intersection, the impact the signal has on the operations along the corridor should also be examined.

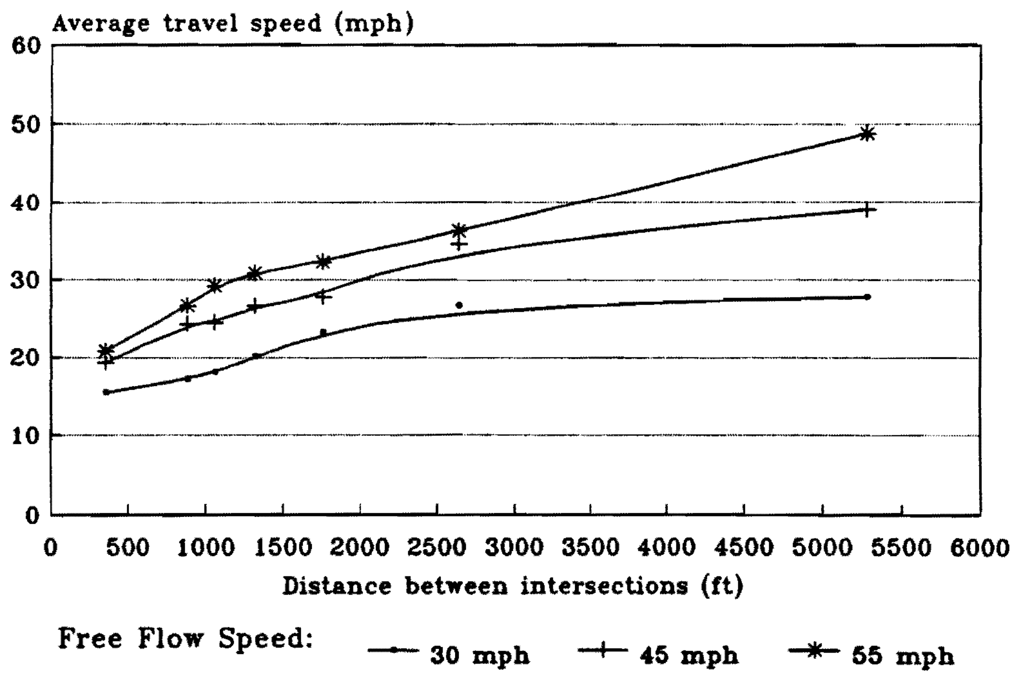

Figure 8. Average travel speed based on intersection spacing and free flow speed.

4.3.5 Prohibit Left Turns and Other Considerations

Transyt-7F and the previous data sets (see Section 4.3.4) were also used to evaluate the following scenarios:

- Prohibit left turns along the corridor -- Vehicles turning left from the major road were coded as making a right turn from the major road and then as through traffic on the cross street (see Figure 9). This assumes that these vehicles will make a U-turn on the cross street. The signal phasing was modified from a four-phase cycle to a two-phase cycle.
- Major streets at each end of the mile -- Intersections at each end of the corridor are intersections with major streets (same volume on cross street as on the major road) and the intersections in between are intersections with minor streets (volume on cross street as shown in Figure 7).
- Unequal spacing between signalized intersections -- The spacing between intersections for the 4 intersection per mile simulation was 750, 100, and 3530 ft. The spacing between intersections for the 7 intersection per mile simulation was 750, 350, 750, 1780, 750 and 900 ft.

The results determined using a free flow speed of 55 mph are listed in Table 4.

Noticeable improvements in average travel speed can result from prohibiting left turns. The actual benefits realized from this type of improvement would also depend on the cross street volume, possibility of U-turns on the cross street, and driver acceptance of accomplishing a left turn by making a series of turns that include a right turn and a U-turn.

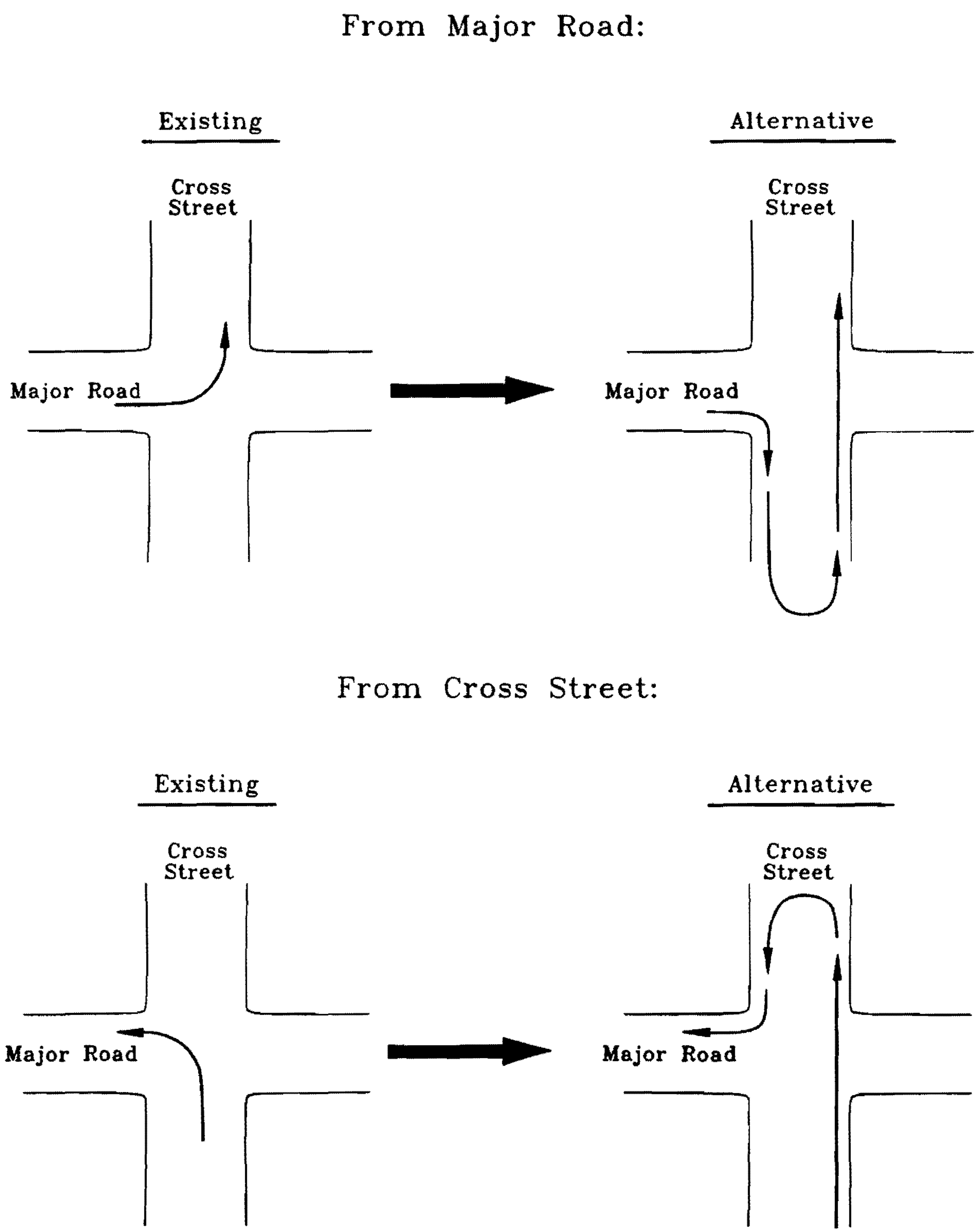

Figure 9. Redirection of left turning vehicles.

Table 4. Transyt-7F results for various scenarios.

Number of Intersections	Equal Spacing Equal Volume (mph)	Prohibit Left Turns (mph)	Major Streets at Each End (mph)	Unequal Spacing (mph)
2	49	51		
4	32	46	28	41
7	27	30	24	28

When the intersections at each end of the mile segment are with major streets, the average travel speed is lower due to the increased delay experienced at the major street intersections. The average travel speed is higher with the unequal spacing, 4 intersection-per-mile simulation than the similar equal spacing simulation because the vehicles were able to achieve a higher speed on the 3530-ft segment which resulted in the average travel speed increasing. The unequal spacing, 7 intersections per mile simulation resulted in an average running speed that was virtually equal to the related equal spacing simulation.

4.4 SUMMARY

A strategic arterial's primary function is traffic movement. Judicious use of turn prohibitions, signal spacing, and grade separations can improve traffic flow and, therefore, result in the high speeds and level of service associated with the strategic arterial classification. Since each arterial street is unique, different combinations of improvements must be examined to determine the optimal set of improvements that will provide the quality of service desired at an acceptable cost.

CHAPTER 5

US 90A CASE STUDY

5.1 OVERVIEW

5.1.1 Objectives

The objective of the case study is to illustrate the impacts on an existing arterial facility (US 90A in Houston) that at-grade and grade-separation improvements have on mobility. Computer simulation runs were used to produce measures of effectiveness for each set of improvements applied to the arterial. These measures, that included average through speed, travel time, and delay, were used to compare the different improvement strategies. Alternatives included examining relatively low-cost, easy to implement improvements, improvements planned by the Texas State Department of Highways and Public Transportation (SDHPT), and other strategies which improved the operations of US 90A.

5.1.2 Methodology

Computer simulations provide an understanding of the effect various improvement strategies have on arterial operations. The first Transyt-7F simulation (called Case I) uses existing (1986) geometrics and 1986 traffic volumes. The objective of this simulation is to determine if the program replicates existing conditions. The average US 90A speed from this run was compared to the findings from a floating-car study to validate the computer program. The results from the Case I simulation are then used as a basis of comparison for the do-nothing simulation (Case II). The do-nothing simulation uses 1986 geometrics and

2000 year volumes projected by the State Department of Highways and Public Transportation to demonstrate the potential consequences of not implementing any improvements. Case II results are then used as a basis of comparison for the other simulations that use different improvement strategies and 2000 year volume. The series of improvements range from at-grade, low-cost improvements to costly grade separations, with each successive improvement becoming more complex to implement. Table 5 is a summary of the Transyt-7F simulations.

Table 5. Summary of Transyt-7F simulations.

Conditions	Simulation
Existing (1986) Geometrics and Volumes	Case I
Existing Geometrics and 2000 Year Volume (Do-Nothing Alternative)	Case II
Intersection Spacing (Removal of 2 signals)	Case III
Prohibit Left Turns on Each Approach	Case IV
Eight Through Lanes on US 90A	Case V
Extensive At-Grade Improvements	Case VI
Proposed Improvements	Case VII
Strategic Arterial	Case VIII

The different simulations are also evaluated to determine if the computed speed on US 90A could be within the speed range that is desired for a strategic arterial. A speed between 45 and 55 mph is desired for the portion of US 90A outside of IH 610. This portion satisfies several of the strategic arterial general characteristics (see Section 4.2) including connecting two routes of similar or higher functional classifications (i.e., currently US 90A connects IH 610 South and US 59 South; in the year 2000, US 90A will also connect to Beltway 8, a proposed loop road around Houston). The portion of US 90A within the IH 610 Loop does not satisfy several of the strategic arterial general characteristics. Also, the improvements proposed by the State Department of Highways and Public Transportation terminate four blocks within the IH 610 Loop (at Old Spanish Trail). This portion of US 90A is retained in the computer simulations for comparison purposes to illustrate the differences that shorter signal spacing, lower speed limits, greater development intensity, and other differences will have on average through speed.

The measures of effectiveness for each simulation were analyzed to assist in determining other improvement strategies for evaluations. Average through speed and total system delay were the primary measures used to determine the improvements needed in other cases. The presence of over saturated conditions on an approach or a high percent of vehicles stopped assisted in identifying specific intersection improvements which could aid in supplying a more efficient at-grade US 90A system (Case III to VI).

5.2 CORRIDOR BACKGROUND

5.2.1 Location of Case Study

The segment of US 90A selected for the case study is located in the southwest quadrant of Houston, Texas (see Figure 10). US 90A is one of many primary arterials which radially intersect Houston; however, unlike freeways, US 90A is not access controlled. The roadway currently functions as a high-capacity arterial street and serves as a link between several suburban communities (Sugarland, Stafford and Missouri City) and inside IH 610 Loop area. US 90A serves as a major east/west arterial connector and also functions as an alternate route for the congested US 59 (Southwest Freeway). US 90A is a major connector between Houston's Harris County and the neighboring Fort Bend County. Fort Bend County is predicted to undergo a phenomenal growth of 315 percent in the early 21st century as more commuters choose to reside in Houston's surrounding communities [6].

5.2.2 Background of Case Study

US 90A (Main Street) in Houston, Texas was chosen to illustrate the effects improvements could have on arterial mobility since information on existing and proposed geometrics and traffic volumes were readily available. The facility also currently satisfies several of the general characteristics of a strategic arterial such as continuity throughout an urban area (i.e., it provides a connection from IH 610 and US 59 South) and part of a system of regional high-capacity arterial streets. It also has the potential to satisfy other requirements such as long, uniform signal spacing, non-traversable medians, and right-of-way availability for grade separations.

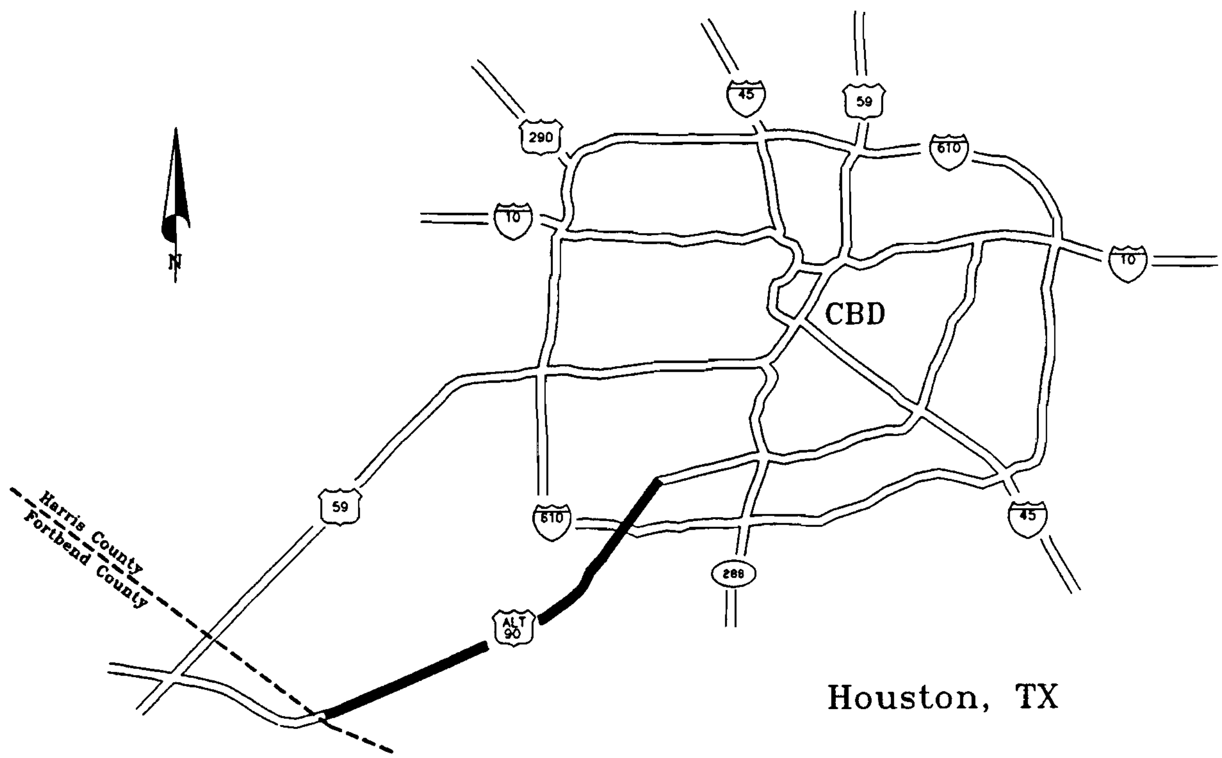

Figure 10. Location map of US 90A in Houston, TX.

The Texas State Department of Highways and Public Transportation presently is planning to implement a series of improvements along US 90A in an effort to increase capacity in this corridor. Improvements include grade separating most of the major intersections along US 90A between IH 610 and US 59 South. The project limits (see Figure 11) for the planned improvements are from US 59 South to Old Spanish Trail (four blocks north of IH 610). Case study project limits for the simulation runs were less than the project limits and were selected based on maintaining a reasonable data base size that could provide the information needed for the evaluations. The study limits selected are the Harris County line for the southern end and Old Spanish Trail for the northern terminus.

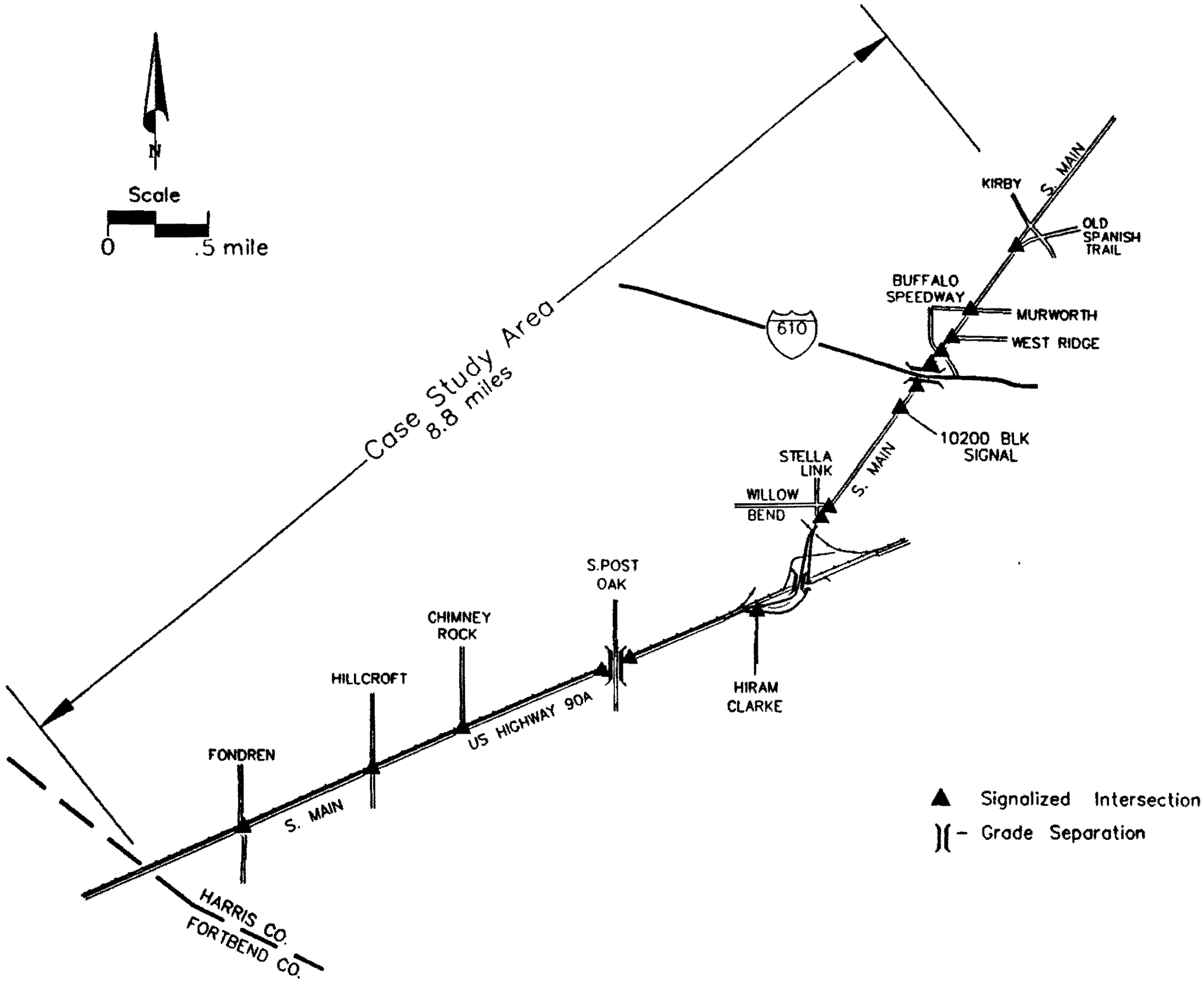

Figure 11. Case study area, existing conditions.

5.3 CONDITIONS

5.3.1 1986 Geometry and Operations

The geometry of US 90A was available from existing schematics supplied by the Texas State Department of Highways and Public Transportation. Posted speed limits, the use of shoulders as right turn lanes, and other operational data were available from a video recording made early during this project. Signal timing information was obtained from the City of Houston Traffic Department and the State Department of Highways and Public Transportation.

The case study portion of US 90A is 8.8 miles (1.6 miles inside the loop and 7.2 miles outside the loop), with 15 signal-controlled intersections. Two sets of signals operate at compressed diamond interchanges and each effectively functions as a four-phase signal. One set of signals is located at South Post Oak and the other set is located at IH 610. The portion of US 90A south of IH 610 has an average free flow speed in excess of 40 mph and average signal spacing greater than half a mile. North of IH 610, speeds are less than 35 mph and intersection spacing is closer than half a mile. The two study segments of US 90A (inside the IH 610 Loop and outside the IH 610 Loop) represent different types of arterial street operations.

US 90A has four through lanes (two lanes in each direction) and a wide median which could provide room for capacity improvements. Existing right-of-way varies from 175 feet at the southern end of US 90A to a maximum width of approximately 775 feet at the Holmes/R.R. overpass before US 90A turns northeast. Right-of-way diminishes to 150 feet inside IH 610 Loop. Most intersection approaches have two through lanes and a left turn and right turn bay. Commercial roadside development density is lower south of the Holmes/R.R. overpass than it is to the north. Wide, paved and unpaved shoulders exist along the entire length of US 90A. Drivers use this shoulder as a right turn lane, which enhances right turning traffic flow at intersections and traffic flow along the arterial. Figures 12 and 13 show the geometry existing at each intersection.

Signal timing on US 90A is a combination of semiactuated and pretimed control. Inside the IH 610 Loop, cycle lengths vary from 70 seconds to 100 seconds. Outside IH 610 Loop cycle lengths vary from 70 to 90 seconds excluding the possible green extensions that could be caused by an actuation at a semiactuated signal. Posted speed is 50 mph at the southern end of US 90A and inside the loop the speed limit is 35 mph. For analysis purposes, it was assumed that signals could be coordinated to provide the timing plans developed through the Transyt-7F optimization program.

Signal phasing had four phases with leading lefts, a 3-second yellow interval, and no all-red time at each four-leg intersection. Protected and permissive left turns were used for high-volume, left-turn movements. T-intersections varied between 2 and 3 phases depending on traffic volume and geometrics. Left turns had a minimum green time of 7 seconds and through movements had a minimum green time of 10 seconds. The startup lost time was assumed to be equal to extended green time.

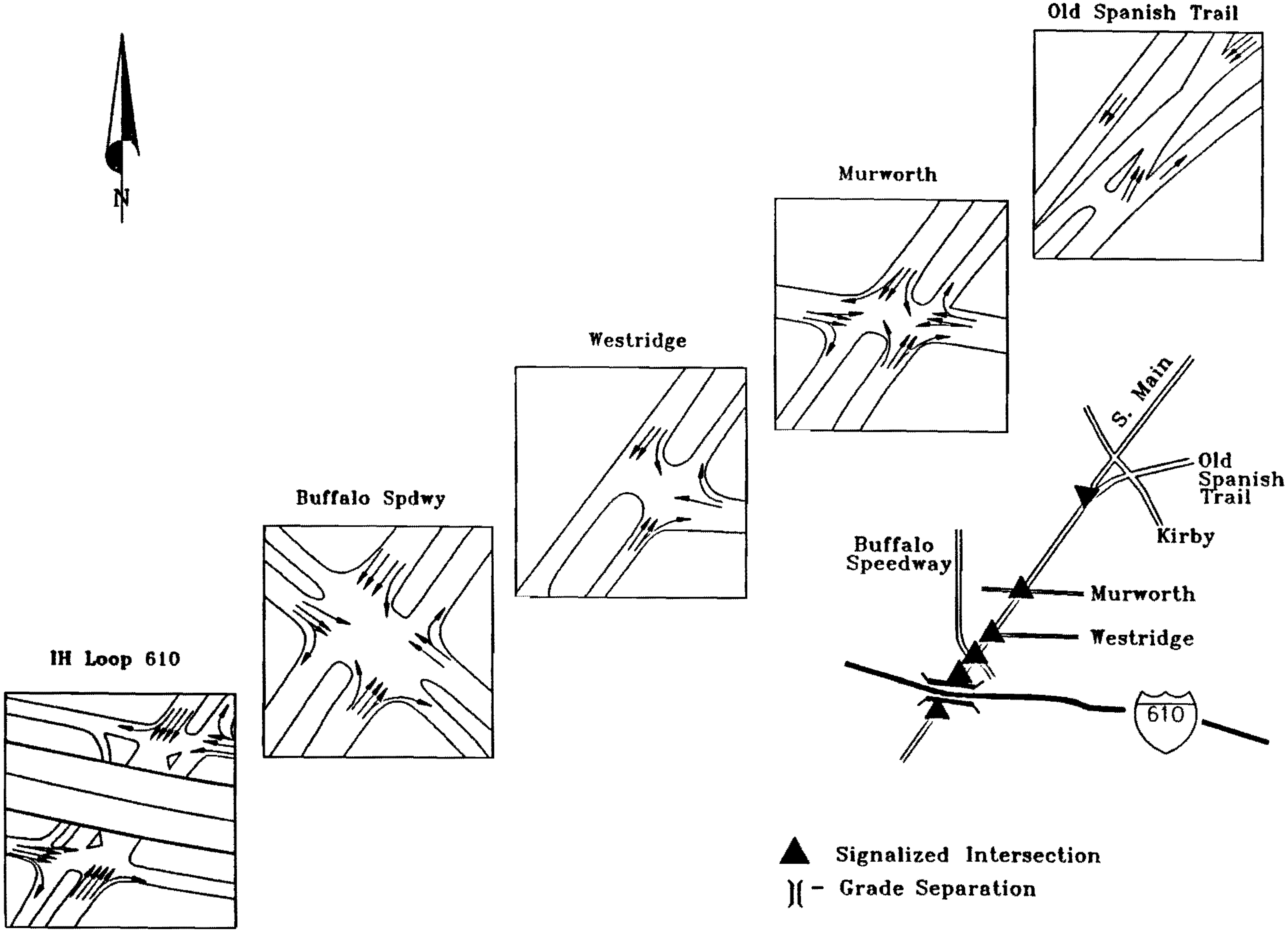

Figure 12. Existing geometrics inside IH 610 Loop.

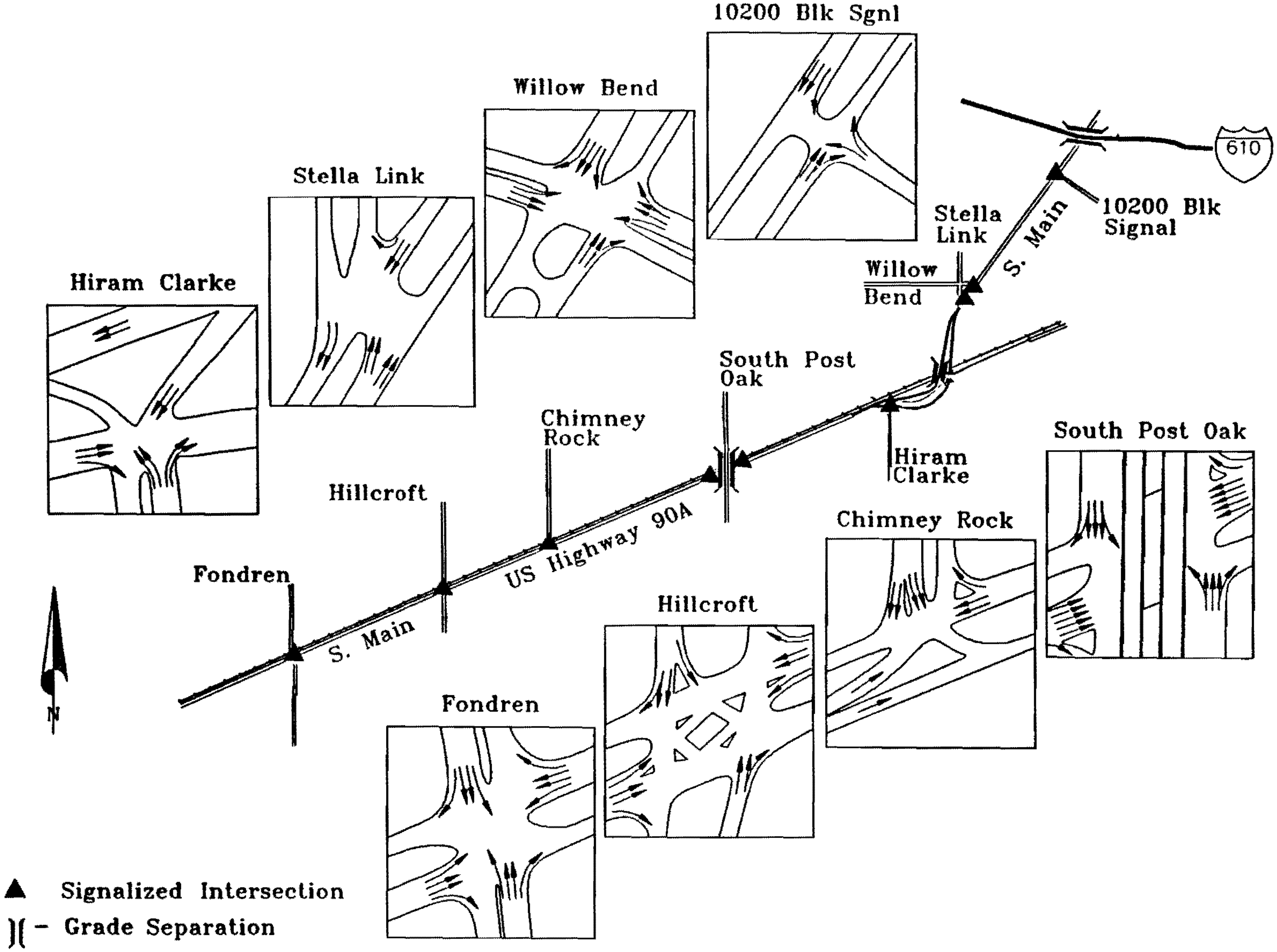

Figure 13. Existing geometrics outside IH 610 Loop.

All signals, with the exception of the 10200 Block Signal, were modeled as pretimed operation. The 10200 Block Signal controls a shopping center driveway. The traffic volumes exiting from the shopping center are low in comparison to the volumes on US 90A, therefore this single intersection was modeled as an actuated intersection instead of a pretimed intersection.

5.3.2 1986 Traffic Volumes

Traffic volumes on US 90A were obtained from two sources: the State Department of Highways and Public Transportation and the City of Houston Traffic and Transportation Department. Peak hour traffic volumes for US 90A were calculated based on information from the State Department of Highways and Public Transportation's 1986 District Highway Traffic Map [7]. Cross street volumes were from the City of Houston's 24-Hour Express Street Traffic Volume Summary [8]. Due to the available traffic count data along the US 90A corridor, 1986 was selected as the base year.

The 1986 District Highway Traffic Map [7] showed the Average Annual Daily Traffic (AADT) for US 90A inside IH 610 Loop as 38,000 while outside the Loop the AADT was 35,000. Several assumptions were necessary to convert the AADT volumes into the hourly volumes needed by the Transyt-7F program. Ten percent of daily traffic was assumed to occur during the peak hour (i.e., K-factor was .10). The directional distribution of the p.m. peak hour traffic was assumed as 60 percent in the outbound direction (away from downtown Houston) and 40 percent inbound. Right turn and left turn volumes were assumed to be 20 percent of the through volume with 10 percent assigned as right turning movements and 10 percent assigned as left turning movements. These assumptions produced the needed hourly volumes for US 90A.

Cross street daily volumes were obtained from the City of Houston's 24-Hour Express Street Traffic Volume Summary [8]. The volumes were either the average of a several day count or a 24-hour count of a typical weekday (i.e., Tuesday, Wednesday, or Thursday) depending upon what data were available. Peak hour volumes for the cross street were calculated using the procedure used for the US 90A volume. The percent of daily traffic occurring during the peak hour was again assumed as 10 percent. Directional distribution of the cross street traffic was assumed as being equal; 50 percent of the peak hour traffic was going in either direction. Turning movements were set at 20 percent of the through volumes with 10 percent proportioned as right turns and 10 percent proportioned as left turns.

Midblock traffic volumes were introduced as needed in order to equalize any volume differences between adjacent intersections. Figures 14 and 15 show a summary of the 1986 hourly volumes used in the Transyt-7F runs.

5.3.3 2000 Geometry and Operations

Schematics of the proposed improvements to US 90A were provided by the State Department of Highways and Public Transportation. These improvements included grade separations at each of the major intersections outside of the IH 610 Loop and a grade

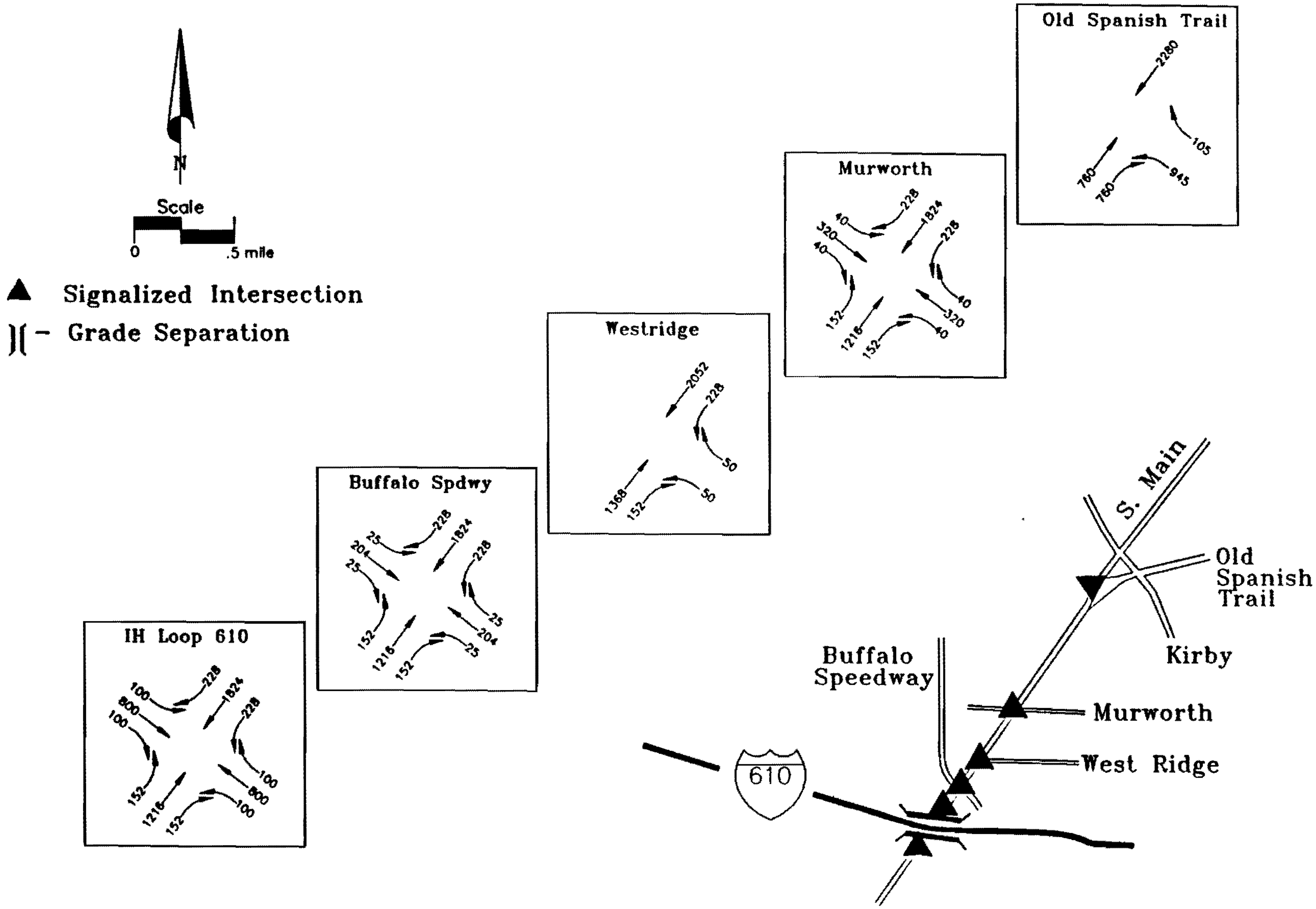

Figure 14. 1986 volumes inside IH 610 Loop.

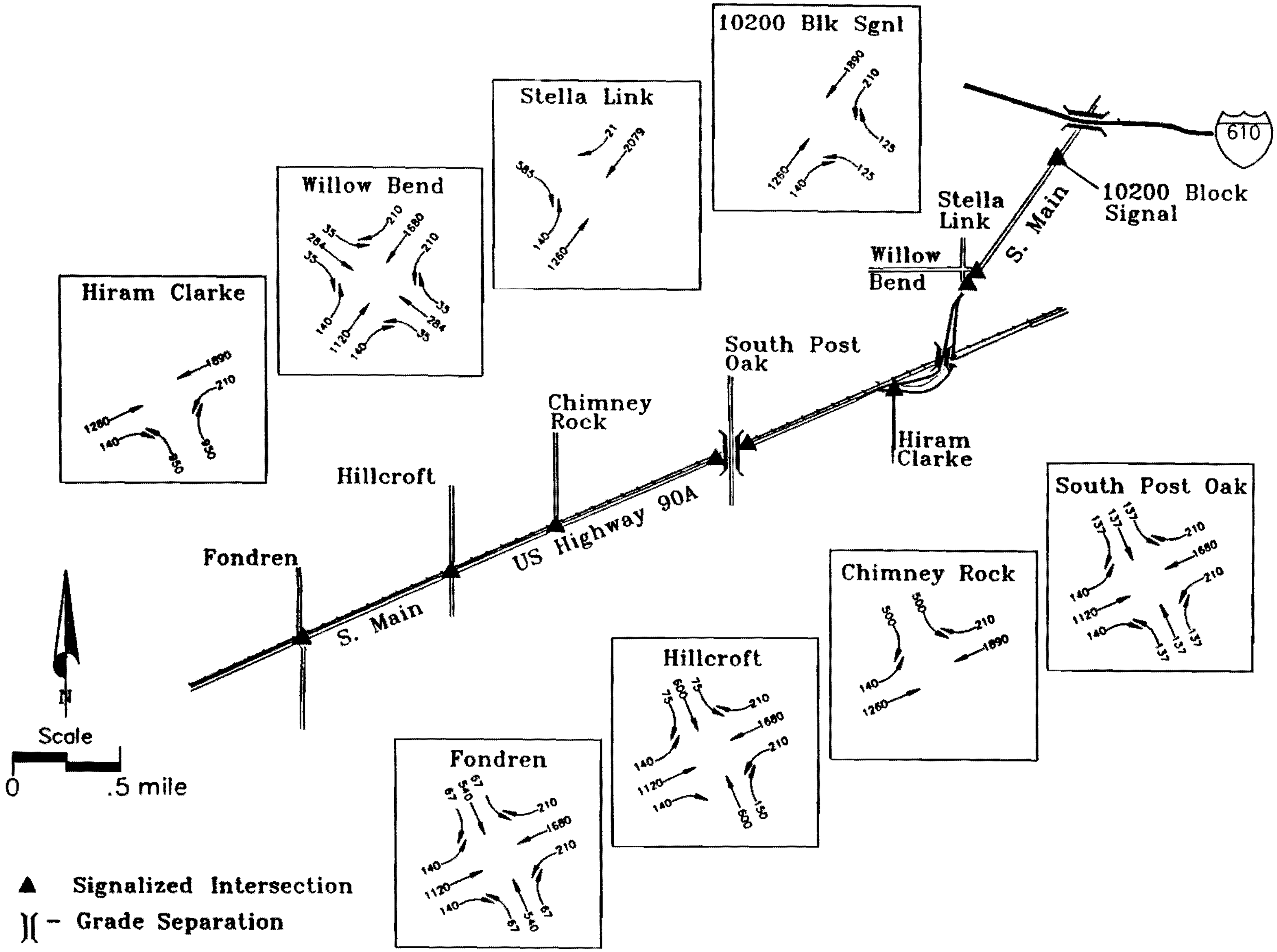

Figure 15. 1986 volumes outside IH 610 Loop.

separation and at-grade improvements inside the loop. Figures 16 and 17 show the improvements proposed by the State Department of Highways and Public Transportation.

Outside the Loop, three new roads will cross US 90A: West Bellfort will be located approximately where the existing 10200 Block Signal is, West Airport will cross US 90A between South Post Oak and Chimney Rock, and Beltway 8, a new loop road that will circle Houston, will cross near the county line. From Buffalo Speedway (first signalized intersection north of IH 610) to past the southern limit of the case study, all the intersections have some form of grade separation. There are three, 3-level diamond interchanges: Beltway 8; South Post Oak; and IH 610. The other grade separations operate as compressed diamond interchanges or single point urban interchanges.

US 90A outside the Loop has an eight lane (four in each direction) cross section between intersections. Prior to an intersection with a grade-separated structure, the outer two lanes for both directions split from the through lanes and became ramps to the cross street. Traffic on the inner four lanes (the two lanes in each direction on either side of the median) passes over the intersection on the grade-separated structure. At North Bellfort and Hillcroft, the cross street is on the grade-separated structure; therefore, all of the US 90A traffic on the eight through lanes and the turn lanes is forced to pass through traffic signals. Inside the loop, the cross section at the intersections is comprised of eight through lanes (four in each direction) and turning lanes.

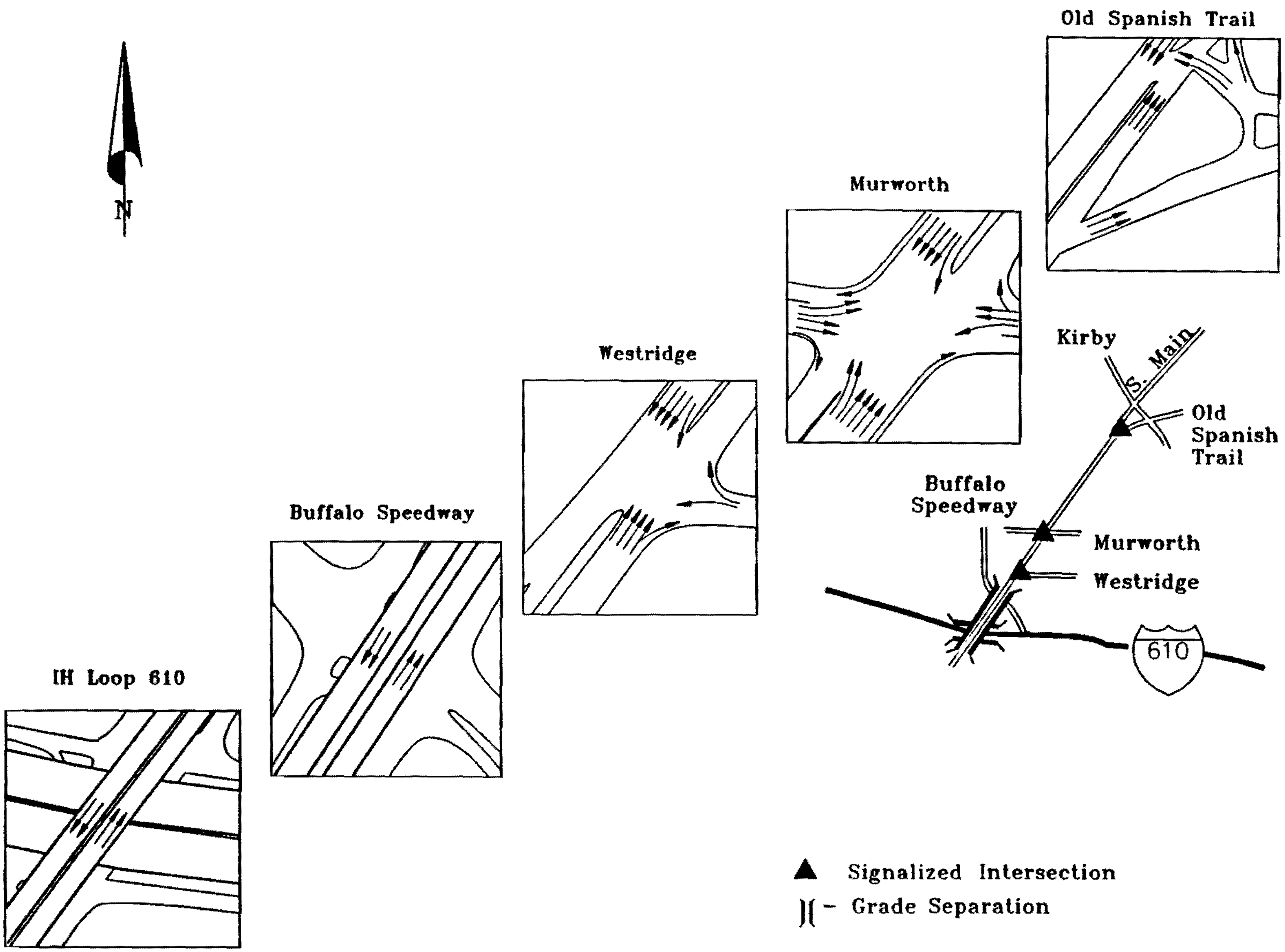

Figure 16. SDHPT proposed geometrics inside IH 610 Loop.

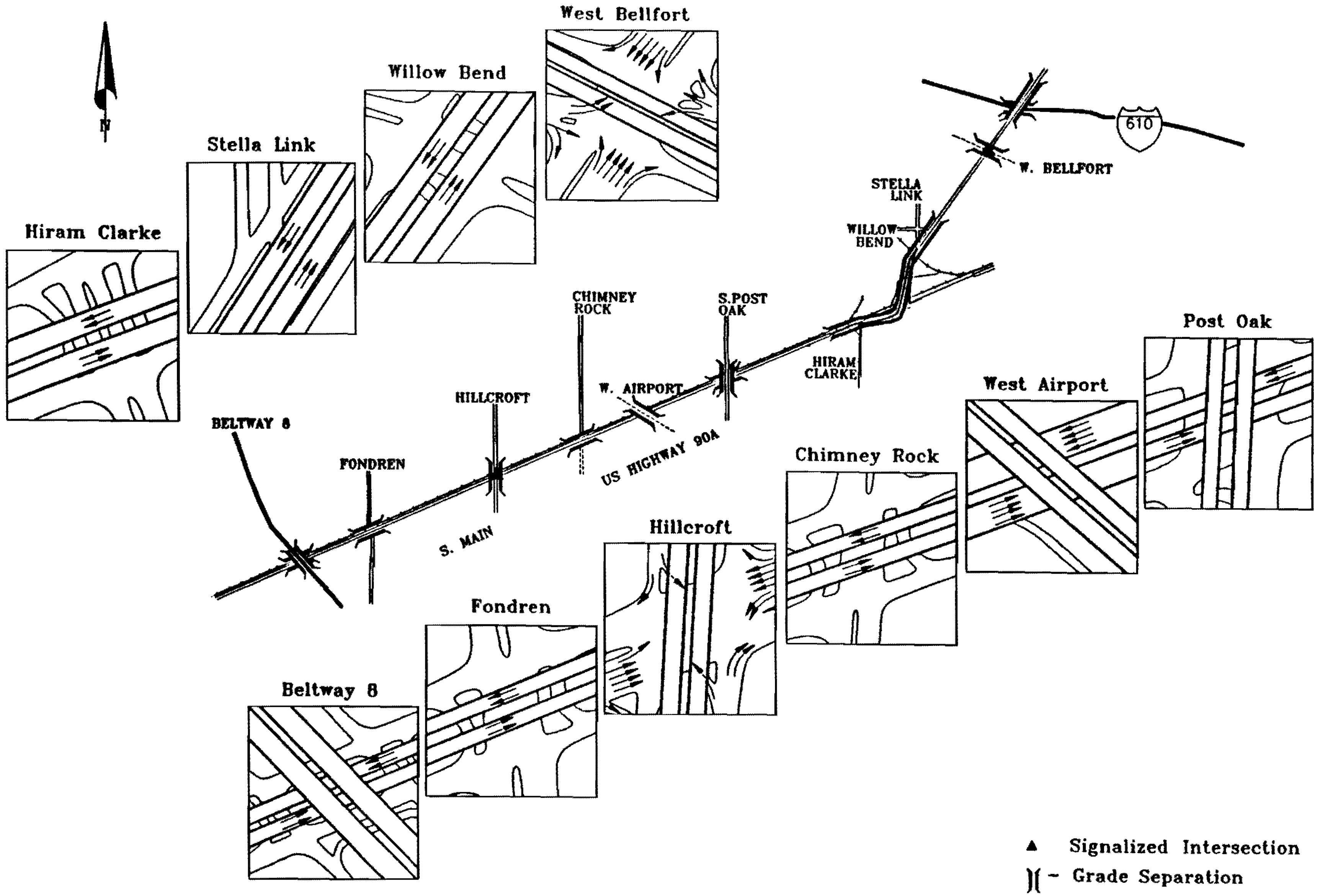

Figure 17. SDHPT proposed geometrics outside IH 610 Loop.

The proposed geometrics determined whether the intersection signalization was modeled as a single point diamond configuration or a compressed diamond configuration. The grade-separated through movements were modeled as having 100 percent green time. Signal phasing used with the 2000 traffic volumes was similar to the phasing used for the 1986 volumes. Left-turn phasing was coded as protected and permissive for the high-volume movements. The yellow interval was 3 seconds and no all-red time was included at the intersections.

5.3.4 2000 Traffic Volumes

Projected design hour volumes (DHV) for the year 2000 were available from the State Department of Highways and Public Transportation schematics of the planned US 90A improvements. DHV represent the 30th highest hour of volume expected during the design year. Traffic volumes included all turning movements, at-grade and grade-separated movements, and mainlane and service road traffic. Figures 18 and 19 summarize the 2000 design hour volumes used in the Transyt-7F program.

5.4 TRANSYT-7F RESULTS

Transyt-7F results for the cases listed in Table 5 are segregated into findings for inside IH 610 Loop and outside IH 610 Loop since conditions at US 90A intersections inside IH 610 Loop are not consistent with strategic arterial characteristics. Inside IH 610 Loop, the ADT is higher, the posted speed limits are lower, and the signal spacing is closer than outside the loop. Table 6 presents the summary of the results from the Transyt-7F

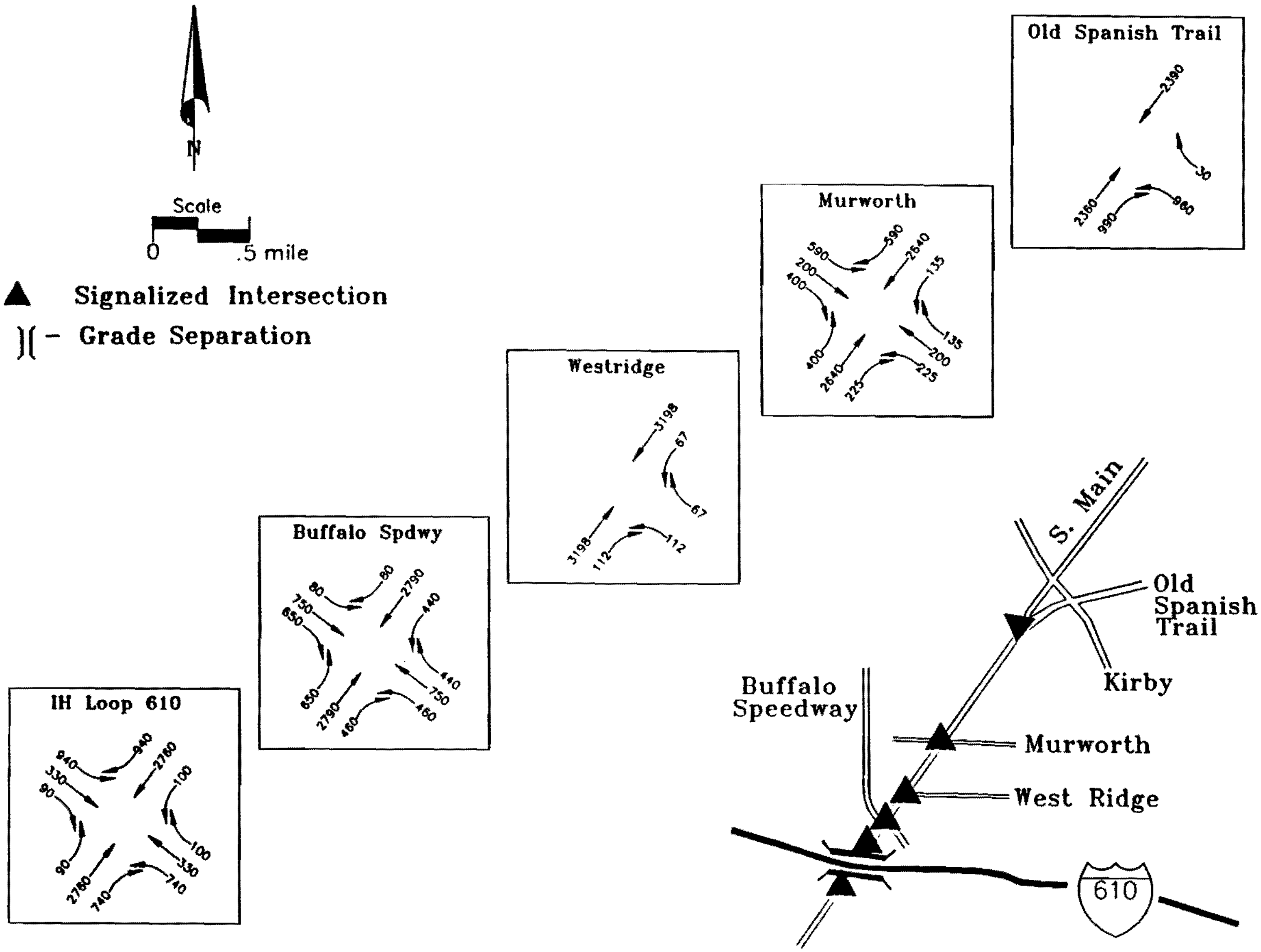

Figure 18. 2000 volumes inside IH 610 Loop.

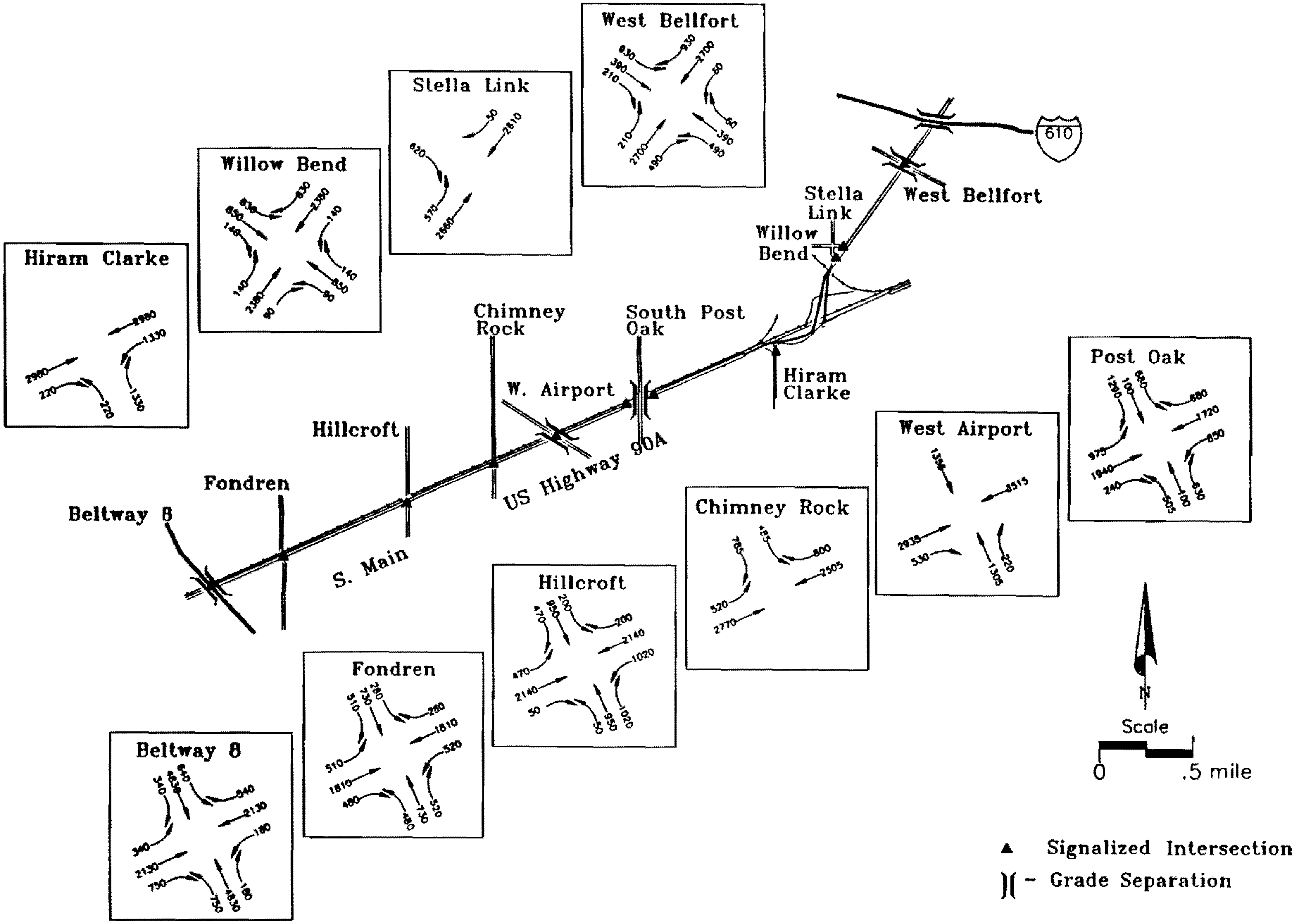

Figure 19. 2000 volumes outside IH 610 Loop.

Table 6. Results from Transyt-7F runs.

Operational Conditions on US 90A	Total Uniform Delay Veh-hr/hr		Total Random Delay Veh-hr/hr		Total System Delay Veh-hr/hr		Total Travel Time Veh-hr/hr		Average Through Speed Mi/hr		Total Stops %(Veh/hr)		Optimal Cycle Length Sec	
	Inside IH 610 Loop	Outside IH 610 Loop	Inside IH 610 Loop	Outside IH 610 Loop	Inside IH 610 Loop	Outside IH 610 Loop	Inside IH 610 Loop	Outside IH 610 Loop	Inside IH 610 Loop	Outside IH 610 Loop	Inside IH 610 Loop	Outside IH 610 Loop	Inside IH 610 Loop	Outside IH 610 Loop
1986 VOLUMES Case I Existing Geometrics	109	193	74	249	183	442	313	940	22	39	53	43	95	115
2000 VOLUMES Case II Do-Nothing Alternative	573	746	3,007	6,368	3,580	7,114	3,812	8,058	4	12	58	41	180	140
Case III Intersection Spacing	573	889	3,007	5,500	3,580	6,389	3,812	7,333	4	17	58	37	180	170
Case IV Prohibit Left Turns	555	698	2,964	5,137	3,519	5,836	3,750	6,787	4	10	58	47	170	145
Case V 8 Thru Lanes	405	709	877	1,958	1,283	2,667	1,514	3,611	14	32	62	48	145	145
Case VI Extensive At-Grade Improvements	298	445	363	1,056	661	1,501	893	2,445	21	34	57	49	125	100
Case VII Proposed Improvements	86	158	45	188	131	346	309	822	37	48	32	27	95	115
Case VIII Strategic Arterial	86	0.7	45	0.6	131	1.3	309	477	37	57	32	0	95	NA*

* No signalized intersections exist on US 90A outside of IH Loop 610 in Case VIII.

simulations. The measure of effectiveness values reflect how well each portion of US 90A is functioning under the various operational conditions. Each operational condition is discussed in the sections that follow (5.4.1 through 5.4.8).

Average through speed on US 90A is the measure of effectiveness that was primarily used during the evaluations and comparisons of the different cases. Average through speeds less than 15 mph represent an unlikely situation. Motorists will not accept such low level of service and will seek alternative routes or modes of transportation. The computer generated speeds do demonstrate the highly congested nature of the facility. Other measures of effectiveness, both system wide measures and specific intersection measures, provided information used to select improvements used in other cases. For example, high delays for a turning movement indicate that an additional turning lane may be necessary.

5.4.1 Case I - Existing (1986) Geometrics and Volumes

The Case I simulation was a model of US 90A as it existed in 1986. It used 1986 conditions and volumes to attempt to reproduce travel speeds that were measured in 1985. The simulation is used to validate the Transyt-7F modeling process and as a basis for comparison with the other cases.

The principle measures of effectiveness of interest in Case I are the average through speed and the optimal cycle length. These two calculated outputs should reflect existing conditions. Cycle lengths were obtained from the City of Houston's existing signal timing records. The speed on US 90A was determined with a floating car study in April 1985 [9].

The average speed calculated by Transyt-7F on US 90A inside IH 610 Loop was 22 mph. The average speed measured during an April 1985 p.m. peak period on the case study area was 25.2 mph. The Transyt-7F calculated speed outside IH 610 Loop was 39 mph and the average speed measured in 1985 was 34.0 mph.

The optimal computed cycle lengths for the system were 95 seconds for inside the loop and 115 seconds for outside the loop. Existing signals are either pretimed or actuated. During peak rush hour traffic, constant actuation of each actuated signal phases would increase the overall cycle length to its maximum length. Inside IH 610 Loop, the maximum peak hour cycle length is 100 seconds. The diamond interchange at IH 610 also has a peak period cycle length of 100 seconds. Outside IH 610 Loop, the actual peak period cycle lengths range between 90 and 115 seconds when actuated green times are fully extended. The optimal cycle length calculated by Transyt-7F inside and outside IH 610 Loop approximate the cycle lengths at the intersections.

Based on the calculated average through speed and the cycle length, the simulation of the existing 1986 conditions is reasonably accurate. Transyt-7F results (for 1986) used estimated peak hour traffic volumes from ADT counts, not an actual corridor peak hour traffic count. The objective behind the simulation was reasonable accuracy, not precision. The results from Case I simulation will be used to compare to results from the Case II simulation.

5.4.2 Case II - Existing Geometrics and 2000 Year Volume (Do-Nothing Alternative)

Case II uses the State Department of Highways and Public Transportation projected 2000 year volumes with the existing US 90A geometry and operation characteristics. This simulation models the do-nothing alternative. The geometrics and signal operations were identical to the 1986 conditions; however, due to the much higher traffic volumes, the upper limit for the optimal cycle length calculations was increased from 120 seconds to 180 seconds.

The calculated optimal cycle length inside IH 610 Loop was 180 seconds, Transyt-7F never found an optimal cycle length; it reached the upper cycle limit and terminated the search routine. The higher traffic volumes increased each measure of effectiveness significantly (see Table 6). Most noteworthy are the random/saturation delay and the speed values. The random/saturation delay for the system (3,007 veh-hr/hr) is much higher than the uniform delay (573 veh-hr/hr). An inspection of the individual intersection results shows that all of the intersections on this portion of US 90A are severely over saturated. Over saturation on some movements was well in excess of 200 percent or in other words, the demand was more than double the capacity. The over saturation adversely affected the average through speed which was found to be 4 mph for the portion of US 90A inside the Loop.

The results for the portion of US 90A outside IH 610 Loop are similar; each measure of effectiveness increased significantly. Transyt-7F converged on an optimal cycle length of 140 seconds out of a maximum limit of 180 seconds. Every signalized intersection operated with three or more saturated links. Both inside and outside the Loop, over saturation was extensive.

The Transyt-7F simulations indicate that the existing geometrics and operations will be inadequate for the projected traffic volumes of the year 2000. It is highly unlikely that these poor operating conditions would ever actually be observed, the average commuter would not accept this level of service and would seek out an alternate route or mode of transportation. While the values may loose reasonableness when congestion reaches these extremes; the simulation results can be used for comparison purposes.

5.4.3 Case III - Intersection Spacing (Removal of 2 Signals)

One alternative operational strategy to improve the speed along an arterial is to maximize the spacing between signals. For comparison purposes, two signals outside IH 610 Loop were removed. Removing signals to increase the spacing between signalized intersections is easily done in a computerized model; however, this alternative could be difficult to implement on an established arterial. It may, nevertheless, be possible to avoid installing some signals that would degrade arterial performance.

Both signals removed from the US 90A corridor were three-leg, T-intersections with relatively low volume of crossing traffic and less than a quarter mile from the next closest signal. The signals were located at the 10200 Block and Stella Link. The 10200 Block signal services left-turning traffic into and away from a strip shopping area. The diverted or rerouted peak hour traffic was 450 vehicles. The displaced traffic at Stella Link is 1240 vehicles. These vehicles comprised two movements, northbound left-turns and southbound right-turns. The displaced vehicles were assumed to be able to access or egress US 90A at minor, unsignalized intersections.

The results for Case III are listed in Table 6. They indicate that operations did not noticeably improve compared to the do-nothing alternative (Case II). US 90A remained unchanged inside the Loop because no signals were removed in that area. Outside IH 610 Loop the increased intersection spacing did cause small decreases in the delay, travel time, and percent stops. The random delay components are still extremely high and the entire corridor remains over congested. In this simulation, increasing the signal spacing did not significantly impact the operations on US 90A because the overall operations is very poor and the intersections which were removed only displaced a small amount of traffic.

5.4.4 Case IV - Prohibit Left Turns on Each Approach

A relatively low cost, capacity improvement is to prohibit left turns on each approach. Since the signal system operates on two phases instead of four, increases in timing efficiency should translate into improved traffic flow. Traffic that desired to turn left from US 90A was assumed to execute a right turn initially and then a U-turn on the cross street to merge with the cross street through traffic. Left turns from the cross street proceeded through the intersection, U-turned on the cross street, and then executed a right turn from the cross street as illustrated in Figure 9.

Drivers desiring to turn left could also make a series of right turns and essentially "go around the block," but this strategy translates into shifting the left turn volumes to adjacent intersections. With the U-turn on cross street procedure, the left turning traffic associated with each intersection impacts only that specific intersection. Implementation of this strategy would require construction of U-turn bays on each cross street intersection approach. Drivers would also have to be educated on how to use the U-turn lanes to reach the destinations they previously reached through a left turn.

In this simulation, all left turn phases were deleted with the exception of the phasing at the two existing diamond interchanges (IH 610 and South Post Oak). The maximum cycle length was set at 180 seconds. The results are shown in Table 6.

Relative to the do-nothing simulation (Case II), the elimination of left turns had little overall effect on the operational efficiency of US 90A. There are no large decreases in delay due to the indirect left turns and average speed did not significantly change. Since the left turn movement actually passes through the intersection twice (see Figure 9), the increased intersection volume should cause the percentage of stops to increase. Outside IH 610 Loop the percent of total stops increased from 37 to 47 percent while inside the Loop the percent stopped remained constant at 58 percent. Time previously dedicated to left turn phases is now available to be reapportioned between the through movements. The calculated optimal cycle lengths were 170 seconds inside the Loop and 145 seconds outside the Loop. The optimal cycle length for inside the Loop is slightly lower than both the maximum 180 seconds and Case II (do-nothing alternative) cycle length, therefore it represents a slightly more favorable condition. Outside IH 610 Loop, prohibiting the left turns does not noticeably change US 90A's operations.

An analysis of the results for individual intersections reveals that removing over saturated left turn movements only transfers the over saturation to through movements. As shown in Figure 9, the elimination of left turns caused the left turn volume to pass through each intersection twice (once as a right turn and then as a through vehicle after the U-turn). This caused an increase in the total intersection volume. Eradicating an over congested movement just caused the problem to manifest itself on another movement. This strategy may have produced more acceptable results if the initial through volumes had not been so high prior to the addition of the left turn volumes. This alternative yielded slightly improved operations relative to Cases II (do-nothing alternative); however, overall conditions still remain highly unacceptable to the commuter.

Cases III (intersection spacing) and IV (prohibit left turns) demonstrate that minor, low-cost capacity improvements will not be sufficient to accommodate the major increase of traffic. Clearly, major operational improvements are needed along US 90A in order to provide a reasonable level of service for the projected major increase in traffic volume.

5.4.5 Case V - Eight Through Lanes on US 90A

Another at-grade improvement strategy would be to increase the capacity of US 90A. The existing wide median could provide room for additional through and left turn lanes. US 90A was expanded from four through to eight through lanes (four lanes in each direction). Dual left turn lanes on an US 90A approach were also added if demand was greater than 300 vehicles per hour. The objective of this simulation was to improve the geometrics on US 90A and thereby improve traffic flow. Cross street geometrics were unchanged. The results of Case V are listed in Table 6.

Delay decreased considerably when compared to prior simulations. The improvements in the delay values also positively impacted total travel time and average through speed. Shorter signal spacing and over saturated cross street approaches inside IH 610 Loop kept the average through speed at a low 14 mph. Outside IH 610 Loop the longer spacing between signals allowed the traffic platoons to attain a higher average speed of 32 mph.

The Case V simulation when compared with the do-nothing alternative (Case II) shows a significant improvement in all measures of effectiveness. Total system delay and travel time has decreased and through speed has increased. The above results indicate that the overall conditions are improving; however, within Case V the random/saturation delay component (877 veh-hr/hr inside and 1,958 veh-hr/hr outside the Loop) is still much higher than the uniform delay component (405 veh-hr/hr inside and 709 veh-hr/hr outside the Loop) which indicates that more improvements need to be made to the system.

5.4.6 Case VI - Extensive At-Grade Improvements

Several of the cross street links in Case V were over saturated. Case VI represents extensive at-grade improvements on both US 90A and the cross street approaches. Each intersection approach was widened with left and right turn bays and additional through lanes. This additional width to each approach serves as supplemental storage for queuing vehicles. The extra capacity should cause a decrease in delay at the signals.

Table 6 lists the results of this simulation. The uniform and random/saturation delay components have decreased in comparison to all previous simulations. Since the random/saturation delay components are still higher than the uniform delay components (1,056 veh-hr/hr random/saturation delay versus 445 veh-hr/hr uniform delay outside the Loop and 363 veh-hr/hr random/saturation delay versus 298 veh-hr/hr uniform delay inside the Loop), significant congestion still exists.

Average through speeds increased inside the loop. When the through lanes on US 90A doubled to 8 lanes (Case V) only a slight increase from 4 to 14 mph was found. By increasing the capacity on the cross streets with additional through lanes and turning bays, the average through speed increased from 14 mph to 21 mph. Only a slight improvement in average through speed outside IH 610 Loop between Case V and VI occurred because separate turning bays already exist at most of the cross streets outside the Loop.

Case VI represents the situation where the volumes on US 90A have approximately doubled between 1986 and 2000 while the intersection capacity has also almost doubled relative to what was available in Case I. The average speeds between Case I (existing conditions) and Case VI (extensive at-grade improvement) are comparable (22 and 21 mph inside and 39 and 34 outside the Loop). Case I and VI illustrate that in order to maintain the 1986 measures of effectiveness values, if the traffic volume doubles then the capacity needs to also increase a relative amount.

No appreciable change in the total stops occurs between Case V and Case VI. The optimal cycle lengths for Case VI are less than both Case II (do-nothing alternative) and Case V (Eight Through Lanes) due to the additional lane capacity on the cross streets. The overall mobility of US 90A has improved, but the low speeds for a principal arterial street (both inside and outside the Loop are below 35 mph) and the high random/saturation delay component outside the Loop indicate that the high volume demands placed on US 90A are still severe.

5.4.7 Case VII - Proposed Improvements

Case VII represents the series of grade separations and at-grade improvements developed by the Texas State Department of Highways and Public Transportation for the US 90A corridor. Figure 20 shows the location and orientation of the grade separations on this segment of US 90A. Two new arterials, West Bellfort and West Airport, are proposed. West Bellfort will intersect US 90A near the existing 10200 Block signal. West Airport will cross US 90A between Chimney Rock and South Post Oak intersections. A new loop road, Beltway 8, that will circle Houston crosses US 90A near the county line.

Inside IH 610 Loop, US 90A will be grade separated at both Buffalo Speedway and IH 610 and outside of the Loop all but two intersections (West Bellfort and Hillcroft) will

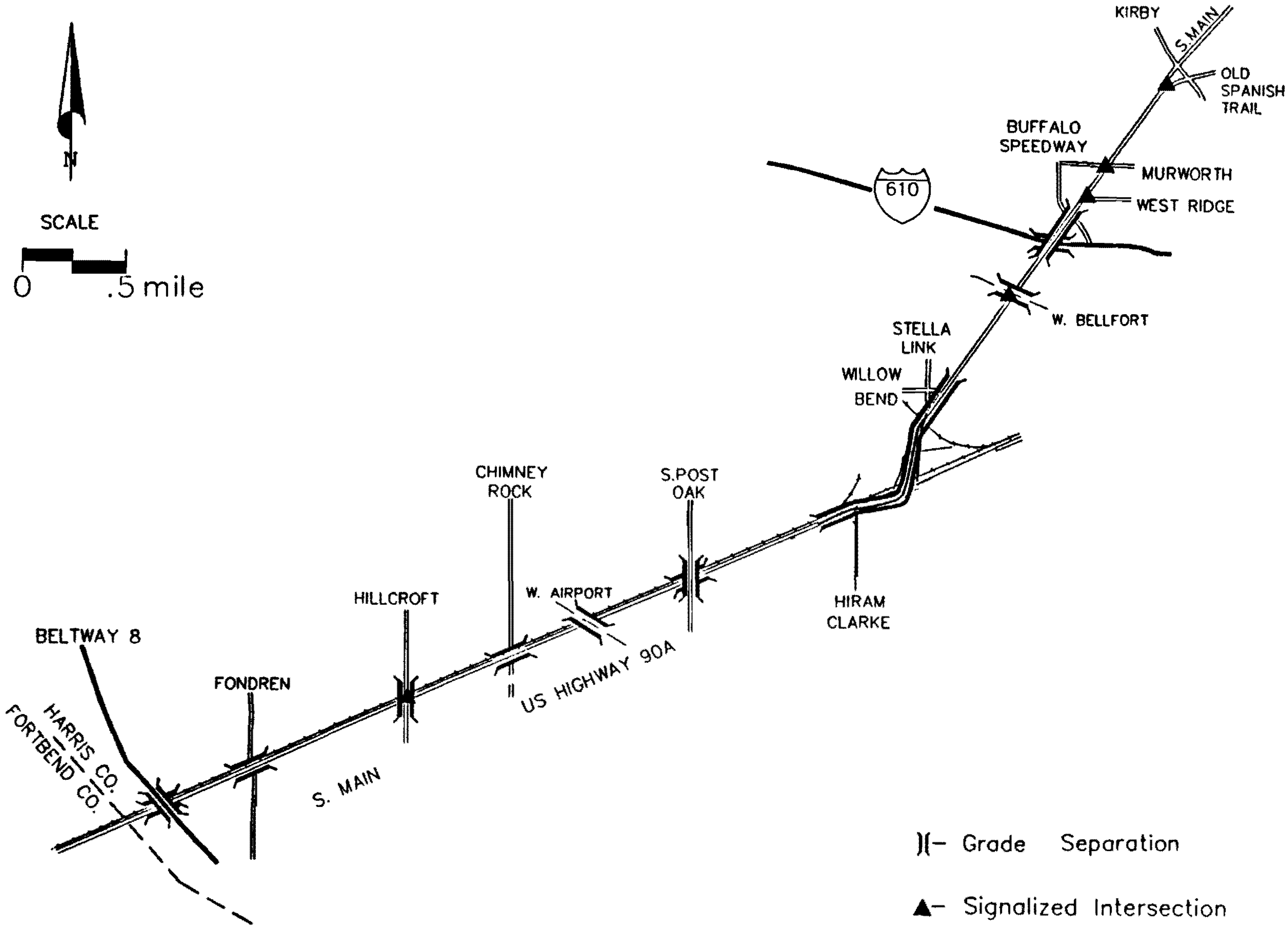

Figure 20. Case VII - planned improvements.

have the US 90A main lanes on a grade separated structure. At these two intersections the cross street main lanes are on the structure and US 90A remains at-grade with signal operations. Four through lanes operate along US 90A. The assumptions for the signal phasing at the at-grade intersections were similar to the previous simulations (see Section 5.3.1) while the grade separated through movements were phased as having 100 percent green time. The results are presented in Table 6.

The proposed grade separations produced dramatic results. System wide delay, travel time, and total stops have decreased significantly over other simulations, and average through speed has risen. The random/saturation delay component both inside and outside the Loop (45 and 188 veh-hr/hr) has reached an acceptable level. This alternative yields the best results for the commuter when compared to the other alternatives. The grade separations eliminated a large portion of the delay which produced a notable increase in the average speed (37 mph inside and 48 mph outside the loop).

The speed range for a strategic arterial is 45 to 55 mph (see Section 4.2). Inside IH 610 Loop, US 90A speed is near 35 mph. Outside IH 610 Loop, US 90A is slightly above (48 mph) the lower end of the desired speed range. Delay at the two at-grade intersections outside the Loop limits the speed on US 90A. The random/saturation delay component outside the Loop (188 veh-hr/hr) is slightly larger than the uniform delay component (158 veh-hr/hr). Over saturated turning movements exist at West Bellfort and Hillcroft. Dual turning lanes could lower the delay at West Bellfort, but the same problems at Hillcroft are not solved as easily because the turning volumes are extremely high and the turning bays are already configured with dual lanes. At both intersections, the turning movements adversely impact the high volume through movements. These problems could be reduced if the grade separations at these two intersections were oriented to favor the through traffic on US 90A as illustrated in the following simulation (Case VIII).

5.4.8 Case VIII - Strategic Arterial

A potential solution to decrease the random delay values on US 90A outside IH 610 Loop is to add more lane capacity to the turning movements at West Bellfort and Hillcroft; however, the large volume of through traffic on US 90A is still delayed. The traffic volumes for the year 2000 indicate that the projected through traffic on US 90A is 225 percent higher than the through traffic on Hillcroft and the projected through traffic on US 90A is 730 percent higher than the through traffic on the proposed West Bellfort.

Reorienting the grade separations at West Bellfort and Hillcroft (as shown in Figure 21) would also remove all signalized control for the through movements on US 90A between IH 610 and the county line. Delay would accrue to the cross street through traffic rather than on the heavier through traffic volumes on US 90A. While reorientation of the grade separations may not be possible due to right-of-way restrictions or other constraints, the simulation would illustrate the benefits that the modifications could provide.

Results of the simulation are listed in Table 6. Since no modifications were made inside IH 610 Loop, the results inside the Loop remained unchanged between Case VII and

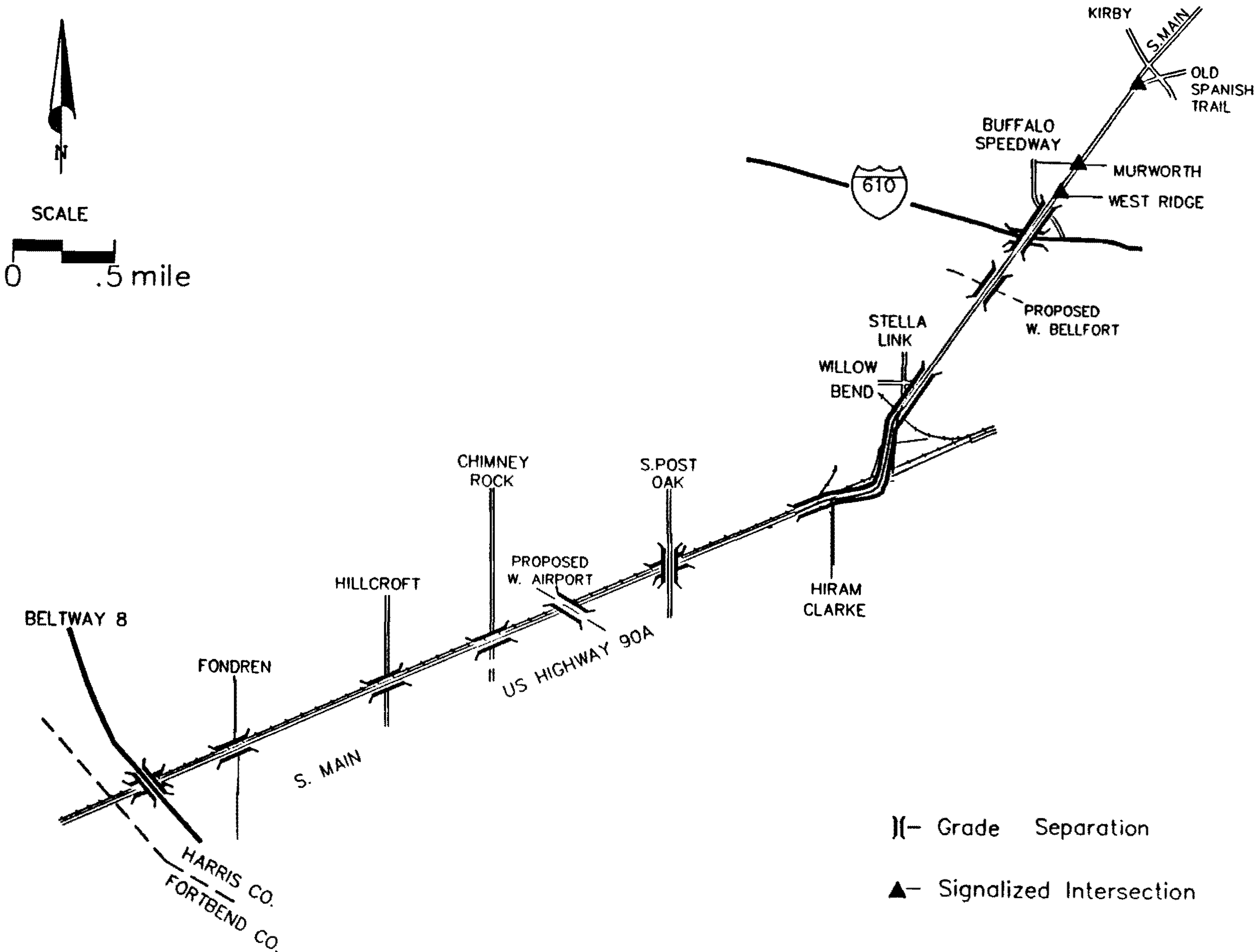

Figure 21. Case VIII - strategic arterial improvements.

Case VIII. Delay outside IH 610 Loop has been reduced to a very small value (1.3 veh-hr/hr) and the speed increased from 48 mph in Case VII to 57 mph when the grade separations outside IH 610 Loop are realigned. US 90A (outside of IH 610 Loop) in this case would be classified as a strategic arterial since it has high speeds and level of service, strategic location in the city, grade separation of major intersections, and most importantly, connection of routes of similar or higher classification (e.g. IH 610 to Beltway 8 and US 59).

CHAPTER 6

SUMMARY AND CONCLUSIONS

The Texas State Department of Highways and Public Transportation is exploring methods to improve mobility and provide additional roadway capacity for major traffic movement by increasing the capacity of the arterial street system in large urban areas. Streets identified as being able to serve an enhanced role could be improved to operate at high speeds and a high level of service but would not be required to satisfy the strict access control and right-of-way needs of a freeway. Strategic arterial was the term selected to describe this new street category.

Through a case study format, the mobility impacts from improvements to an existing arterial street were evaluated using computer simulation. Transyt-7F was the computer program used to evaluate improvements to US 90A (Old Spanish Trail to the Harris County Line in Houston). The improvements ranged from a do-nothing alternative to providing grade separations at all major intersections along the arterial. The program was also used to examine conceptual scenarios of prohibiting left turns, grade-separated structure orientation grade separating the most congested intersection, and number of signals per mile.

The case study evaluation illustrated the mobility impacts from various improvements applied to an existing arterial. The primary measure of effectiveness used to describe the mobility impacts was average through speed. Table 7 summaries the findings from the

Table 7. Average through speed results from Transyt-7F runs.

Operational Conditions on US 90A	Average through speed (mph)	
	Inside IH 610 Loop	Outside IH 610 Loop
1986 VOLUMES **Case I** Existing Geometrics	22	39
2000 VOLUMES **Case II** Do-Nothing Scenario	4	12
Case III Intersection Spacing	4	17
Case IV Prohibit Left Turns	4	10
Case V 8 Thru Lanes	14	32
Case VI Extensive At-Grade Improvements	21	34
Case VII Proposed Improvements	37	48
Case VIII Strategic Arterial	37	57

different simulation runs. At-grade improvements (e.g., adding lanes, prohibiting left turns) showed limited increases in travel speed due to the highly congested nature of the case study area. Grade-separated improvements were needed to cause significant increases in travel speeds. The Texas State Department of Highways and Public Transportation planned improvements included grade separations at all major intersections outside of IH 610 Loop. This simulation resulted in an average through speed (48 mph) for US 90A outside of the Loop that is within the preset range of a strategic arterial (45 - 55 mph). When two grade-separated facilities were modified to give priority treatment to US 90A instead of the cross street, the average through speed outside of the Loop rose to 57 mph.

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