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Control Strategies And Route Guidance In Signal Controlled Networks

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Control Strategies and Route Guidance in Signal Controlled Networks

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Foreword

The goals of the California PATH Program are to improve traffic safety, decrease traffic congestion and energy consumption, and improve air quality. It is evolutionary and voluntary. It is a cooperative venture of automakers, electronic companies, local, state and federal governments and universities.

The purpose of the study described in this report is to provide a better understanding of the impacts of route guidance on urban arterials and networks controlled by traffic signals. Control and timing strategies to handle diverted traffic from the freeways to surface streets were developed and tested through simulation on carefully selected real-life networks. These strategies ranged from conventional fixed-time timing plans to real-time signal control. The results showed that for a small number of diverted vehicles, optimal timing plans favoring the diverted routes improved the performance of diverted traffic without significant adverse impacts to the rest of the network. Optimal timing plans for existing traffic patterns could not accommodate large diversion volumes on the network. Alternative approaches for generating signal settings developed in this study resulted in better network performance. Optimization of timing plans taking into account the diverted volumes significantly improved the traffic performance for both the local network and the diverted traffic. On-line control strategies produced the best results with significant benefits for traffic on surface streets.

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CHAPTER 1

INTRODUCTION

1.1 Problem Statement

Continuous increase in travel demand, limited resources for the construction of new highway facilities, and environmental concerns necessitate systematic operational improvements on the existing transportation network. These improvements involve minor design modifications to increase capacity (e.g., adding lanes, channelization at intersections), changes in circulation patterns, or installation of systems to control and monitor the traffic flow (e.g., traffic signal systems, ramp metering, incident management systems.) Considerable attention has been given recently to the potential of route information and guidance as a way of reducing congestion on major highways. Prototype information systems have been developed to provide instructions to drivers to divert to alternate routes when an accident has occurred on a freeway or when traffic conditions have otherwise deteriorated.

What are the anticipated benefits from implementation of route information and guidance systems? Diversion of traffic to alternate routes may provide benefits to freeway managers and individual drivers. But under some circumstances, it may also impose adverse impacts on the local street system. Thus, there may be trade-offs between freeway management and efficient operation of local networks. Consider, for example, a case in which traffic is encouraged to divert from a freeway to a parallel signalized arterial ("corridor management"). Traffic signal timing along the arterial could be adjusted to accommodate the increased through traffic. This in turn would affect the performance on the cross-streets and other movements. Furthermore, if the arterial is part of a larger network of signalized streets, it may necessitate retiming numerous other signals in the network as well. Under some conditions the overall result may be positive, but under other conditions added delays on local streets may more than offset the benefits for the through traffic on the freeway and the arterial.

Research on route information and guidance systems to date has been concerned with systems' development, human factors requirements for in-vehicle displays, and assessment of the potential benefits to the users through simulation and demonstration projects [15]. The results from simulation experiments on a real-life freeway corridor have shown that the benefits are marginal during typical peak hour conditions but increase significantly for short-term fluctuations in traffic volumes, or when the capacity is reduced because of incidents on the freeway[1,2]. The benefits reported in other studies were largely network-specific, depending on the network configuration, drivers' familiarity with the network, availability and utilization of alternate routes, distance travelled and overall traffic patterns [6]. These studies, however, assumed a small number of guided vehicles and did not consider the impacts of the diverted traffic to signal controlled networks.

Traffic signal control systems largely affect the traffic performance on surface streets, and advancements in signal equipment have resulted in a number of improved systems. Several studies and demonstration projects have shown that these systems operating under optimal timing plans significantly improve travel times, and reduce stops and fuel consumption on signalized streets. However, the effectiveness of such control systems to handle additional traffic volumes along selected routes of the network, and their relationships with information and guidance systems has not been systematically evaluated.

1.2 Objectives of the Study

The objectives of this research are to investigate the impacts of route management on local transportation networks that are controlled by traffic signals. The study addressed the following questions:

- What kinds of traffic impacts could result from re-routing traffic from freeways to surface streets?
- What traffic control strategies could be used on the local streets to accommodate this traffic?
- What data and what level of control system sophistication would be needed to accurately predict and manage these effects?
- How would control strategies and impacts vary with the capacity and network configurations of alternate routes?

1.3 Overview of the Project

This study has been sponsored by the California PATH (Partners for Advanced Transit and Highways) Program at the University of California at Berkeley [18]. PATH is funded by the California Department of Transportation and the Federal Highway Administration, and its goals include enhanced safety, improved fuel efficiency and reduced congestion and air pollution. PATH program's main areas of emphasis include research in vehicle control and transportation management and information systems. The project is concerned with advanced traffic management systems (ATMS) and advanced traveller information systems (ATIS).

A number of control strategies for handling the diverted traffic were developed and applied to real-life test networks for several traffic diversion scenarios. The control strategies ranged from conventional fixed-time optimal timing plans to real-time control. The test networks were carefully selected to represent a range of network configurations and traffic and geometric conditions. Next, the strategies were evaluated using the NETSIM microscopic simulation model. The predicted performance measures (travel times, delay, stops) were then analyzed to assess the impacts on both the entire system and the diverted traffic, as well as to determine the effectiveness of each control strategy.

The report begins with a critical review of the state-of-the art on advanced traffic control and management systems with emphasis on traffic control strategies and their relationships with route information and guidance systems. Chapter 3 describes the study methodology, including the development of the control strategies and the selection of the test sites. Chapter 4 describes the application of the methodology on each test site, and presents the findings from the analysis of the results. The major study findings and recommendations are summarized in Chapter 5 along with suggestions for future research.

CHAPTER 2

BACKGROUND

This Chapter briefly reviews the state-of-the-art in traffic signal systems and control strategies for urban arterials and networks. The relationships between traffic control systems and traveller information systems are discussed next, and functional requirements for signal control are identified for improving traffic operations on surface streets considering route information and guidance. The information was obtained from literature search, discussions with researchers, practitioners and manufacturers, and field visits to traffic control centers in the U.S. and Europe.

2.1 Traffic Control Systems and Strategies

Traffic signals are the predominant form of traffic control in urban areas. In most metropolitan areas, about 40 percent of all travel occurs on signalized streets, and delay at traffic signals accounts for up to 30 percent of travel time. Improving the operation of signals could significantly improve the efficiency of existing street networks by reducing stops and delays at traffic signals, thus resulting in shorter travel times and smoother traffic flows. Accordingly, considerable effort has been devoted to advances in signal technology and to the development of methods for the efficient operation of signal systems. Hardware developments have produced advanced signal equipment which allows greater flexibility for signal operations at lower costs.

There are several approaches for coordinating traffic signals to operate as a system along arterials and grid networks[24]. These include interconnection of pretimed controllers, time-based coordination, on-street master controllers, closed loop arterial systems, and central control systems. Small systems (up to 20-30 signals in one or more subsystems) use Type 170 or NEMA microprocessor controllers as on-street masters along with dedicated lines to provide for traffic responsive plan selection and signal coordination. “Closed loop” control provides for remote plan development, coordination and monitoring of local controllers from the central office, using a microcomputer.

Central control systems use a central computer to control and monitor their status second-by-second. Communication between the control center and the local controllers is provided by various means including dedicated lines, coaxial cables, fiber-optics cables, phone lines or radio frequencies. The timing plans are selected and implemented through the central computer; other control functions (preemption, unattended system operation, detection of equipment malfunction) also are implemented centrally. Most of the central control systems in the US are UTCS type. UTCS is a general purpose, hardware-independent software package developed by FHWA. A number of modifications have been made to the UTCS software to provide for additional flexibility and improve the operators interface, e.g., displays of signal indications and real-time volume and occupancy data. Traffic surveillance is usually provided through loop detectors. The number and location of traffic detectors depend on the control strategy in operation.

Table 2.1 presents the basic operating strategies currently employed by traffic signal control systems. Most of the existing systems use the “first generation” control strategy. Fixed-time timings are prepared off-line based on historical data. Separate timing plans are developed for each time period (e.g., a.m. peak, midday and p.m. peak) and they are implemented by time-of-day (T.O.D.) The number of timing plans is a function of both signal system capabilities and the resources allotted for developing the plans. Some control systems select the timings based on real-time volume and occupancy data collected from system detectors located in key areas of the network (traffic-responsive plan selection.) The first generation strategy with optimal timing plans works well in undersaturated networks with stable traffic patterns and does not require detectors, except for traffic responsive plan selection. It cannot, however, respond to real-time changes in traffic volumes. In addition, the timing plans become outdated because of the traffic growth and changes in traffic patterns.

A number of enhancements have been implemented to the first generation control strategy. The critical intersection control (CIC) option adjusts the green times at critical intersections on each cycle to accommodate fluctuations in traffic volumes and prevent congestion, but the cycle length and offsets remain unchanged to maintain coordination with the rest of the signals in the network. The system operator may also override the timings (e.g., changing timings at certain intersections, or implementing a different plan) or the operation of specific signals (fixed-time, semi-actuated or fully actuated) based on real-time surveillance data. Currently, expert systems are being developed to assist the operator in managing the system, and to detect traffic incidents [19].

An increasing number of first generation control systems use traffic actuated controllers operating in coordination with a common background cycle length. These systems provide for improved progression by utilizing the spare green time in the signal cycle from the “early” termination of actuated phases. At the same time, they reduce the total intersection delay by responding to the cycle-by-cycle fluctuations in traffic volumes. Figure 2.1 shows the changes in delay from this strategy compared to fixed-time plans for seven real-life signalized arterials [21]. Coordinated actuated signals significantly improved the performance on the arterial at the expense of the cross-streets. The highest benefits were obtained on systems with predominant arterial through traffic, multiphase signals, and little pedestrian activity.

The “1.5 generation” control strategy uses a combination of historical and real-time traffic data in developing new timing plans. Data from system detectors are used to update intersection approach volumes and prepare off-line new timing plans. The system then determines the improvement that can be obtained from implementing the new timings as compared to the plan currently in operation. Based on this evaluation, the operator decides whether to implement the updated plan. The verification and

TABLE 2.1 CONTROL STRATEGIES IN SIGNAL CONTROLLED NETWORKS

CONTROL STRATEGY	TIMING PLAN DEVELOPMENT	TIMING PLAN IMPLEMENTATION	DATA USED*	DETECTOR REQUIREMENTS
1 st Generation	Off-line	Time-of-Day (TOD) Traffic Responsive Operator	Historical	N/A System System
1.5 Generation	Off-line	Operator	Predicted/ Real-time	System
2nd Generation	On-line	On-line	Predicted/ Real-time	Intersection Approaches

*** for developing the timing plans**

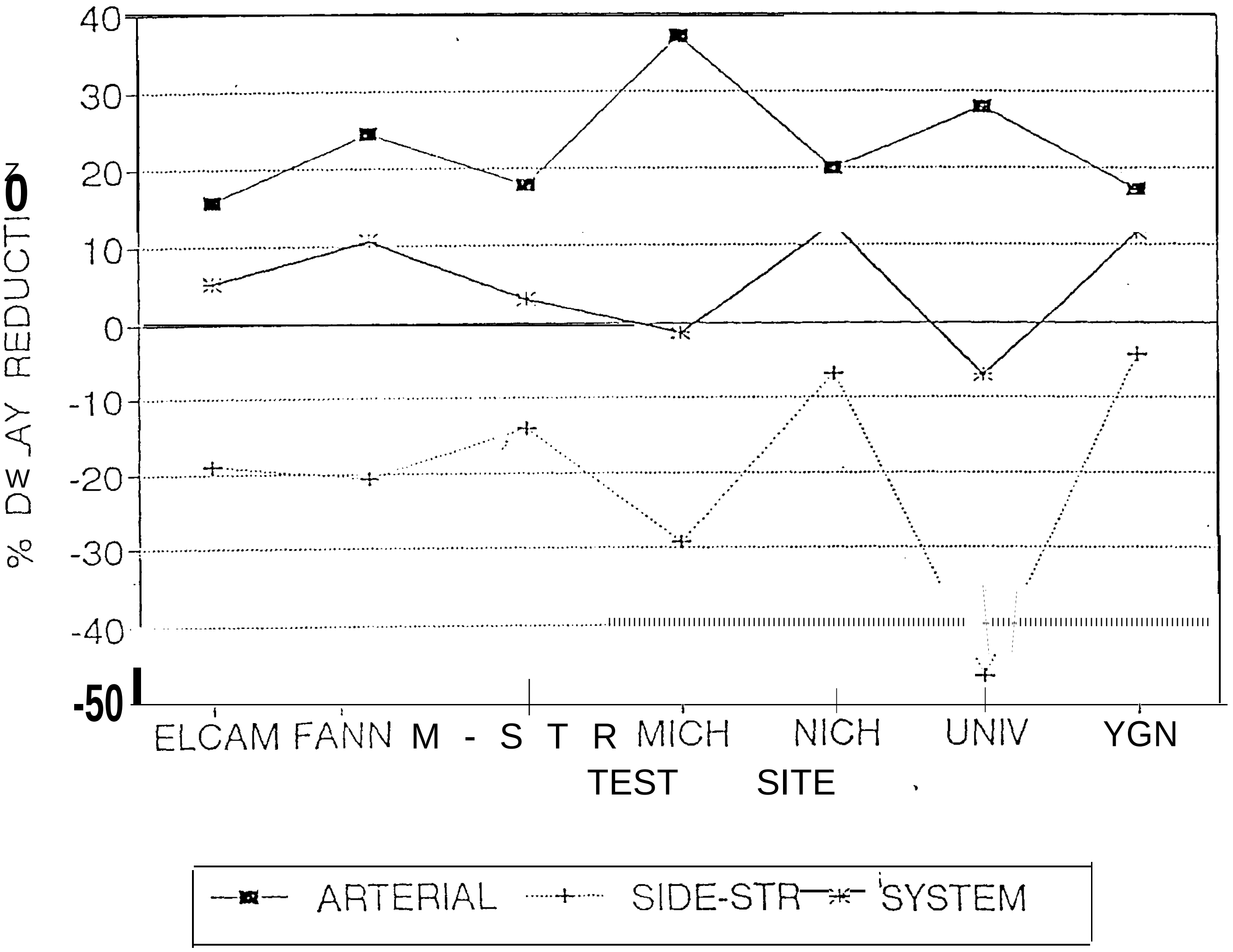


FIGURE 2.1 FIXED-TIME vs. COORDINATED ACTUATED SIGNALS

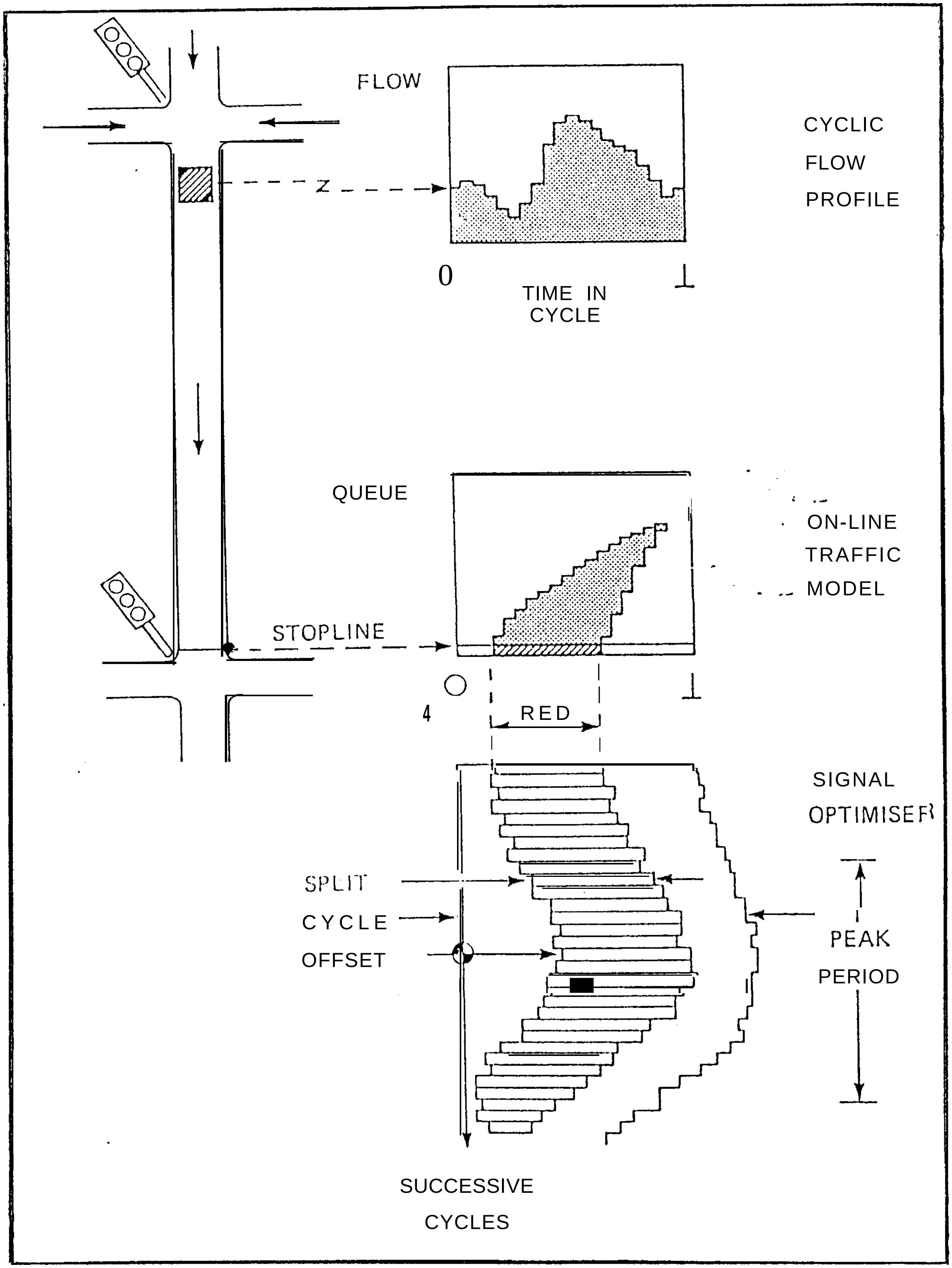
assessment of the timing plans prior to implementation ensures that the plans are operationally acceptable. This strategy reduces the effort to update timing plans, but still cannot respond to real-time changes in traffic patterns. In addition, it requires careful detector placement and calibration of algorithms for estimating approach volumes at each signal.

"On-line" control strategies update the timing plans in real-time based on data from detectors located on each signalized intersection approach. Thus they can respond to both short-term and permanent changes in traffic patterns in a network. Other benefits include staff time savings to prepare and update fixed-time plans. These strategies, however, require a high level of detectorization and their effectiveness largely depends on the reliability of traffic detectors to provide accurate information. In the UTCS "Second Generation" strategy, the timing plans are developed on-line and implemented approximately every 15 minutes based on traffic volumes predicted from detector data. Field experiments have shown that this strategy produced mixed results compared to the first generation control strategy [10,16]. The main weaknesses were the difficulty in accurately predicting future traffic volumes, and the transition effects due to the frequent changes in the timing plans.

The SCOOT (Split Cycle and Offset Optimization Technique) control method [11] developed in UK first estimates the size and shape of traffic platoons on each intersection approach for each signal cycle, using data from detectors located at the upstream end of each approach. It then adjusts the timings on-line to allow most of the traffic to proceed without delays and stops. The incremental changes in the timings does not require longer term predictions of traffic volumes or sudden changes in the plans. Figure 2.2 gives an overview of the SCOOT control strategy. Field evaluations indicate that SCOOT has reduced delay by 12 percent on the average compared to optimal fixed-time plans. The highest benefits were achieved on dense networks in downtown areas with variable flows and complex traffic patterns. Recent enhancements to the SCOOT software [4] include the designation of priority routes within the system, metering algorithms to restrict traffic from entering into congested areas of a network, and determination of congested offsets [25] to avoid link blocking.

SCATS (Sydney Coordinated Adaptive Traffic System) [13] is another traffic responsive control system developed and implemented in Sydney, Australia. It has been evolved from arterial systems with coordinated actuated signals. The system uses data from detectors located at each intersection approach to measure the degree of saturation (volume/capacity ratio) and to adjust on-line the background fixed-time plans. This strategy accounts for traffic volume variations and also determines the desirability of coordination of signals due to changes in traffic conditions. Field studies have shown that SCATS is superior to both fixed-time and conventional vehicle actuated control [14]. Recently, a facility has been added in the SCATS system to automatically record the travel times of vehicles equipped with automatic vehicle identification (AVI) systems traveling through the network [12]. These travel times are analyzed to evaluate the

FIGURE 2.2 THE SCOOT CONTROL STRATEGY



performance of the system, and, could be used to change the timings in real time to better match actual traffic conditions.

2.2 Traffic Control and Traveller Information Systems

Route information and guidance systems gather information on the current traffic conditions in a network, and inform/guide drivers in changing their route, departure time and other behavior to reduce their travel time, avoid congested areas and improve their travel time variability. The calculation of optimal routes requires the knowledge of the existing and future travel times on each link of the network, as well as several additional data including the physical characteristics of the network, circulation patterns, traffic control devices, traffic volumes, incidents and other short-term disruptions to the normal travel patterns [23].

Data on link travel times throughout the day are normally provided from historical data. This data can be updated from the information transmitted from the guided vehicles as they travel through the system. However, such data may exhibit a fairly large variability, especially if the number of equipped vehicles is small [20]. Furthermore, it would be difficult to obtain travel time estimates along congested routes unless guided vehicles were assigned to those locations. Advanced traffic control systems could provide more accurate information on traffic volumes and delays at signals for the entire network. Thus, traffic control systems could provide the information necessary for route guidance purposes. This points out the need for an effective and comprehensive surveillance system in order to have accurate information for route guidance. Such a system is in place for advanced control strategies. Off-line strategies need to employ detectors on all the major links of the network and a model to calculate performance measures based on real-time traffic data and the timing plan in operation.

As was discussed in Chapter 1 route guidance could have several implications for traffic control. Diversion of a significant number of vehicles to selected routes in a network changes the traffic patterns. Furthermore, the timing plans in operation are no longer optimal. The traffic control system should be able to respond to these changes in traffic patterns. On-line control strategies offer the highest potential for such treatment, but may not be the best for the diverted vehicles because they consider the total system performance.

CHAPTER 3

METHODOLOGY

3.1 Basic Considerations and Assumptions

The impacts of route information and guidance on signal controlled networks depend on several factors including:

- network configuration and geometrics (single arterial, parallel arterials, grid network, number of lanes, signal spacing)
- traffic patterns in the network (traffic volumes, turning movements, day-to-day and peak hour variability in traffic flows, level of congestion)
- capabilities of the signal control system in place (surveillance system, control strategy, timing plans in operation)
- diverted traffic (diverted volume, origin-destinations of guided vehicles, characteristics of the route guidance system)
- incidents (location, duration and severity of incidents on the freeway and the surface street network)

An exhaustive study of all these factors and their interrelationships was beyond the scope of this study, and a number of assumptions had to be made. Emphasis was placed on the impacts of the diverted traffic under different signal control strategies. These impacts were assessed on test sites carefully chosen to represent the variabilities typically found in the physical and traffic characteristics of real-life networks. The assumptions made and their implications are discussed below:

> **Diversion scenarios:** Diversion volumes were assumed, ranging from low levels (about 100 vph.) to high levels (about 700 vph, which is equivalent to an additional lane on surface street networks.) These diverted vehicles were assigned to routes with the shortest travel times in the network. These routes, normally the major streets in the system, were assumed to remain constant and not changing with the level of diverted traffic.
>
> Assuming fixed diversion paths, we probably underestimate the effectiveness of dynamic route information/guidance systems which would direct vehicles on alternate routes considering travel times and volumes in real-time. This assumption, however, is valid for a small number of diverted vehicles and for surface street networks consisting of a single parallel arterial to the freeway. This

assumption is also applicable to more general surface networks where through traffic on minor streets is discouraged because of safety and environmental concerns.

Flow patterns on the surface street network: It was assumed that the traffic patterns on the surface street networks would remain constant. This implies that a) vehicles on the surface streets do not change their routes because of the interaction with the diverted vehicles, or the traffic control strategy, and b) day-to-day flow variations do not influence the traffic performance.

Incidents: no incidents affecting the traffic performance were assumed to occur in the signal controlled networks throughout the evaluation of the alternative strategies.

3.2 Development of Traffic Control and Timing Strategies

The control and timing strategies developed could be implemented within the existing systems' hardware and software capabilities described in Chapter 2. These strategies fall in three major categories:

- fixed-time control
- semi-dynamic control (e.g., traffic responsive plan selection, 1.5 generation)
- real-time control

Within each control strategy a number of options for generating signal timing plans were developed and tested, including i) network-wide optimization, ii) route-specific timings (e.g., favoring routes used by guided vehicles), and iii) congestion avoidance settings (i.e., maximize the capacity and/or avoid queue spillbacks). These control and timing strategies developed in this study are discussed in detail below:

3.2.1 Fixed-time control

Optimal fixed-time signal plans are developed assuming that no information is available on the additional traffic volumes from diversion. This strategy can be implemented with most of the control systems currently in place and does not require any real-time information. Furthermore it provides a benchmark to test the effectiveness of more advanced strategies. This strategy is also appropriate for a small number of guided vehicles which do not influence the traffic performance in the network. Four options for developing optimal timing plans were analyzed:

Network-wide optimization for minimum delay/stops: Signal timing plans were optimized using the TRANSYT model [8] to minimize a combination of delays and stops on the entire network. All traffic movements (e.g., arterial through traffic, minor streets) and vehicle types (guided, non-guided vehicles) are equally treated in the optimization. This is the most commonly used approach in signal timing optimization and serves as the base case in comparing alternative methods for generating timing plans.

Priority treatment on major routes: Timing plans are developed to provide priority to major routes in the network which are likely to be used by diverted vehicles (e.g., arterial through traffic). Priority treatment can be accomplished in the TRANSYT model by applying delay and stops weighting factors to selected links of the network. This is an iterative process consisting of applying several weighting factors in multiple computer runs, and selecting the plan based on the benefits to the weighted links, as well as the disbenefits, if any, to the rest of the system.

Priority treatment on diversion routes: Timing plans are developed to favor the routes normally used by diverted traffic. It is assumed that information on those routes is available from historical data. Similar to the previous option, alternative weighting factors were applied to the selected links in multiple computer runs. The "optimal" plan was then selected based on the trade-offs in performance between the weighted links and the total system.

Capacity maximization timings: Signal settings are developed to maximize the “reserve capacity” (i.e., for the minimum degree of saturation) at each signal in the system. This plan usually employs a longer cycle length and results in higher delays than the optimal timings for minimum delay and stops. However, it can accommodate higher additional volumes and their fluctuations than the other timing plans, without oversaturation. The additional volume of traffic on an approach can be estimated from the predicted reserve capacity at the critical intersection approach in the network as follows:

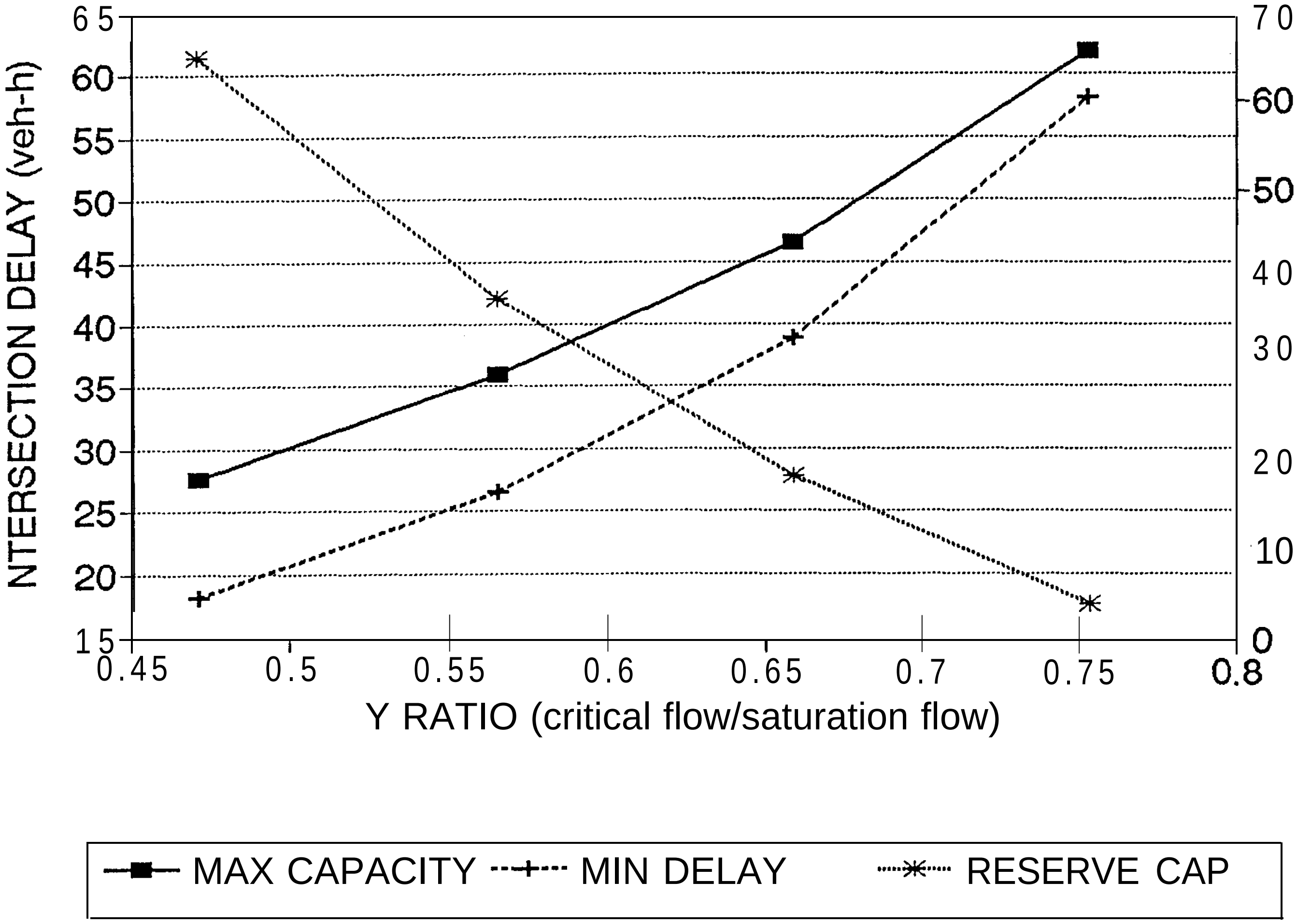
$$dV_i = \frac{RC_i}{X_i} 100 \qquad (3\text{-}1)$$

where:

Dv_i : *additional traffic volume on approach i (%)*
RC_i : *reserve capacity =* $1 - X_i$ *(%)*
X_i : *degree of saturation on approach i (%)*

Figure 3.1 compares the total delay under delay minimization and capacity maximization settings for an isolated signalized intersection. For low approach volumes the capacity maximization plan results in about a 50 percent increase in delay compared to the delay minimization settings, but provides a reserve capacity of 70 percent. These differences in performance become smaller with the increase in traffic volumes, and the two plans result in similar delays for traffic volumes near saturation.

FIGURE 3.1 INTERSECTION DELAY
CAPACITY MAX vs DELAY MIN SETTINGS



3.3.2 Semi-dynamic control

This strategy takes into account the diverted vehicles in the network in the development and implementation of the timing plans. The signal settings for the network are developed off-line, based on historical and current data on the diverted volumes. The data are gathered from system detectors and are used to update the optimal timings developed in Strategy 1 (fixed-time control) for the existing traffic patterns in the system. This approach is equivalent to the 1.5 generation control strategy. alternatively optimal timing plans are developed off-line for a range of diversion volumes based on historical data. The plans are implemented based on real-time volume and occupancy information from system detectors. This is equivalent to traffic responsive plan selection. The following options were tested in generating the optimal fixed-time plans:

> **Network-wide optimization for minimum delay/stops:** Timing plans are developed to minimize the delay and stops on the entire network. This is the same approach as the base option in the fixed-time control. However, traffic volumes on selected links were modified to take into consideration the amount of diverted traffic.
>
> **Priority treatment for diverted traffic:** This is the same approach as the priority treatment for diversion routes in Strategy 1 except that the volume of diverted traffic is taken into consideration. The “shared stopline” facility in TRANSYT model was used to differentiate the diverted vehicles from the rest of the traffic stream moving on the same routes of the network. Weighting factors were then assigned only to the links assigned to the diverted vehicles.

3.2.3 Real-time control

This strategy involves on-line optimization of the timings plans based on real-time information on traffic patterns. Of the various on-line strategies discussed in Chapter 2, a SCOOT type strategy was selected for evaluation. This strategy does not involve short-term prediction of traffic volumes, but continuous incremental changes in the signal settings. This approach can be approximated by developing a series of fixed-time plans for each variation in traffic volumes and implementing them in the system ignoring the transition effects.

On-line strategies normally optimize the timings for network-wide minimum delay and stops. This approach provides the best overall performance because it considers all the traffic movements in the system and automatically favors the movements with the heavier volumes. However, route biased settings and flow metering strategies were also tested. Route biased settings were developed using weighting factors for selected links. Flow metering strategies involved adjustments of the offsets and green times to prevent congestion at critical intersections.

3.3 Test Plan for Evaluating Control Strategies

A bi-level approach has been adopted to evaluate the effectiveness of control strategies in managing the impacts of diverted traffic in a network. First, for a given control strategy (e.g., first generation control) the alternative approaches for developing timing plans are tested for each diversion scenario. The analysis of the results provides an estimate of the improvements that can be achieved with the existing system in place, i.e., without investments in signal control equipment/software. Next, the alternative strategies with the best timing plans are compared (e.g., fixed-time vs. on-line control.) These comparisons provide an estimate of the improvements from enhancements in the traffic control center for different levels of diverted traffic. The evaluation considered the performance at each test site and across all sites.

The assessment of the traffic impacts of diverted vehicles and the effectiveness of the control and timing strategies consisted of the following steps:

- selection of the analysis techniques
- selection of the test sites
- selection of the evaluation criteria

3.3.1 Choice of the analysis techniques

The NETSIM microscopic simulation model [7] was selected to predict the impacts of the alternative strategies. NETSIM is a powerful microscopic model suitable for detailed simulation of alternative designs and control strategies. The latest version of the model (TRAF-NETSIM) is operational on microcomputers and provides graphical displays of the simulation results. NETSIM requires coding the network into a link/node scheme, and data on link distances, intersection geometrics, traffic volumes, turning movements, speeds, and signalization. Direct output from the NETSIM model includes travel time, delay, stops, fuel consumption, and air pollutant emissions for each link and for the total system.

Optimal fixed-time plans were developed using the latest version of the TRANSYT-7F model. TRANSYT is a macroscopic deterministic model which simulates the traffic flow in a network of coordinated signals and predicts travel time, delay, number of stops, degree of saturation, fuel consumption and queue length. The signal optimizer then selects the system cycle length and optimizes the splits and offsets at each intersection to minimize a weighted combination of delays and stops (Performance Index.) TRANSYT can model a variety of network configurations, traffic patterns and vehicle classes (e.g., guided vehicles moving on exclusive lanes or sharing the roadway with the rest of the traffic.) The model requires coding the network into links and nodes and data on traffic volumes, saturation flows, distances between intersections, cruise speeds and existing signal settings.

The PASSER [5] and MAXBAND [9] models are also increasingly being used in signal timing. These models optimize the timing plans to maximize the green bandwidth on the arterial. The modeling of traffic flow is simplified as it ignores the dispersion of traffic platoons, and the turning flows from cross streets. Bandwidth maximization does not necessarily minimize the stops and delays in the system and tends to penalize the cross-streets. In addition, these models cannot optimize the timings in grid networks. Because of these limitations these models were not used in developing optimal timing plans, except for determining the best phase sequence at multiphase signals. This is because the TRANSYT model cannot optimize the sequence of phases directly. Thus, PASSER/MAXBAND were used first to determine the phasing. The optimal phasing was input to TRANSYT for final optimization of splits and offsets.

3.3.2 The test sites

A major arterial and a dense grid network were selected to test the alternative strategies and assess the impacts of diverted traffic. The selected sites provide for a variety of design characteristics, traffic patterns, speeds and signal timing.

A. San Pablo Avenue

San Pablo Avenue (Figure 3.2) is a major urban/suburban arterial in the San Francisco Bay Area. The study segment parallels the I-80 freeway. It is 7.1 miles long and contains 30 signalized intersections. It extends from the city of Oakland through the cities of Berkeley, Albany, and El Cerrito to the city of Richmond. San Pablo is a divided arterial with two through lanes per direction and exclusive left turn lanes at all signalized intersections. Table 3.1 provides information on signal spacing, geometrics, and signalization for each intersection in the study area. Most of the signals operate in coordinated systems. Approximately half of the signals are multiphase, mostly with protected left turns on the arterial. Signal equipment ranges from electromechanical (single and multiple dial) controllers, to solid state pretimed and actuated controllers, to 170 microprocessor controllers. Coordination is provided by hardwire interconnect, and by time-based coordination.

Traffic patterns range from predominantly through traffic, to a grid of arterial and cross street movements, to complicated turning patterns, particularly in the vicinity of the I-80 freeway interchanges. Cross-street traffic is highly variable, with several cross-streets having higher volumes than those on San Pablo Ave. The p.m. peak period was selected for analysis because of the highest traffic volumes and the availability of the data. Several intersections experience operational problems during the p.m. peak. The majority of the p.m. peak traffic on the arterial is northbound. This direction also serves as an alternate route to I-80 freeway, since eastbound I-80 is congested for most of the p.m. peak period.

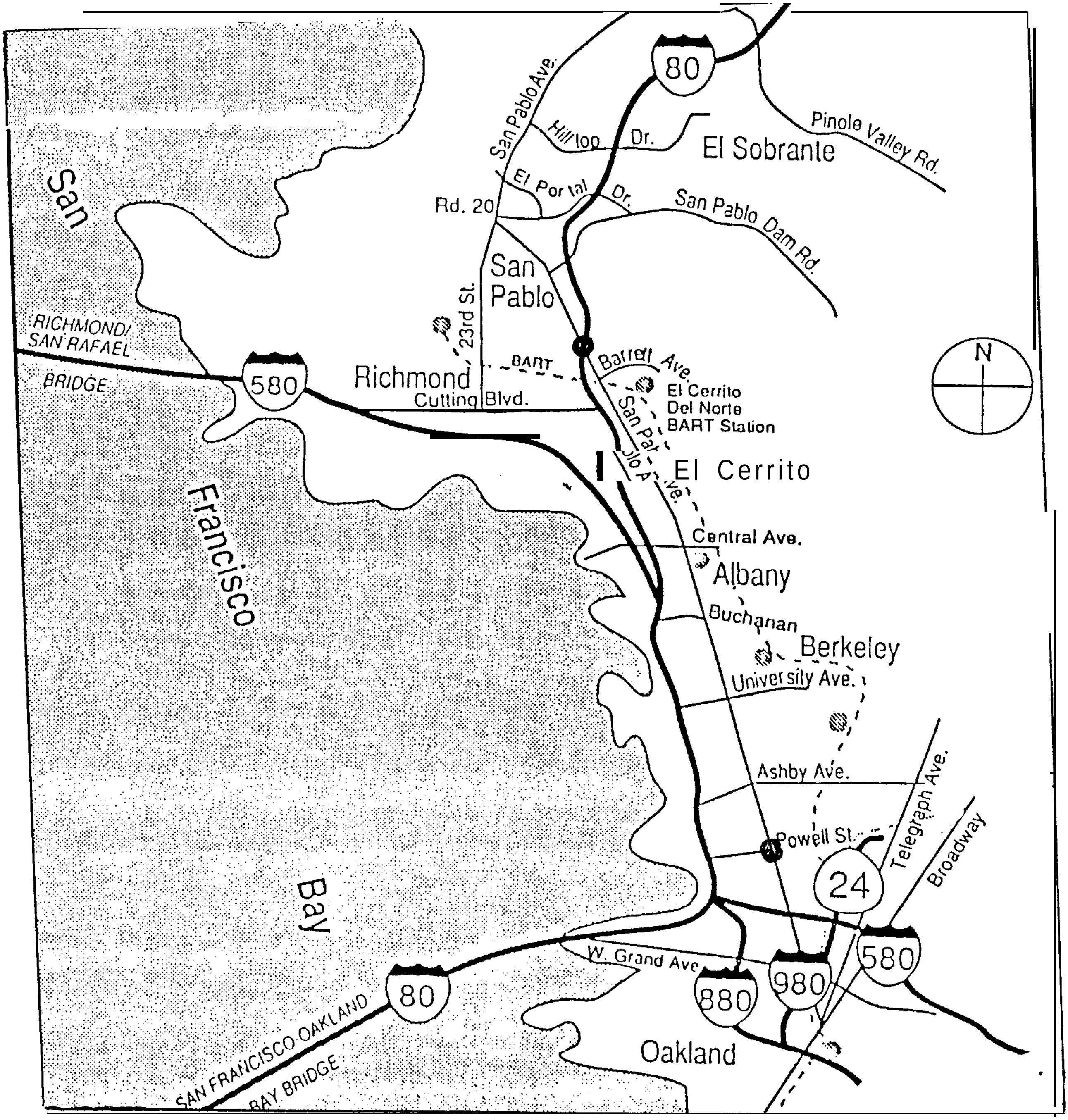


FIGURE 3.2 SAN PABLO AVENUE TEST SITE

TABLE 3.1 SIGNALIZED INTERSECTIONS ALONG THE SAN PABLO TEST ARTERIAL

IG ℓ	ITY	STREET NAME	PACING (ft)*	-INT	# LANES CROSS STREET**	SIGNALIZATION		
						P/A	HASES	YCLE
1	AKLAND	STANFORD			2(1)	P	2	60
2		ALCATRAZ	2280	x	1	P	2	60
3	ERKELEY	ASHBY	1943		3(1)	P	2	80
4		GRAYSON	1631	x	1	P	2	80
5		DWIGHT WAY	ıa35		2	P	2	70
6		ALLSTON WAY	1980		1	P	2	70
7		ADDISON	520	x	1	P	2	70
a		UNIVERSITY	450		3	P	2	70
9		DELAWARE	977		1	P	2	70
10		CEDAR	1300		3(1)	P	2	70
11		GILMAN	1983		2	P	2	70
12	LBANY	MARIN	2380		2(1)	A	4	90
13		BUCHANAN	400	x	1	A	2	90
14		SOLANO	420		2	A	4	90
15		WASHINGTON	790	x	1	A	2	90
16		CLAY	1410	x	1	A	2	90
17		BRIGHTON	240	x	2	A	2	90
18	L CERRITO	CARLSON	a70		3	A	4	80
19		FAIRMOUNT	630		2(1)	A	4	80
20		CENTRAL	630		3(f)	A	4	80
21		STOCKTON	2190	x	1	A	4	80
22		MOESER	1470	x	2	A	4	80
23		SCHMIDT	1150	x	2	A	4	80
24		MANILA/BAYVIEW	720		1	A	4	80
25		PORTRERO AVE	2070		3(1)	A	4	80
26		HILL/EASTSHORE	1230		3(1)	A	4	80
27		CUTTING BLVD	760		4(2)	A	6	80
28	RICHMOND	McDONALD AVE	3000		3(1)	A	6	I
29		BARRET	1220		4(1)	A	6	I
30		ROOSVELT/EB I-80	620	X	3(1)	A	2	70

NOTES:
*xxxx: Distance to the previous signalized intersection
**X(Y): Total # of lanes on the critical approach (# of exclusive lt lanes)
P/A: Pretimed (fixed-time) signal/Actuated signal
4-phase: protected LT on the arterial
6/8 phase: protected LT on the arterial and the cross-streets
Cycle: Existing cycle length (I : signals operating uncoordinated)

Data on the study area were assembled from past ITS research studies, Caltrans and local agencies. The data were first coded into the TRANSYT model and simulation runs were performed to replicate existing conditions. Performance estimates from the model were compared against measured values (primarily the degree of saturation and delay at the critical intersections). The data were corrected as needed, along with adjustments to the model parameters, to obtain a better agreement between model results and field data. Figure 3.3 shows the predicted average intersection delay against field measurements for eight intersections in the study area. The differences between measured and predicted values are within 10 percent, and all correspond to the same level of service (LOS) according to the 1985 Highway Capacity Manual [22].

B. Silverlake Network

The Silverlake network (Figure 3.4) is located in the edge of downtown Los Angeles adjacent to the US 101 and I-I 10 freeways. The network consists of fifteen signalized intersections in a grid of major arterials. The signal spacing ranges from 750 to 2200 ft. Table 3.2 lists the intersections in the study area and provides information on intersection geometrics and signal phasing. All signals are type 170 microprocessor controllers and operate coordinated on a common cycle length of 90 sec. The network is part of the Los Angeles Automatic Surveillance and Control System (ATSAC). Traffic volumes are generally high, particularly along the E-W arterials, but none of the intersections is oversaturated. Alvarado and Rampart carry the highest volumes in the N-S direction.

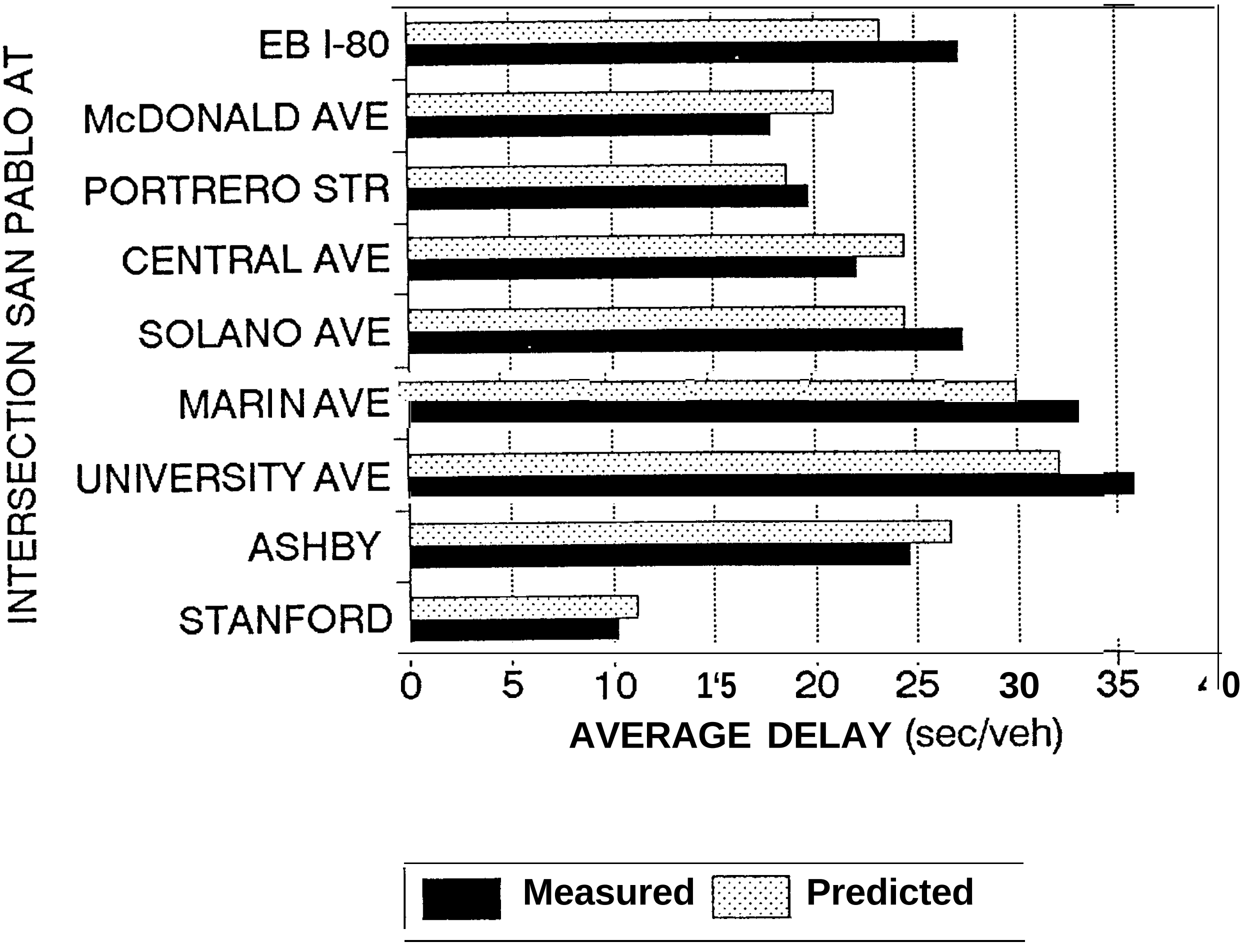
Data on intersection geometrics, traffic volumes and signalization were available from the city of Los Angeles FETSIM project, and a FHWA sponsored project on timing systems with actuated controllers [21]. The data were coded into the TRANSYT and NETSIM models and initial simulation runs were made. The model outputs were thoroughly checked to verify that the models are working correctly. Adjustments were made as needed to obtain reasonable agreement with field conditions.

3.3.3 Evaluation criteria

The following criteria were used in evaluating the impacts of diverted traffic and the alternative control strategies on each test site:

> **Impacts to diverted traffic:** Travel time (average speed) and number of stops for the guided vehicles. Travel time has been used as the primary measure for estimating the benefits to guided vehicles. The number of stops has been chosen because it significantly influences the quality of operation perceived by motorists in signal controlled networks, and the attractiveness of the alternate routes.

FIGURE 3.3 MEASURED .vs PREDICTED INTERSECTION DELAYS -- SAN PABLO AVE



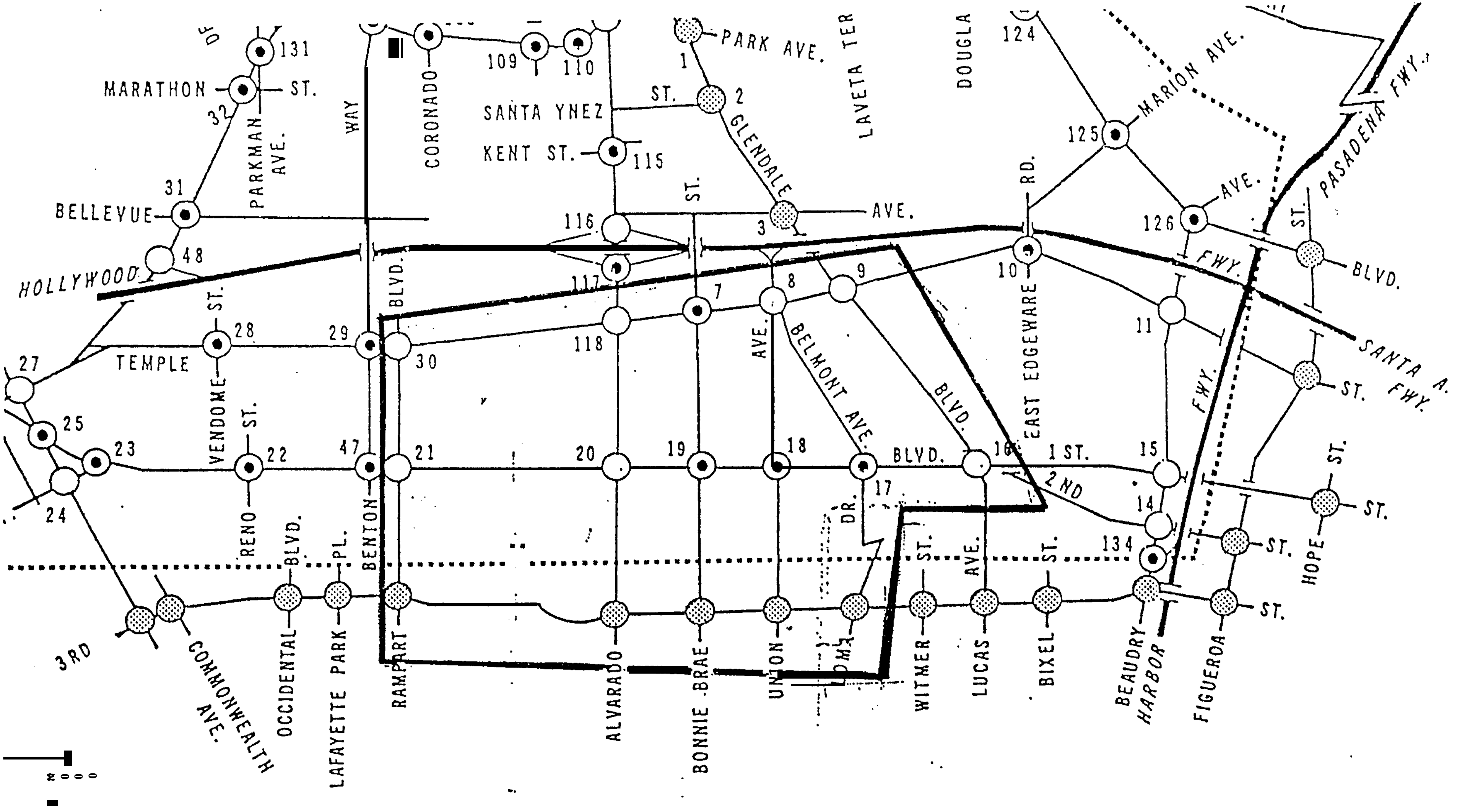


FIGURE 3.4 SILVERLAKE NETWORK -- LOS ANGELES

TABLE 3.2 SIGNALIZED INTERSECTIONS--SILVERLAKE NETWORK TEST SITE

SIG #	INTERSECTION	# LANES*	# PHASES
1	TEMPLE/RAMPART	2(1)/2	4
2	TEMPLE/ALVARADO	2/2	2
3	TEMPLE/BONNIE BRAE	2(1)/2(1)	2
4	TEMPLE/UNION	2(1)/2(1)	8
5	TEMPLE/GLENDALE	2(1)/2(1)	8
6	BEVERLY BLVD/RAMPART	2(1)/2(1)	8
7	BEVERLY BLVD/ALVARADO	2(1)/2	4
8	BEVERLY BLVD/BONNIE BRAE	2(1)/2	4
9	BEVERLY BLVD/UNION	2(1)/2	4
10	BEVERLY BLVD/BELMOND	2(1)/1	4
11	BEVERLY BLVD/GLENDALE	2(1)/1(2)	4
12	THIRD/RAMPART	2(1)/2(1)	8
13	THIRD/ALVARADO	2(1)/2	4
14	THIRD/BONNIE BRAE	2(1)/1	4
15	THIRD/UNION	2(1)/1	4

NOTES:

****X(Y): Total # of lanes on the critical approach (# of exclusive lt lanes)**
4-phase: protected **LT on one street**
8 phase: protected LT on all approaches

Impacts on the local network: Travel time, delays and stops. The results were analyzed separately for the total system, major routes (e.g., arterial through traffic), and minor movements (e.g., cross streets, entry links to the network.)

Detailed analyses compared the traffic performance on a) the total system, b) individual segments, c) individual intersections, and d) specific links. Such analyses are important because the impacts at a specific location might mask the overall effectiveness of a strategy, or vice versa.

CHAPTER 4

APPLICATION AND RESULTS

This Chapter presents the results from the application of the methodology and the selected strategies on each test site, and discusses the general findings and their implications.

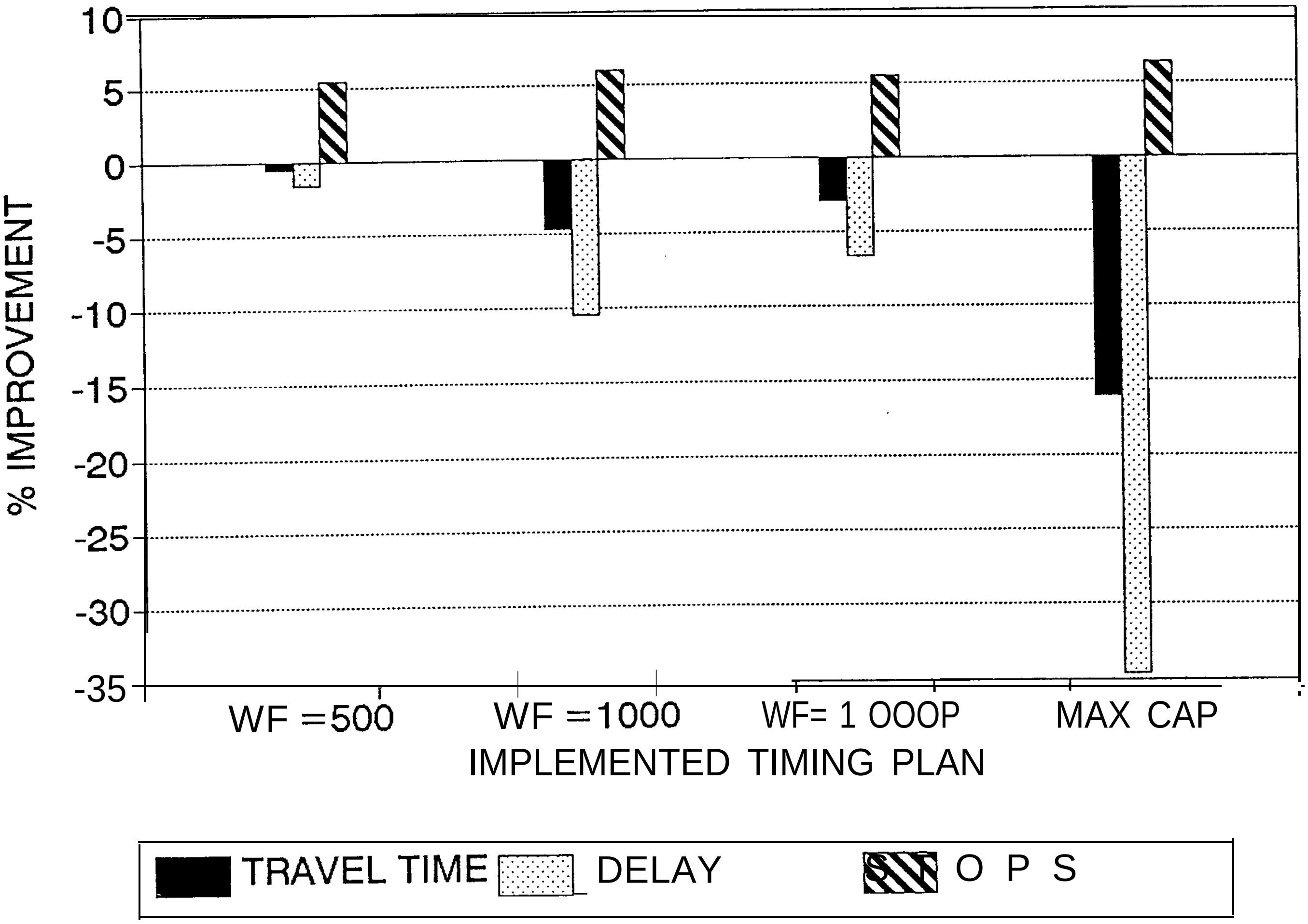
4.1 San Pablo Avenue

Figures 4.1 and 4.2 show the impacts of the alternative timing plans developed in Strategy 1 for the total system and the arterial through traffic compared to the base plan (optimal settings for minimum delay and stops.) Signal settings to favor the arterial through traffic (priority treatment for the arterial) improved the arterial performance but increased the delay and travel time for the total system. The differences in MOE's depend on the weighting factors (WF) applied to the selected links. The plan with WF of 500 (i.e., delay and stops on the arterial links weighted five times more than the rest of the system) improved the arterial performance by about 10 percent with marginal disbenefits to the total system. The plan developed using WF of 1000 resulted in a 15 percent savings in delay and stops for the arterial, but increased the total system delay by about 10 percent.

The timing plan to provide priority on the route used by the diverted vehicles, (i.e., the northbound direction on the San Pablo Avenue), produced similar results as the arterial priority plan with weighting factors of 500 but the delay for the total system increased by 6 percent. This plan resulted in the best performance for the traffic on the diversion route. The travel time was reduced by 5 to 7 percent and stops were cut by 17 to 24 percent compared to the rest of the timing plans. The capacity maximization settings significantly increased the travel time for both the arterial and the total system. This is largely because of the high cycle length employed in the system (120 sec. vs the optimal 80 sec in the rest of the timing plans) which results in wasted green time and large delays on certain approaches. Note that all the alternate plans reduced the number of stops on the total system by about 5 percent.

These results also provide an estimate of the travel time savings for the diverted vehicles in the corridor due to the alternative timing plans, assuming that these vehicles do not influence the network performance (i.e., "single" guided vehicle.) The plan favoring the diversion route improved the travel times of guided vehicles by about 2 minutes (7 percent) and significantly reduced the number of stops. Further analysis of the model outputs showed that the increase in delay for the rest of the system occurred mostly on the cross-streets and left-turn movements. The delay increases, however, did not worsen the level of service for those approaches. Thus, priority settings could result in modest benefits to guided vehicles without significant adverse impacts to the rest of the system.

FIGURE 4.1 IMPACTS OF TIMING PLANS ON TOTAL SYSTEM PERFORMANCE

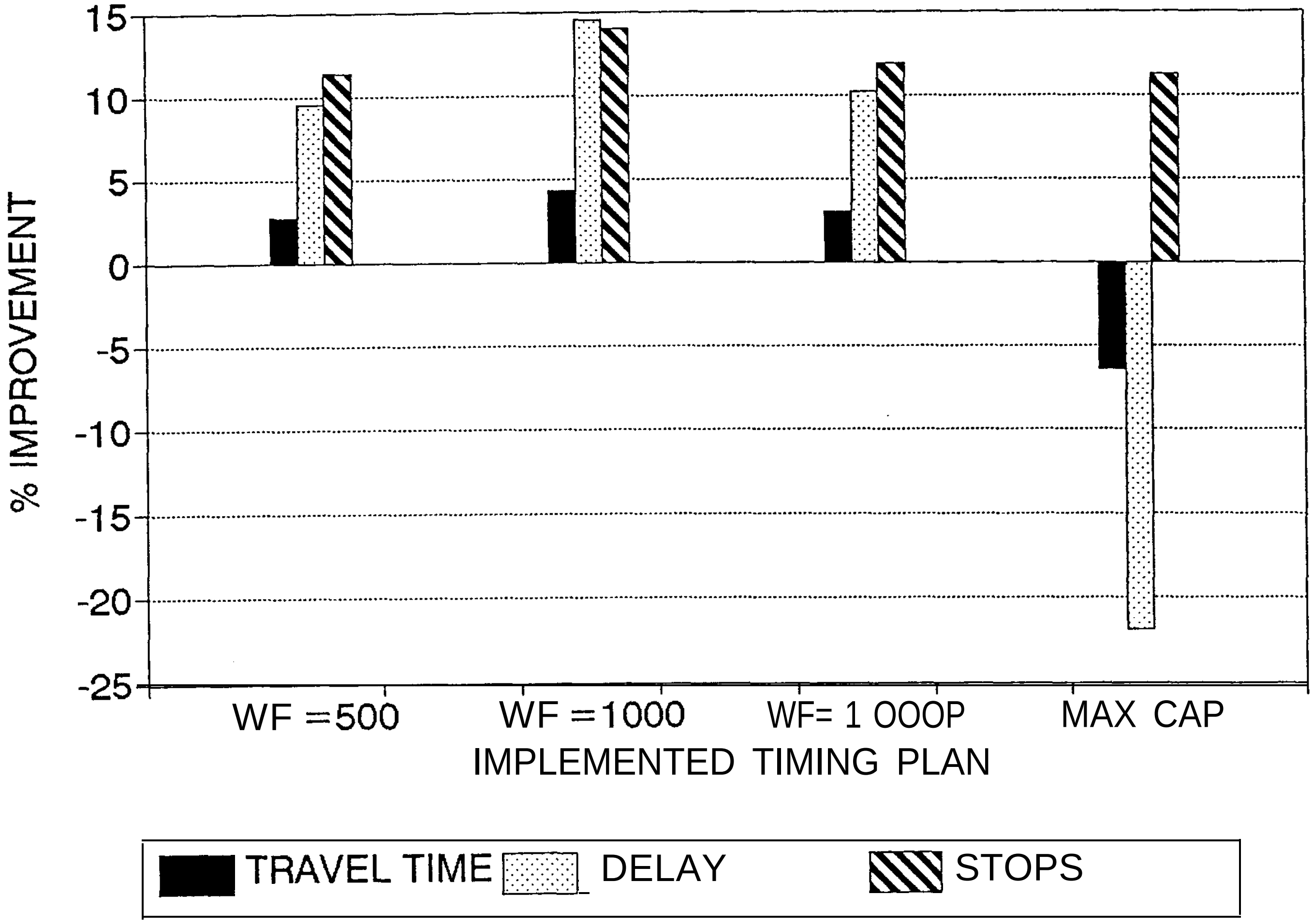


WF: Delay and stops weighting factors

P: timings favoring routes used by diverted vehicles

MAX CAP: Capacity maximization settings

FIGURE 4.2 IMPACTS OF TIMING PLANS ON ARTERIAL THROUGH TRAFFIC



Next, alternative diversion volumes were specified and the network performance was simulated under each timing plan. Figure 4.3 shows the changes in travel time for the vehicles on the arterial compared to the base case (optimal timings for minimum delay/stops with the existing traffic patterns.) The travel times, delays and the number of stops increased substantially with the increase in the diverted volumes. Also, several approaches on the arterial became saturated. Most of the impacts occurred on the diversion route and the left-turn movements on the arterial. The alternative timing plans displayed similar performance characteristics for diversion volumes of up to 300 vph. The arterial/route priority and capacity maximization settings resulted in better performance under high diversion volumes (about 10 percent less increase in travel times than the rest of the plans.)

The sensitivity of each plan to the diverted traffic volumes is shown in Figure 4.4. As it was expected the capacity maximization settings had the lowest sensitivity to the diversion volumes, whereas the delay/stops minimizing settings had the highest sensitivity. This indicates that alternative timing methods could more effectively accommodate fluctuations in the diverted volumes.

The average speeds of diverted vehicles under each timing plan are shown in Figure 4.5. The travel speeds decrease substantially with the increase in diverted traffic, largely because of the high delays at the critical intersections. Thus, the increase in diversion rate diminishes the benefits of diverting from the freeway to the arterial and at the same time worsens the performance of the rest of the network. Figure 4.5 also shows that the route (arterial) priority signal settings provide the best performance for low volumes of diverted traffic. Under heavy diversion volumes, however, the capacity maximizing settings result in the highest speeds. In the latter case, the travel time savings for diverted vehicles become significant (savings of about 3 to 8 min or 10 to 22 percent compared to rest of the timing plans.)

The analysis of the results indicates that this control strategy (optimal plans without considering the diverted volumes) could accommodate an increase of about 25 percent in traffic volumes along the diversion route on this test arterial. Higher diversion significantly worsens the traffic performance on the test site and diminishes any time savings to diverted vehicles. The alternative approaches for developing the timing plans produced modest improvements for the diverted traffic and the total system. The route priority settings had the best overall performance.

FIGURE 4.3 IMPACTS OF DIVERTED TRAFFIC ON TOTAL SYSTEM--EXISTING TIMINGS

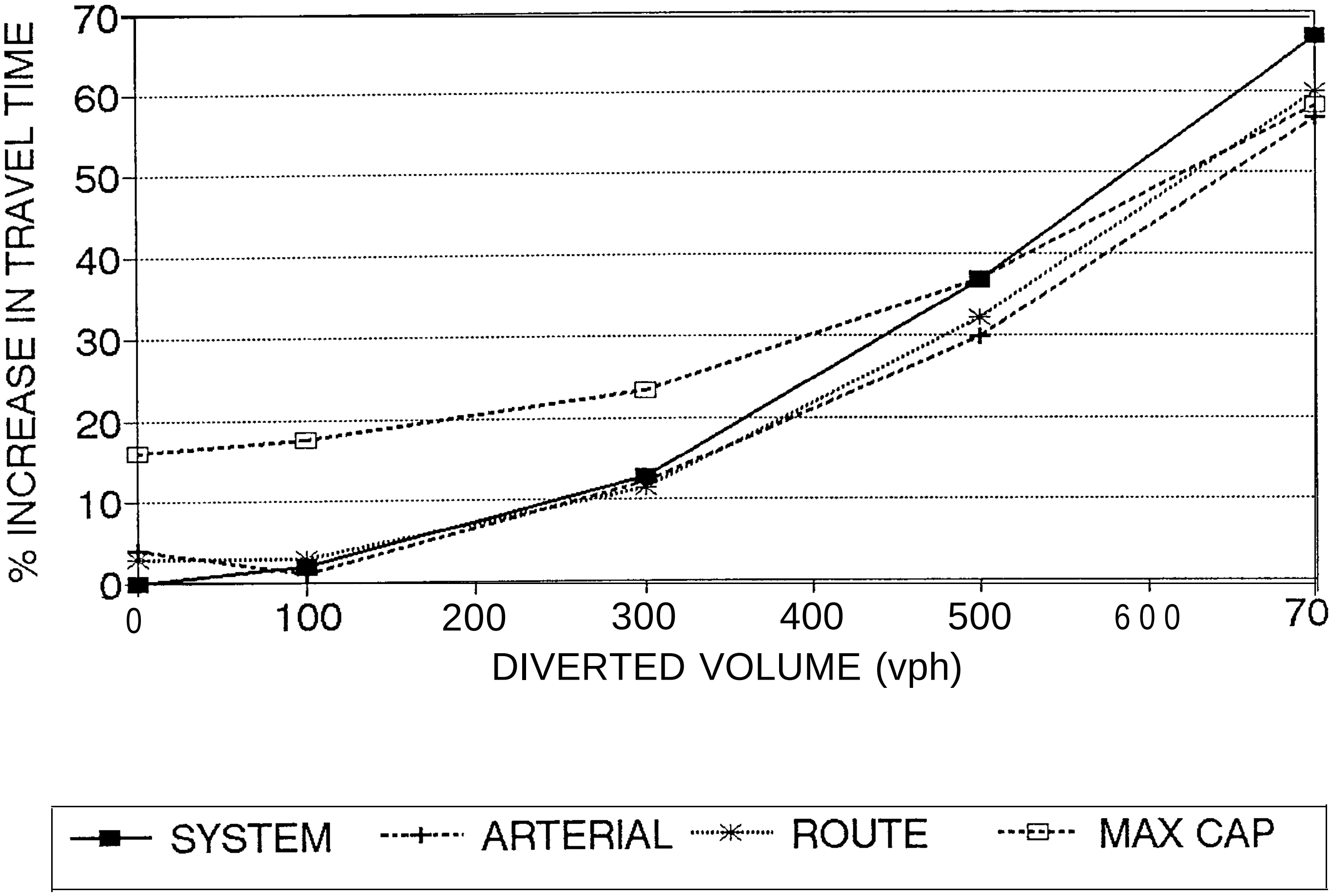


FIGURE 4.4 SENSITIVITY OF TIMING PLANS TO DIVERTED VOLUMES--TOTAL SYSTEM

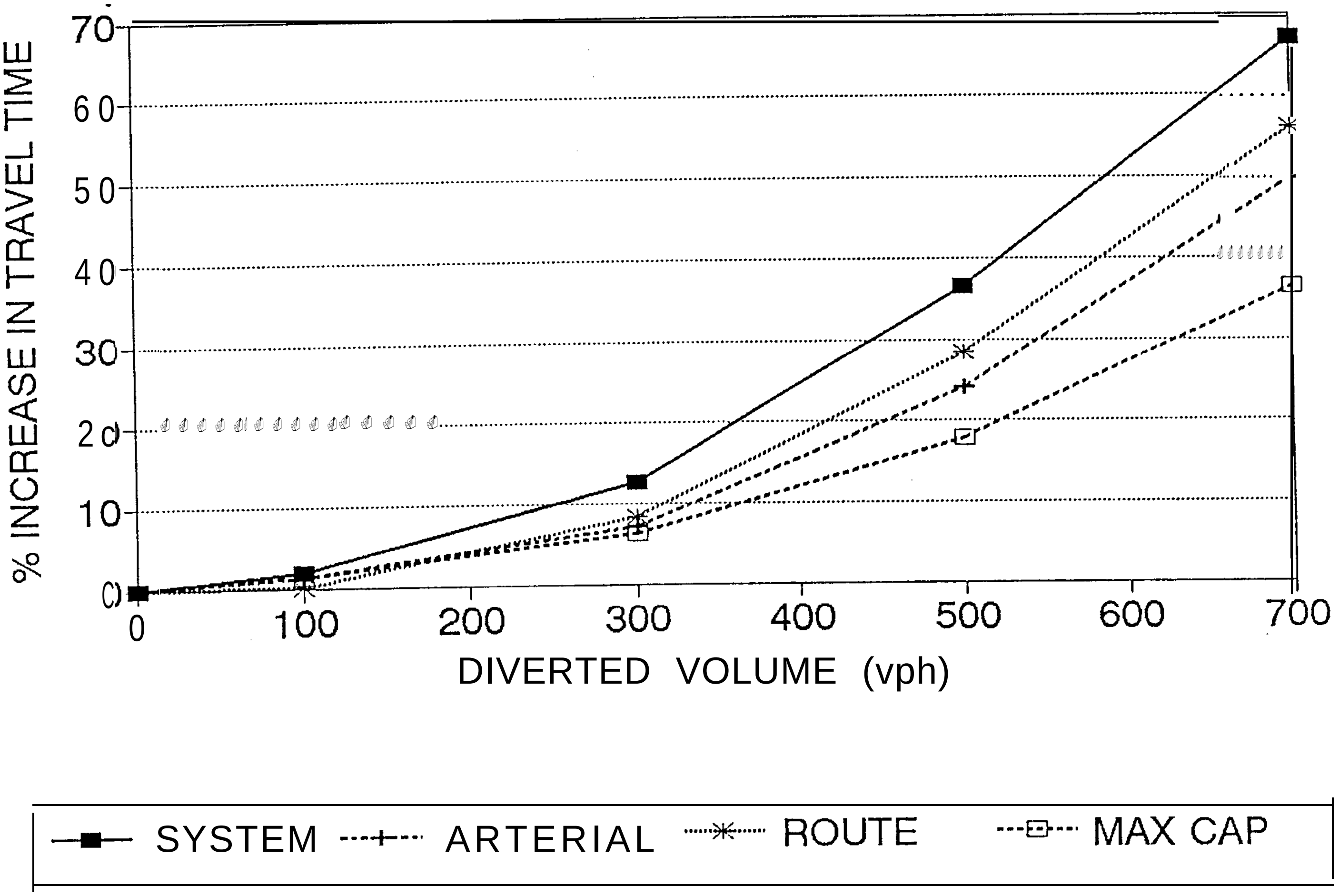
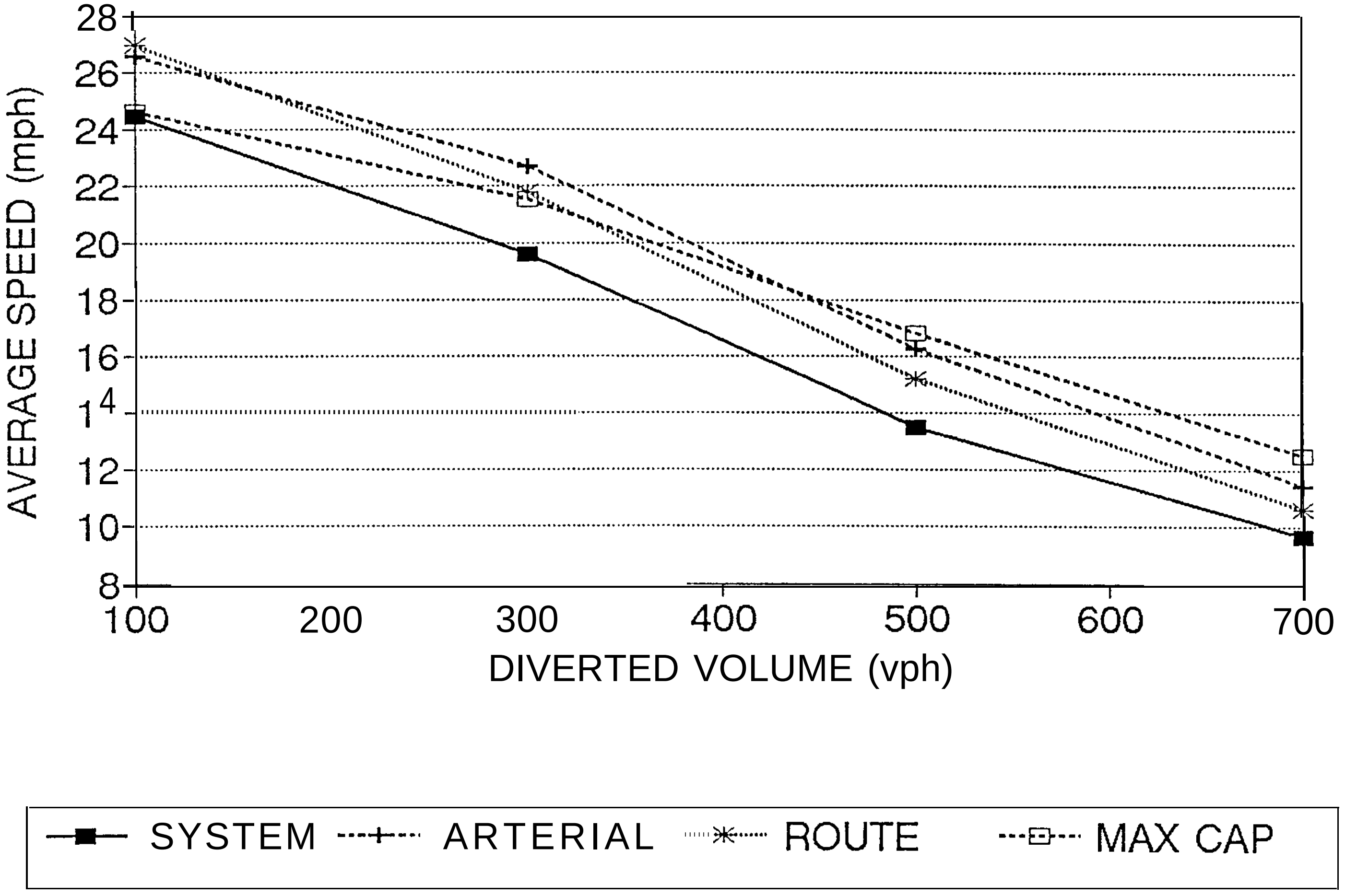


FIGURE 4.5 SPEED OF DIVERTED TRAFFIC UNDER EXISTING TIMING PLANS



The performance of semi-dynamic control was evaluated on the test arterial. This strategy consists of developing optimal timing plans for a range of diversion volumes and implementing the appropriate plan based on volume information from system detectors. Figure 4.6 shows the impacts of the diversion on the total system under signal settings optimized to i) minimize the total system delays and stops (opt sys), and ii) provide priority to the diversion route (opt pr.) Also shown in this Figure are the impacts of the same timing plans in Strategy 1 (fixed-time control.)

Semi-dynamic control resulted in similar performance with the Strategy 1 for low diversion volumes, but it significantly improved the travel times and other MOEs for the high diversion scenarios (about 30 percent decrease in travel time.) This was largely achieved by employing a higher cycle length and adjusting green times to avoid congestion at the critical intersections. Most of the benefits were obtained on those segments of the arterial with short spacing and intersections operating close to saturation.

The speeds of the diverted vehicles shown in Figure 4.7 were much higher under semi-dynamic control than in Strategy 1. Also, the speeds were similar under a range of diversion volumes. These results indicate that semi-dynamic control can handle the diversion of a higher number of vehicles without significant impacts to their travel times.

Figures 4.6 and 4.7 also show that the alternative plans produced very similar results for both the entire network and the diverted traffic (about 5 percent difference in stops and delay.) This is largely because the signal optimization for minimum delay and stops does automatically take into account the traffic volumes. By explicitly considering the volume of the diverted traffic in the plan development, the diversion route automatically receives higher priority over the rest of the system. The added weighting in the route priority settings could not result in significant changes in the MOEs given the constraints in optimization (e.g., minimum duration of cross-street phases.)

The final strategy tested was real-time control in the form of a SCOOT-type system as described in Chapter 2. Exploratory analysis of this control system indicated that benefits of about 10 percent would be achieved for the total system. Most of the benefits are largely due to better accommodating the fluctuations in traffic volumes. The effectiveness of this strategy varied across the various segments of the test arterial. Most of the improvements occurred at the critical intersections. The benefits were minimal on those segments with undersaturated signals and long intersection spacing. The improvements for the diverted vehicles were generally small compared to semi-dynamic control largely because of the constraints in the optimization as discussed previously.

FIGURE 4.6 IMPACTS OF DIVERTED TRAFFIC ON TOTAL SYSTEM--SEMI-DYNAMIC CONTROL

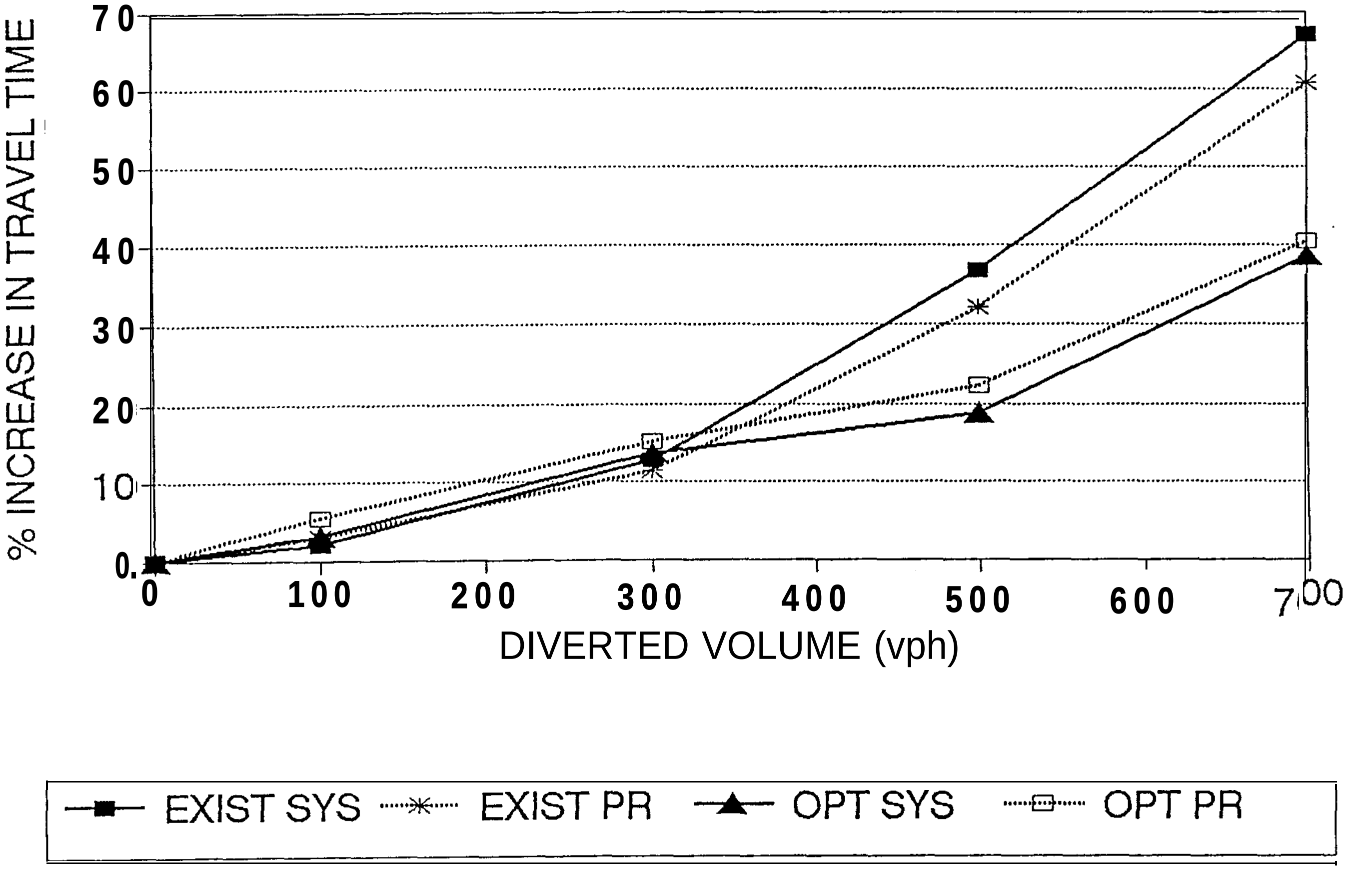
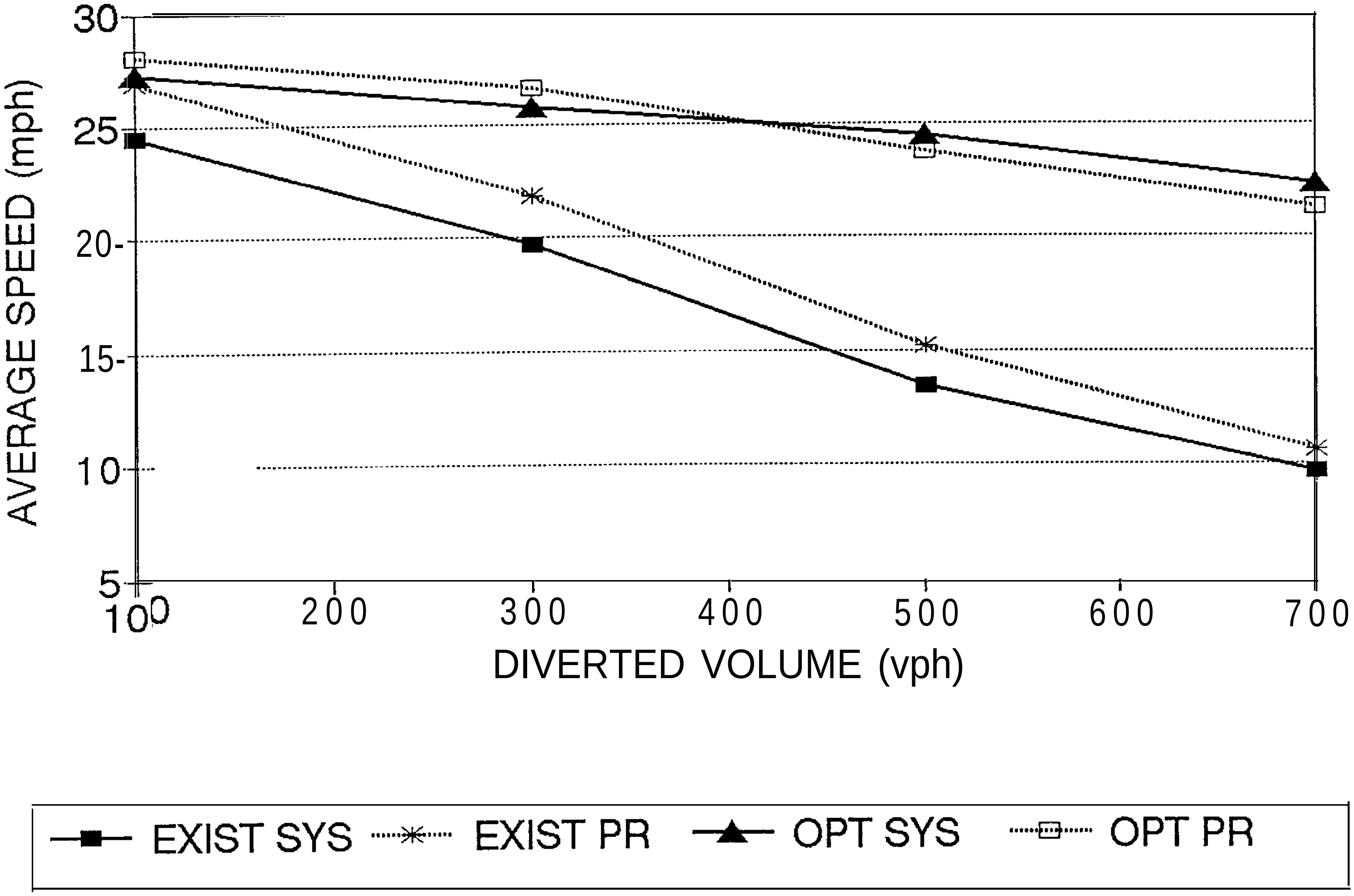


FIGURE 4.7 SPEED OF DIVERTED TRAFFIC SEMI-DYNAMIC CONTROL



4.2 **The Silverlake Network**

The same control and timing strategies were applied to the second test site. First, optimal timing plans were developed for the network with the existing traffic patterns to minimize the total system delay/stops (base case), and to favor the diversion route. The alternative plans produced very similar results; the route priority settings resulted in marginal improvements for the diversion route. Next, the impacts of the diversion volumes were assessed.

Figure 4.8 shows the impacts to the total network under each control strategy for comparing two diversion scenarios to the base case. Low diversion corresponds to about 10 percent volume increase, and high diversion corresponds to 30 percent volume increase along the diversion route. The low diversion did not result in significant systemwide impacts. The large diversion volumes, however, significantly worsened the travel times and delay under fixed-time control, similar to the San Pablo Ave test site. Semi-dynamic control improved the traffic performance by about a 17 percent reduction in delay compared to fixed-time control. Again, the two options for generating timing plans produced similar results. On-line control further improved the total system performance by about 8 percent in delay and 4 percent in travel time.

Figure 4.9 show the impacts of the control strategies on the diverted vehicles for the high diversion scenario. Under the existing timings, the average speeds are only about 13 mph, with 25 percent of the vehicles stopping at one or more intersections along their route. Both timing plans under semi-dynamic control improved travel speeds significantly. Stops were also dropped by about 3 to 5 percent. Real-time control resulted in modest improvements in the MOEs (about 6 percent increase in speeds and 3 percent reduction in stops compared to semi-dynamic control).

4.3 Discussion

It was assumed that the travel patterns on both the network and diversion route remain constant. However, the interactions of the local traffic with the diverted vehicles and the changes in travel times would alter the traffic patterns and/or routes. This might have a positive impact by reducing the traffic volumes on the heavily travelled paths. However, the assignment of traffic is also influenced by the signal control strategy in operation and instabilities could be created because of frequent changes in the timing plans.

The alternative signal control and timing strategies tested in this study were developed subject to maintaining acceptable traffic operations on minor intersection approaches (e.g., cross-streets on arterials and entry links to the network.) This is to the extent possible that no oversaturated movements and excessive delays exist on those approaches. A number of adjustments had to be made to the TRANSYT generated timings to produce operationally acceptable plans. This requirement, however, affects the benefits which are likely to come from diversion. Travel time savings of diverted vehicles would be higher if short-term congestion was allowed on certain approaches on the cross-streets.

FIGURE 4.8 IMPACTS OF DIVERTED TRAFFIC
SILVERLAKE NETWORK--TOTAL SYSTEM

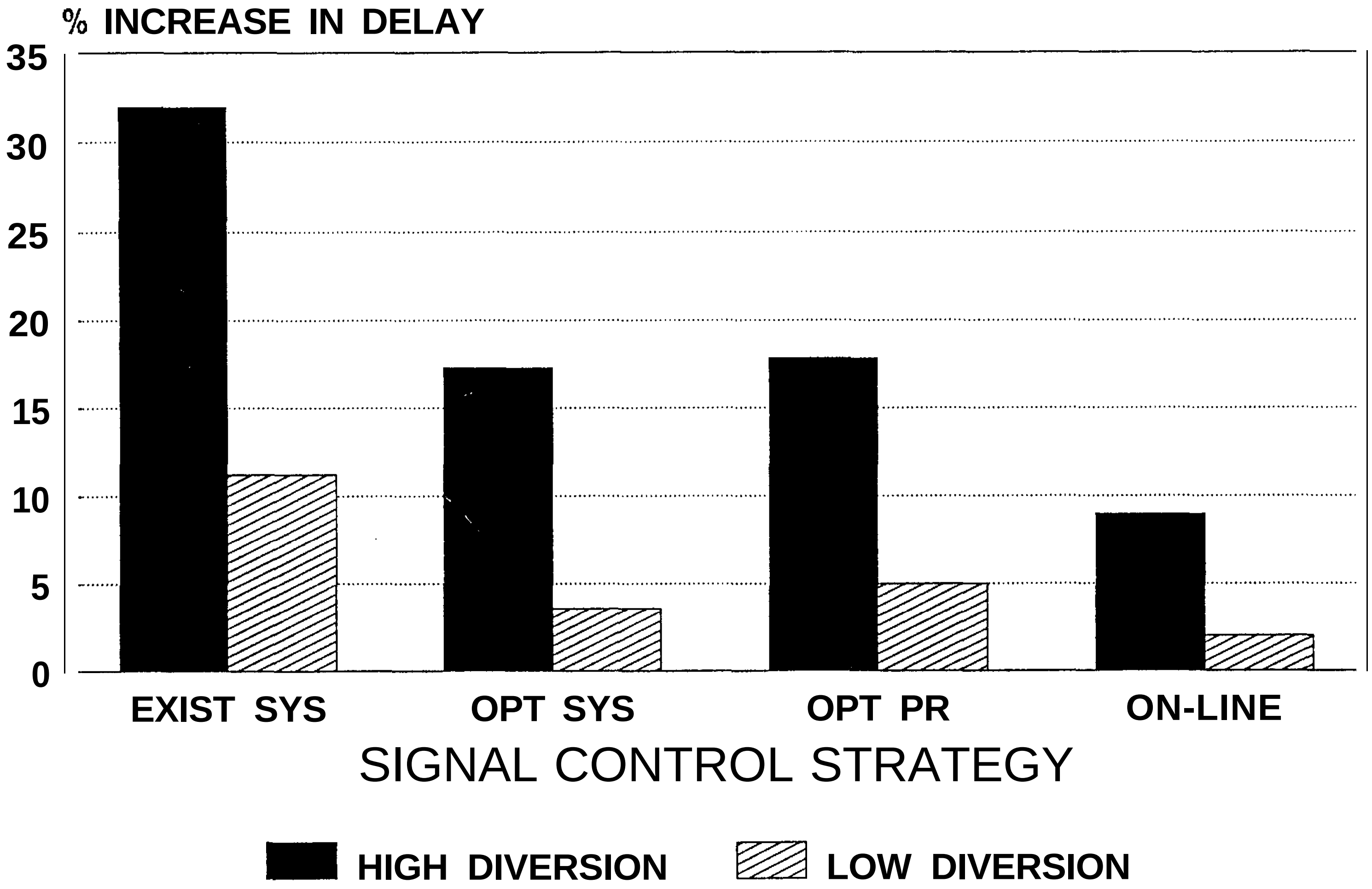
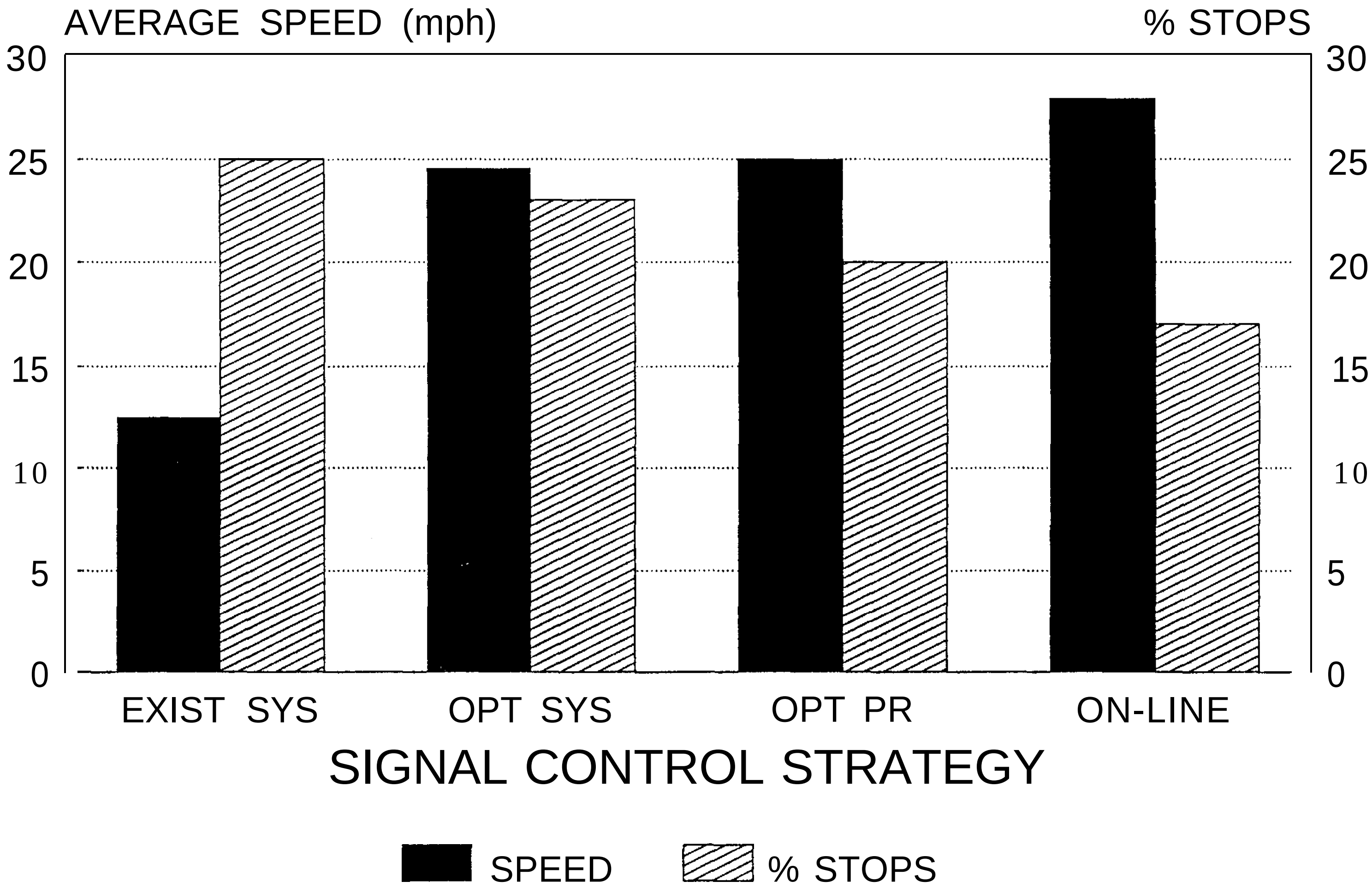


FIGURE 4.9 IMPACTS OF CONTROL STRATEGIES
SILVERLAKE NETWORK--DIVERTED TRAFFIC



CHAPTER 5

CONCLUSIONS

5.1 Summary of the Study Findings

The purpose of this work was to provide for a better understanding of the impacts of route guidance on surface streets, and suggest ways for traffic control considering re-routing. The following are the major findings for the study:

- Signal timing plans optimized to provide priority to diverted routes result in small additional benefits for diverted vehicles without significant impacts on the overall performance in the network, assuming that the diverted volume is small.

- Optimal timing plans developed without information on traffic volumes diverted to the network can only accommodate small additional volumes without significant adverse impacts to the local network. Route priority and capacity maximization signal settings could better handle the additional volumes and their fluctuations.

- Optimization and implementation of timing plans to match the diverted volumes (semi-dynamic control) significantly improved the traffic performance for the total network and diverted traffic on both test sites. The benefits were larger for the arterial than for the grid network.

- On-line control strategies had the best overall performance of all the strategies tested. The largest benefits were achieved for local traffic at critical intersections of the network. The benefits to diverted traffic were small compared to the semi-dynamic control.

5.2 Future Research

This study provided a partial assessment of the impacts from route information and guidance; namely the impacts of diverted traffic from freeways to the local street system, and ways of improving traffic performance in the event of rerouting. However, additional research and improved modeling techniques are needed for a clear understanding of the advantages and limitations of ATIS and ATMS systems for a wide range of conditions. The following ideas emerged from this study as suggested topics for future research:

> **a) Objective functions in traffic signal optimization:** Existing techniques optimize the timing plans to minimize the overall delays and stops in the system. The results from this study showed that alternative optimization criteria could improve traffic performance and better handle additional traffic. However, the application of these criteria is an iterative process involving multiple computer runs. There is

a need to reformulate the objective functions in the optimization models to directly account for network/route optimization. Another approach is to develop optimal timings by explicitly considering the origin and destination (O-D) patterns in a network. Limited results from a European DRIVE project and operational evidence from the UTOPIA traffic control system in Italy have shown significant benefits. However, the benefits strongly depend on the accuracy of the estimated O-D volumes.

b) Flow metering strategies on surface streets: One of the constraints in developing timing strategies in the study was to maintain an acceptable level of operation at each intersection approach. Restricting the entrance of vehicles from minor streets is a promising strategy for providing additional capacity to the specific routes of the network but it has not been systematically evaluated. The analysis and evaluation of such an approach would require, however, improved techniques for network optimization and assignment.

c) On-line control strategies for surface street networks: The results from this study and findings from other studies overseas indicate that on-line control strategies hold the highest potential for managing congestion and maintaining efficient traffic operations. However, currently there are no control systems in the US operating in real-time control. There is a need for additional research and demonstration projects on real-time control, especially with the SCOOT/SCATS type systems which appear to be the most promising strategy. Several issues need to be addressed in these studies including the interface of traffic control with ramp metering strategies, arterial coordination, and high speed multilane intersection approaches.

d) Incidents *on* surface streets: No incidents were modelled in the test networks throughout the evaluation of alternative strategies. However, incidents frequently occur in signal controlled networks which create adverse impacts on traffic performance and degrade the effectiveness of the traffic control strategies. Research is underway to develop procedures for automatic incident detection and approaches for traffic control under incident conditions. Additional research should model the frequency and severity of incidents considering the re-routing of vehicles for a better assessment of the impacts of route information and guidance systems.

e) Interaction of ATIS and ATMS systems: Additional research is needed on the interaction of ATMS and ATIS systems, to develop improved models for combined signal control and traffic assignment using the information from both the surveillance functions of the ATMS systems and the data from vehicles equipped with ATIS. Several issues must be investigated including user vs. system optimum routing, instability in the network because of the frequent changes in control, and data requirements.

f) Data requirements for ATIS: In networks which are not part of an ATMS system, existing data are often sparse. They have also been collected at different time periods. In addition, data from ATMS may not be entirely compatible for the purposes of providing real-time information to motorists. Information on real-time incidents and other changes in traffic patterns also comes from different sources and it is difficult to verify. Furthermore, its influence on other parts of the network cannot be easily determined. Such information, however, could be easily provided by vehicles equipped with ATIS systems. Additional research is needed to determine the number of instrumented vehicles required for getting real-time information with reasonable accuracy. It is also needed to test the findings against computer simulation and field data, and develop relationships between the number of instrumented vehicles and the network configuration, traffic patterns, level of congestion, and traffic control system sophistication.

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