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16. Abstract

This project suggests guidelines and procedures to identify when adjacent signalized intersections should be interconnected. Field data from several Texas cities were used to calibrate the TRANSYT-7F and PASSER II computer programs. These programs were used to address the effects of progression changes in travel time and travel volume. Detailed field studies were performed at six (6) intersections under isolated-actuated, fixed-time coordinated and traffic responsive operations on NASA 1 Road in front of the LBJ NASA Space Center, Houston, Texas.

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WARRANTS FOR INTERCONNECTION OF ISOLATED TRAFFIC SIGNALS

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
in²	square inches	6.5	square centimeters	cm²
ft²	square feet	0.09	square meters	m²
yd²	square yards	0.8	square meters	m²
mi²	square miles	2.6	square kilometers	km²
	acres	0.4	hectares	ha
MASS (weight)				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
VOLUME				
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft³	cubic feet	0.03	cubic meters	m³
yd³	cubic yards	0.76	cubic meters	m³
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
AREA				
cm²	square centimeters	0.16	square inches	in²
m²	square meters	1.2	square yards	yd²
km²	square kilometers	0.4	square miles	mi²
ha	hectares (10,000 m²)	2.5	acres	
MASS (weight)				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m³	cubic meters	35	cubic feet	ft³
m³	cubic meters	1.3	cubic yards	yd³
TEMPERATURE (exact)				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

°F -40   0   32   40   80   98.6   120   160   200   212 °F
°C -40 -20   0   20   37   40   60   80   100 °C

ABSTRACT

This project suggests guidelines, and procedures to identify when adjacent signalized intersections should be interconnected. Field data from several Texas cities were used to calibrate the TRANSYT-7F and PASSER II computer programs. These programs were used to address the effects of progression on changes in travel time and travel volume. Detailed field studies were performed at six (6) intersections under isolated-actuated, fixed-time coordinated and traffic responsive operations on NASA 1 Road in front of the LBJ NASA Space Center, Houston, Texas.

KEY WORDS: Arterial Street, Signalization, Progression, Interconnection, Isolated, Warrants

SUMMARY

Traffic congestion along urban arterials, collector streets and at signalized intersections in Texas are making the efficient operation and utilization of these facilities an important consideration for improving traffic flow and reducing vehicular delay. Significant reduction in congestion may be realized by interconnecting individually isolated intersections into a coordinated signal system, or by adding an adjacent signal into an existing coordinated system.

Existing analytical methods and computer programs offer capabilities for optimizing the traffic signal coordination of a series of signalized intersections. However, the proper procedures for providing methods to analyze the effects from coordinating isolated intersections are lacking. Since the decision of interconnection can be significant within the total signalized operation, it needs to develop warrants, guidelines and simplified procedures to identify where to implement interconnection of signalized intersections.

Recently, transportation research has been directed toward the development of short range, low capital improvement alternatives for the safe, efficient and convenient movement of people and goods. The criteria used to measure these improvement alternatives include travel time, energy consumption, delay and quality of traffic flow. Simplified procedures were developed to permit the transportation engineer to expeditiously evaluate the need to interconnect signalized intersections based on both simulation and field studies.

IMPLEMENTATION

This report provides development material for warrants for interconnection of isolated traffic signals by using both simulation and field validation studies. This study provides a simple procedure for analyzing whether interconnection of an isolated signalized intersection is necessary with respect to the increasing traffic volume in most urban areas of Texas. Guidelines and evaluation procedures were developed to identify conditions where interconnection consideration will be beneficial. These methods can assist in designing beneficial signal interconnection and provide better utilization of both the street system and the fiscal resources for highway operations.

DISCLAIMER

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INTRODUCTION

STUDY BACKGROUND

Traffic congestion in the form of inefficient operation and utilization of urban arterials, collector streets and signalized intersections in Texas is providing the impetus for improving traffic flow and reducing vehicular delay. Significant reduction in congestion may be realized by interconnecting individually isolated intersections into a coordinated signal system, or by adding an adjacent signal to an existing coordinated system.

Existing analytical methods and computer programs offer capabilities for optimizing the traffic signal coordination of a series of signalized intersections. However, the proper procedures and methods for analyzing the effects from coordinating isolated intersections are lacking. Since the cost of interconnection can be significant as compared with the total signalization cost, there is a need to develop warrants, guidelines and simplified procedures to identify where to implement interconnection of signalized intersection.

Recently, transportation research has been directed toward the development of short range, low capital improvement alternatives for the safe, efficient and convenient movement of people, and goods. The criteria used to measure these improvement alternatives include travel time, energy consumption, delay and quality of traffic flow. Simplified procedures were developed to permit the transportation engineer to expeditiously evaluate the need to interconnect signalized intersections based on both simulation and field studies.

STUDY OBJECTIVES

The overall objective of this study is to develop warrants, guidelines, and procedures to identify where interconnection of signalized intersections should be implemented. An effort was made to evaluate interconnecting isolated traffic signals into a progression system to provide interconnected signal operations. Specific objectives for the study are as follows:

1. Identify factors which influence interconnection feasibility of isolated signalized intersections.

2. Evaluate effectiveness of interconnection versus isolated control, and isolated control versus interconnection with progression phasing.

3. Develop guidelines to identify where interconnection of a series of signalized intersections into a progression system should be implemented.

4. Develop a simple, easy to use evaluation procedure to evaluate the need for signal interconnection.

1
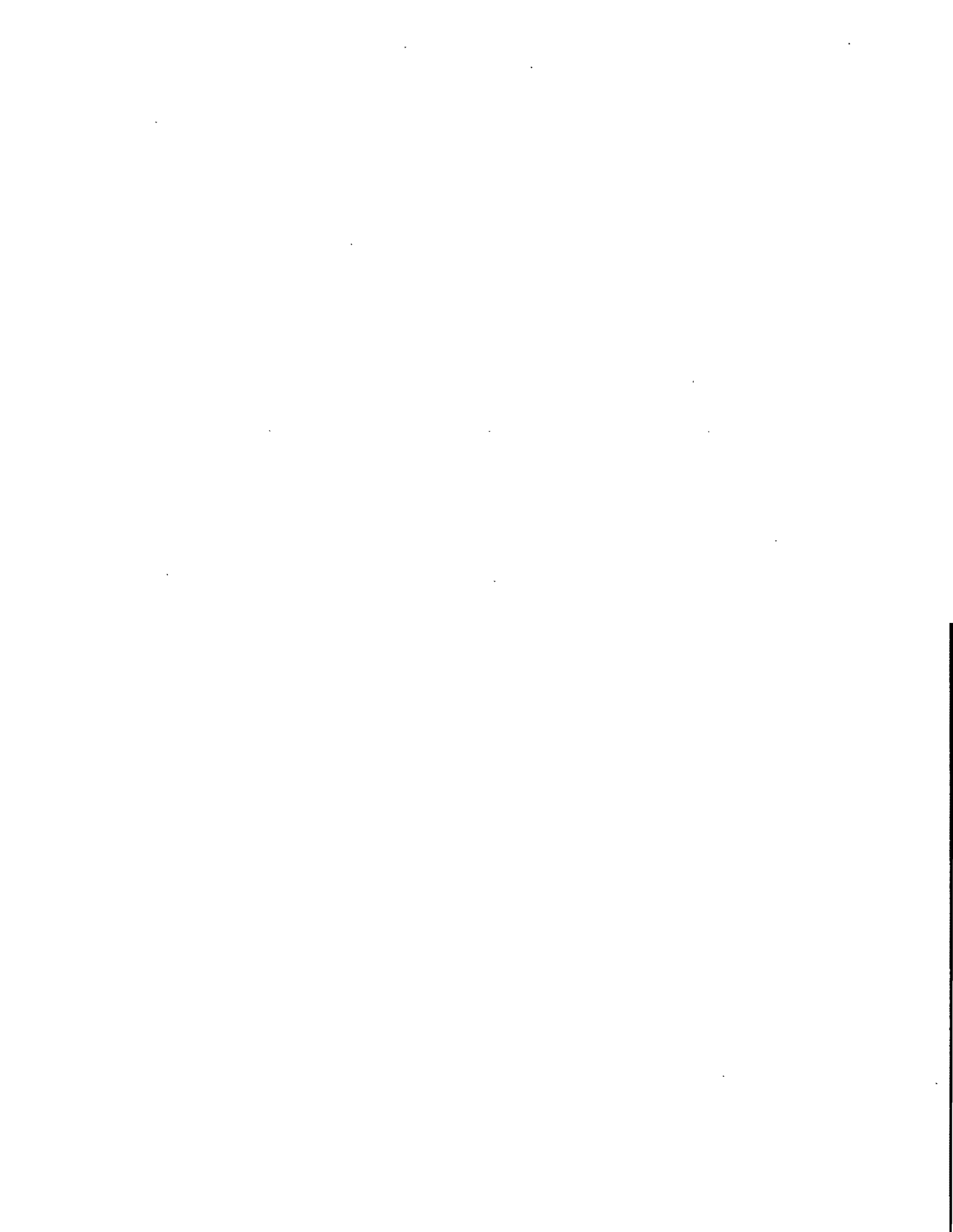
LITERATURE REVIEW

Modernizing traffic signal control as a means of reducing vehicle delay and fuel consumption has been emphasized by readjusting signal timing plans, installing modern control equipment, and providing interconnection (1). Wagner (2) found that "it is fuel efficient if traffic can be kept moving (without stopping). Lost fuel by stopped vehicles may be reduced with more efficient traffic control systems, especially during the off-peak periods when the number of stops and overall delay may be improved through traffic control improvements". Suhbier and Byrne (3) determined that for the arterial street system one half of the vehicular fuel usage was caused by traffic delay at intersections. Since arterial travel is a large portion of the areawide travel and since arterial traffic control can be effective throughout the day, arterial traffic control improvements will decrease fuel consumption during all time periods.

Even though fewer publications exist on when to interconnect a series of isolated signalized intersection, interconnection has been recognized as a viable traffic control improvement alternative. Wagner (4) studied data on the traffic performance improvements possible by four types of traffic control system betterments - interconnection of traffic signals, optimization of traffic signal timing, improved centralized master control of signalized intersections and freeway surveillance and control. He found that the typical improvement in **average travel time** was as follows:

Traffic Control Improvement	Travel Time Savings
Interconnection and optimization of signals	25%
Signal Timing optimization	17%
Advanced master control system improvements	15%
Freeway surveillance and control	20%

The coordination of adjacent signals primarily reduces the overall travel time, stops and delays, and secondarily decreases the fuel consumption and air pollution emissions. Wagner found that "the most dramatic improvements in traffic performance on signalized arterials and networks are those resulting from the combined action of interconnecting previously uncoordinated pretimed signals with a master controller, together with the introduction of new optimized timing plans." His data showed that "simply retiming signals that were already interconnected without any hardware changes averaged a 12 percent improvement in speed or travel time."

The degree of improvement produced by signal timing optimization depends on the quality of the pre-existing signal timing plan, the geometric constraints of the arterial street and the traffic characteristics. Thus, the level of improvement is dependent on the quality of the existing system. Wagner also found that signal timing reoptimization was the most cost effective of any enhancement action. In addition, signal interconnection and optimization were found to be cost effective for most situations.

A number of attempts have been made to define the factors which make coordination effective and necessary. Several studies conducted by Yagoda, Whitson, White, Messer and others (5,6,7) developed an "Interconnection Coupling Index", I, which was the simple ratio of link volume and link length, as shown below:

$$I = \frac{V}{L} \tag{1}$$

where:

I - Coupling Index,
V - Approach Link Volume (VPH),
L - Link Length to Next Signal (Feet).

By computing this index for each link in the potential system a measure of the need for coupling of the signal is determined.

Pinnell discussed isolated versus interconnected control in the Traffic Control Systems Handbook (7). He stated that "any two or more signals which are less than one-half mile apart or within a cycle length (which may be more than one-half on a high speed approach) should be coordinated." He has also identified various factors that affect arterial street signal control. These are as follows:

o Distance between signalized intersections,
o One-way versus two-way street operations,
o Signal phasings,
o Arrival characteristics, and
o Traffic fluctuations with time.

He found, in general, that a number of factors need to be considered in determining the need for interconnection (8,9,10,11,12,13,14):

o **Geographic relationships** - Distance between intersections. Intersections to be interconnected should be adjacent to each other without being affected by natural and artificial boundaries, such as rivers and controlled-access facilities.

o **Volume levels** - A larger link volume usually implies a greater need for coordination between adjacent traffic signals.

o **Traffic flow characteristics** - If traffic arrivals are uniform throughout the cycle, the red phase of the cycle will produce the same delays and stops as the green phase. On the other hand, controlled flow in platoons enhances the signal coordination benefits with the extra consideration of platoon dispersion as related to the travel time and platoon size under varying signal progression quality.

This report presents a model designed to be used in the coordinated traffic signal design and then, in the operation stage, to provide guidelines and procedures to evaluate the feasibility of interconnecting isolated traffic signals (8,9,10).

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MODEL DEVELOPMENT

Intersections should be interconnected only if the arrival flow rates downstream can be guided into compact platoons through effective traffic signal timing. Fluctuation in arrival rates is influenced primarily by the following factors to bring flow rates to a uniform level over time.

(1) the degree of volume variation at the upstream intersection, and

(2) the amount of platoon dispersion occurring between intersections.

Volume Considerations

Interconnection of a system of signalized intersections is beneficial only when platooning of vehicles result in most operational periods. However, due to the different green time used in each traffic signal of the progression system, the amount of stops and amount of delay canbe affected by the coordinated offsets under normally fluctuated arrival conditions. Several conditions may result in the uniform arrival of vehicles at an intersection:

1. An intersection isolated by <u>distance</u> relative to the upstream signalized intersection.

2. Consequential volumes of traffic entering at <u>mid-block</u>; and

3. Significant <u>truck</u> movement between intersections.

Thus, the desirable condition for interconnection is the imbalance in volume level entering at the upstream intersection. In addition, significant traffic entering at mid-block or a large truck traffic between intersections will force arriving flows to slow down such that interconnection can not eliminate the traffic congestion problems.

Consider the typical link flow pattern between two (2) adjacent intersections as illustrated in Figure 1. The entry volume for the downstream intersection (link 3) consists of the right-turn (Link 2), through (Link 1) and left turn volume (Link 4) from the upstream intersection. The degree of flow imbalance at the upstream intersection is represented by the ratio between the maximum link traffic volume feeding from the upstream intersection and the sum of all the link traffic volume arriving at the upstream intersection. It can be stated as Equation (2).

The degree of flow imbalance at intersection (i) is indicated by the ratio:

$$\text{Imbalance} = \frac{q^{max}}{\dfrac{q_1 + q_2 + q_3 + \ldots + q_x}{x}} \tag{2}$$

restating:

$$\text{Imbalance} = \frac{q_{max}}{\bar{q}} \tag{3}$$

4

ENTRY FLOW FOR
A TYPICAL LINK
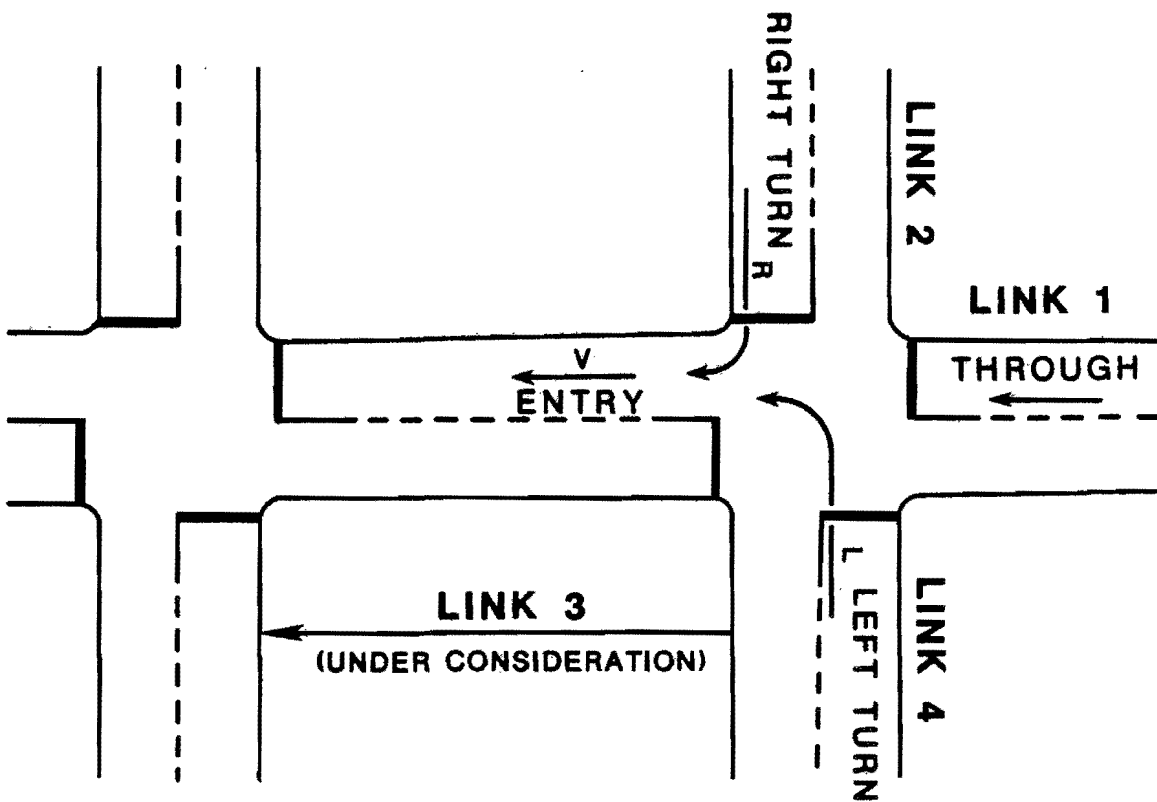
Figure 1. Entry Flow For A Typical Link.

where:

q_x - the flow rate for any movement x, (VPH)
q_{max} - usually the through movement flow rate, (VPH)
$\bar{q}$ - the average flow rate entering a link, (VPH)

The entering flow on the downstream intersection is influenced by the arriving flow over time. The Imbalance Index, as calculated from the maximum link flow divided by the average upstream link flow, is an index representing the fluctuation of traffic volume along a downstream link. It varies as:

$$1 \leq \frac{q_{max}}{\bar{q}} \leq q_x \qquad (4)$$

When this factor is 1, uniform flow exists. That is, cross street, mid-block and turning traffic at an upstream intersection (i-1) is approximately equal to the major entering flow. Interconnection of the upstream (i-1) and downstream (i) signalized intersections in this case is not desirable. However, when the imbalance factor approaches "X" or the total number of approach lanes, the effect of the flow rate is at its maximum on the downstream intersection. This heavy imbalance condition will create the most desirable situation for progression. The existence of imbalance can describe the relationships between flow rates and platoon formation. However, this equation (4) has not yet considered the effects of platoon dispersion nor platoon compression.

Platoon Dispersion

Platoon dispersion results from the drivers adjusting the relative distance between their vehicles and adjacent leading and trailing vehicles. The dispersion of a platoon of vehicles leaving a signalized intersection has been described by the previous research of Nemeth and Vecellio and the North Dallas Corridor study. They approximated dispersion rate in terms of percent change of platoon length by the following model (7,8):

$$\text{Rate of Dispersion, } D = \frac{L + \Delta L}{L*(1+t)} \qquad (5)$$

where:

L - Length of the standing platoon (seconds),
ΔL - Change in length over distance and time (seconds),
t - Average travel time (seconds).

The change in platoon length related to the time and distance travelled can be expressed by simplifying Equation (5) into Equation (6). This relationship can be further illustrated in Figure 2.

6

Distance Traveled

L

L + L

t_0 t_1

Average Speed $\overline{V}$
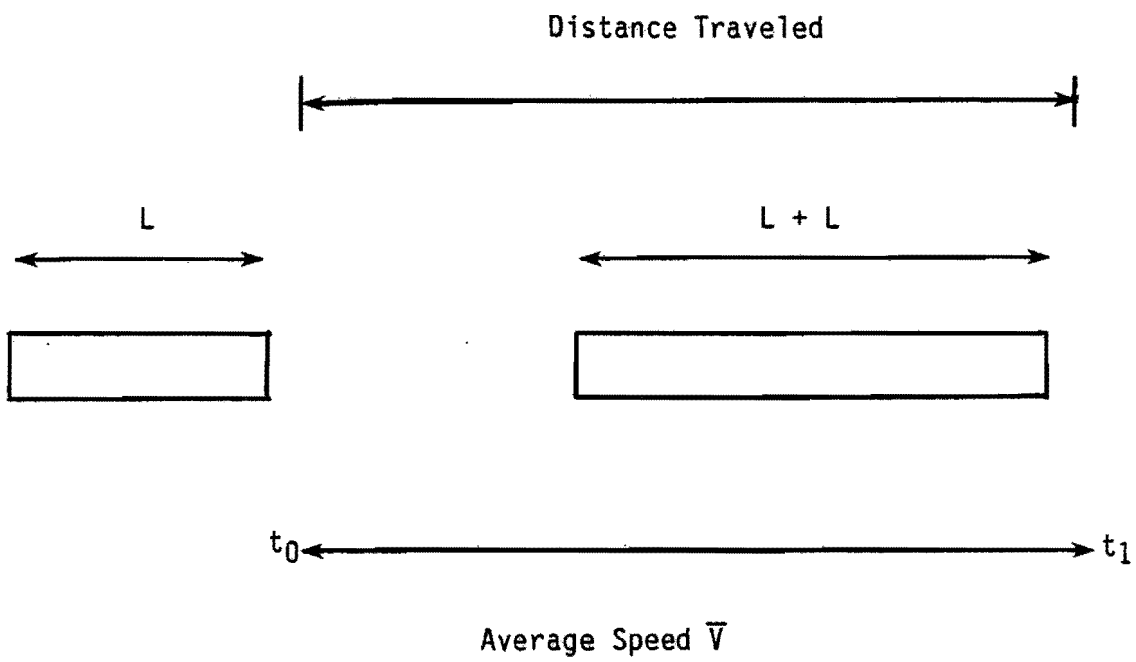
Figure 2.   Platoon Dispersion of a Progression Platoon.

$$D = \frac{1}{1 + t} \tag{6}$$

where:

D - Rate of dispersion.
t - Average travel time (seconds).

Interconnection Model

By combining the previous volume and platoon dispersion concepts, a combined Interconnection Desirability Index (I) can describe both the characteristics of platoon dispersion and traffic signal system as:

$$I = \frac{X * q_{max}}{q1 + q2 + q3 + \ldots qx} - \left[(N-2) * \frac{1}{1 + t} \right] \tag{7}$$

where:

I - Interconnection Desirability Index;
t - Link travel time, link length divided by average speed, (Minutes);
X - Number of departure lanes from upstream intersection;
q_{max} - Straight through flow from upstream intersection, (VPH);
q1, q2,..,qx - Traffic flow arriving at the downstream approach from the right-turn, left-turn and through movements of upstream traffic signals, (VPH); and
N - Number of arrival lanes feeding into the entering link of downstream intersection.

It can be readily seen that equation (7) has a range from 0 to 2. Normalizing for a range from 0 to 1 and rearranging, Equation (7) can be obtained as:

$$I = \frac{0.5}{1 + t} * \left[\frac{q_{max}}{\bar{q}} - (N-2) \right] \tag{8}$$

where a value of "1" indicates the most desirable condition and "0" indicates the least desirable condition for interconnection. By further rearrangement of the above formulation, the Equation (8) can be simplified as Equation (9). Basically, this Interconnection Desirability Index (I) measures the coordination requirements of each one-way link of a potential isolated intersection by taking into account the volume imbalance condition and platoon dispersion effect in measuring the desirability for interconnection for that particular signalized intersection.

$$I = \frac{1}{1 + t} * \left[\frac{X * q_{max}}{q1 + q2 + q3} - (N-2) \right] \tag{9}$$

8

In other words, this approach measures the coordination requirements of each one-way link by incorporating the platoon dispersion effect through the use of an Interconnection Desirability Index (I). In Equation (9), a value of "1" indicates the most desirable condition for interconnection, and "0" indicates the least desirable condition. The scale shown in Figure 3 is suggested as a possible tool for applying signal interconnection in the traffic control strategy. As indicated, when the Interconnection Desirability Index has the value of 0.25 or less, isolated operation is recommended. On the other hand, when the Interconnection Desirability Index has a value of 0.50 or greater, interconnected system operation is recommended. Other evaluation indicators are needed to assist the interconnection decision if the Interconnection Desirability Index calculated falls between 0.25 and 0.50. The interconnection of traffic signals at a study intersection is warranted when the Index equals or exceed 0.35. The relative need for traffic signal interconnections at a number of possible locations could be indicated by the relative number of the Interconnection Desirability Index on both sides of the study intersection.

It should be noted that this approach considers the potential benefits as resulted from the interconnection of isolated intersection or intersections by measuring the combined effects of geographic relationships, traffic volume levels and the traffic flow characteristics. However, this formula does not hold for the case when straight through flow from the upstream intersection (q_{max}) is zero, yet turning flows are relatively high and the intersections are closely spaced, which interconnection may be desirable. Treating the heavy turning flows as "through" movements in the equation could solve the problem at this extreme case. Using this approach, an interconnection desirability index of one would indicate the most desirable condition for interconnection, and zero the least desirable. The scale shown below in Figure 3 could be suggested to be used as a tool for the delineation of signal control strategies.
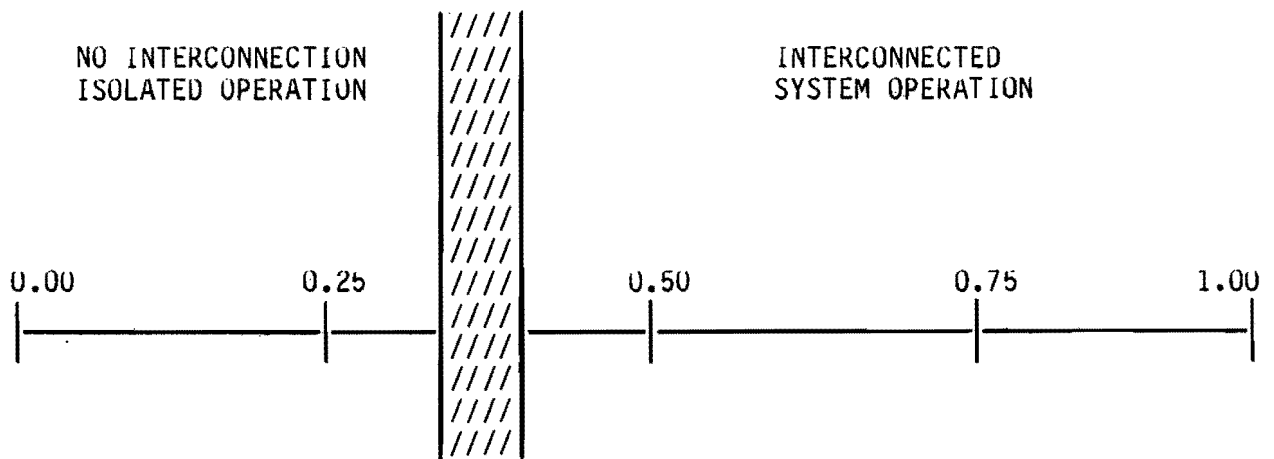
Figure 3. Interconnection Desirability Index.

STUDY PROCEDURE

This study designed the experimental simulation and field studies to develop guidelines for traffic signal interconnection. It was developed upon geographic relationships, volume levels and traffic flow characteristics. Simulation models were used as the theoretical test bed to investigate conditions which cannot easily be reproduced in the field. Then, the field data was collected on selected arterials to validate the simulation results.

SIMULATION STUDY

A detailed review of the literature was made and the most desirable factors and concepts were selected for consideration as elements for interconnection guidelines. Present technology suggests that intersection spacings, percentages of turning traffic and volume levels are candidate elements. A review of existing traffic models suggests that PASSER II, TRANSYT-7F and NETSIM can be used to determine traffic signal interconnected operations. Basically, PASSER II and TRANSYT-7F were used to optimize phase sequence and offsets for pretimed traffic signals under isolated versus interconnected operations. However, the simulation of existing isolated traffic control conditions could not be thoroughly evaluated by the first two models. The NETSIM model was also used to evaluate the coordinated operations of a series of isolated actuated traffic signals. It was further used as a base to analyze isolated versus interconnected actuated traffic control.

Alternative traffic control strategies under different geometric and traffic levels were devised to test the effectiveness of interconnection. The experimental simulation plan, as in Figure 4, was used to collect simulation data, establish numerical guidelines under different intersection spacings and left-turn percentages. Basically, PASSER II and TRANSYT-7F were used to optimize phase sequence and offsets for pretimed and traffic responsive signals under isolated versus interconnected operations. The PASSER II runs were made to provide the optimal settings of cycle length and proper phase sequence. The TRANSYT-7F runs primarily examined the detailed effects of intersection spacings and the percentages of left turning traffic both off and onto the arterial.

The major variables studied include:

1. Numbers of signal phases;
2. Preferred phase sequences or traffic movements;
3. Allowable cycle length ranges based on volume levels;
4. Volume distributions;
5. Speed variations;
6. Left turn movement percentages; and
7. Intersection spacings.

This meant a large number of simulation cases would be required if all the combinations of variables were to be used. Runs of the computer program were made for the range of factors identified to determine the sensitivity of model components. Operational scenarios were then devised to test the practical accuracy, sensitivity and applicability of the simulation model.

11

Prepare PASSER II Data Set   Graph,Table

3 Intersection. Fixed-Time Signal System
4 Intersection. Actuated Signal System

Total Intersection Volume Level
Approach Movement Volume Split

Edit PASSER II Data on WYLBUR & Mod.

PASSER II Runs (Modified PASSER II)

INPUT

2	Left-turn Percentages	5% & 10%
2	Signal Phase	2-phase and 4-phase
2	Preferred Movement	Left-turn & through 1st
3	Volume Level	Low, Medium & High Volume
3	Cycle Length	Vary with volume level
3	Speed Variation	29, 36 & 45 mph
60	Spacing Combination	3 x_1 spacing vs 20 x_2 spacing

OUTPUT -- Optimized CYCLE, PHASE. SEO, GREEN SPLIT & OFFSET
SUMMARY -- Totals 108 sets, 2160 cases, cost $1,080

Store PASSER II INPUT & OUTPUT onto UCC tape

Maintain Base Case & Scratch others on WYLBUR   Graph Table

NO

Finish PASSER II Runs

YES

Statistical Analysis System (SAS) Runs

Summarize & analyze performance MOE's of simulation
runs and plot variables
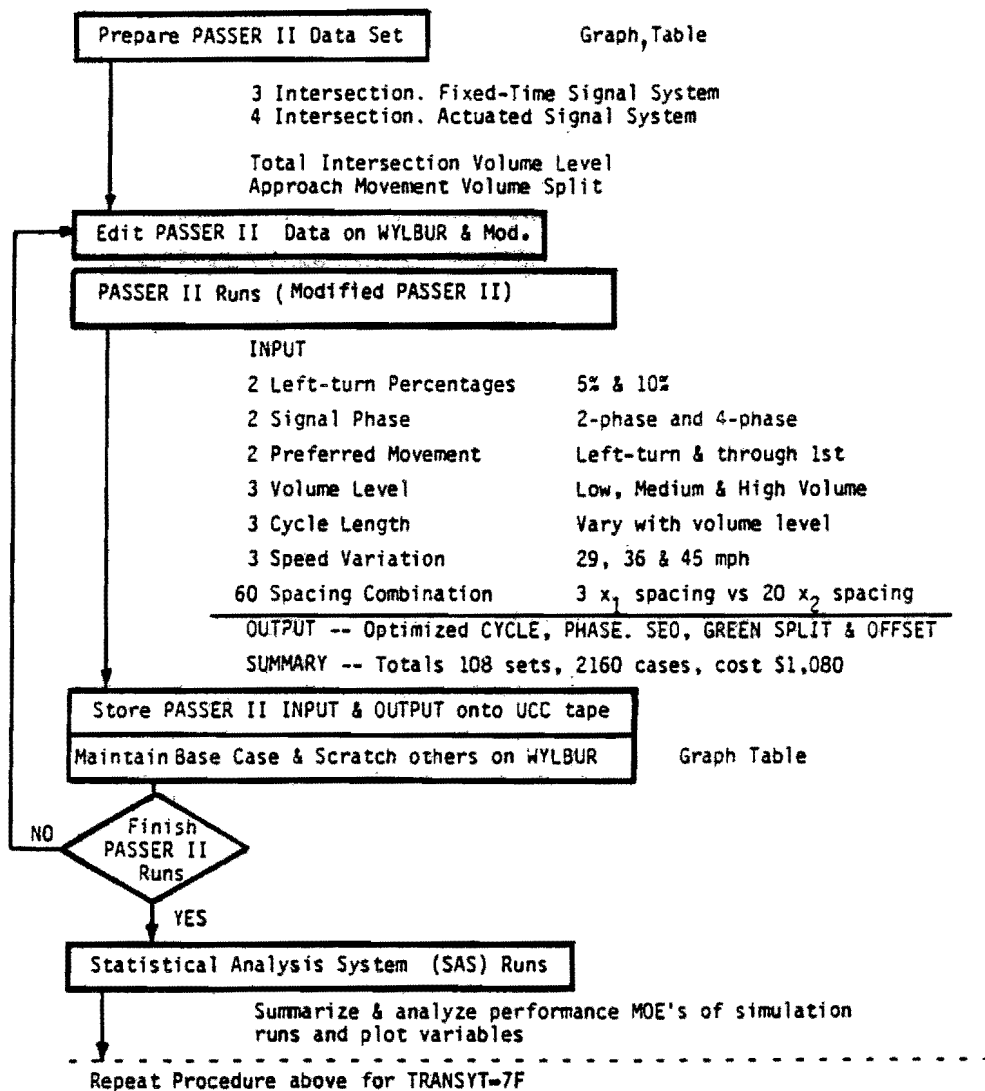
Repeat Procedure above for TRANSYT-7F

Figure 4. Experimental Simulation Design Plan.

The simulation study indicated that arterial link delay was influenced by traffic volume levels (and the resultant Webster minimum delay cycle length), intersection spacing, travel speed and left-turn movement percentages. Therefore, the detailed simulation design was made as illustrated in Figure 4. Most of all, the major impact of the interconnection versus isolated traffic signal operation was found to keep consistent arterial travel movements as well as the uniform platoon dispersion between the intersection in the total progression system.

A synthetic four-node arterial street, as shown in Figure 5, was used to obtain separate but compatible simulation results using both PASSER II-80 and TRANSYT-7F as test models and starting with 10% left-turn movement. In the simulation analysis, sets of PASSER II runs were first made to choose appropriate signal phase sequence and phase length for both two-phase and four-phase operations with respect to different intersection spacings. Then, TRANSYT-7F was used to simulate and optimize PASSER's **"Best Settings"** to provide a common Measure of Effectiveness (MOE) base for PASSER II and TRANSYT-7F comparisons.

Because of the amount of data reduction required, a version of the PASSER II program with simplified output was developed for direct data processing by the **Statistical Analysis System (SAS)** program packages. Performance MOE's, such as delay, stops and queue clearance, were analyzed under regular PASSER II runs, TRANSYT-7F simulated PASSER II "Best Setting" runs and TRANSYT-7F optimization runs. Figure 6 demonstrates an example of the performance measurement of average delay on one approach as compared with the spacing variations given that all other variables remain constant. The simulation results also indicated the wide variation of operational performance with respect to the spacings of progression systems. In addition, they also illustrated the results from different platoon dispersion models applied in both PASSER II and TRANSYT-7F models. However, they confirmed that the "Rule-of-Thumb" ideal cross street spacing for good arterial progression is between 1/4 mile (1320 ft or 440 m) and 1/3 mile (1760 ft or 580 m).

Traffic control scenarios were then devised to test the effectiveness of signal interconnection under different geometric and traffic levels. Guidelines under conditions of different intersection spacings and left-turn percentages were established. TRANSYT-7F was used primarily to examine the effects of intersection spacings and the percentages of left turning traffic both onto and off the arterial. Computer programs evaluated the needs for interconnection in these synthetic conditions.

Selected NETSIM runs, similar to the TRANSYT-7F runs, were conducted for investigating actuated arterial control on a four intersection arterial signal system. This was done principally to determine if actuated and pretimed control were affected similarly by intersection spacing and the percentage of turning traffic. An estimation was also made of the reliability of making recommendations interconnections based upon the simulation programs run under various factor levels. However, these simulation evaluations were made only on the selected case basis because of the complicated operation of the NETSIM simulation even for only one isolated, actuated signal operation during a fifteen-minute real-time simulation period.
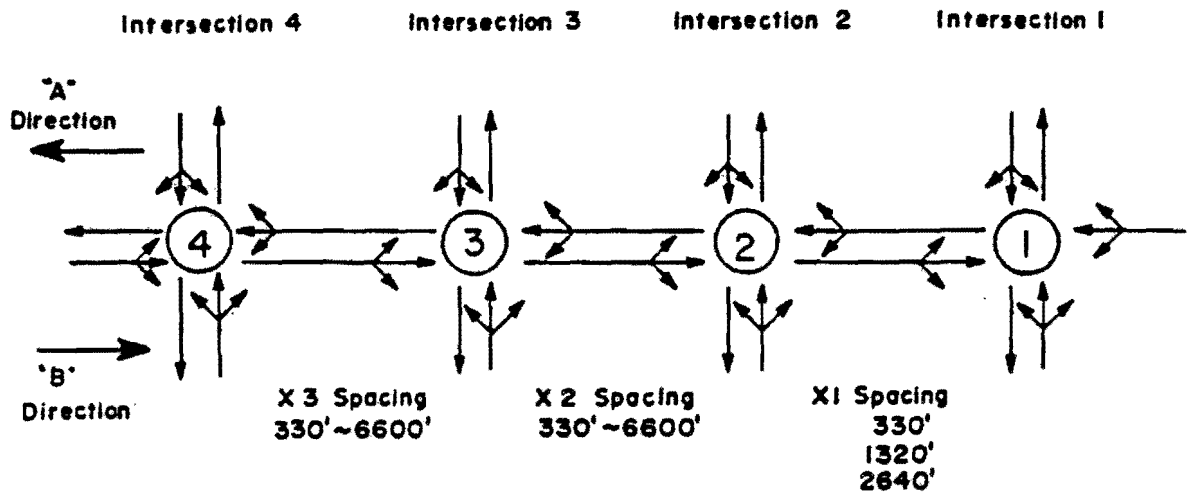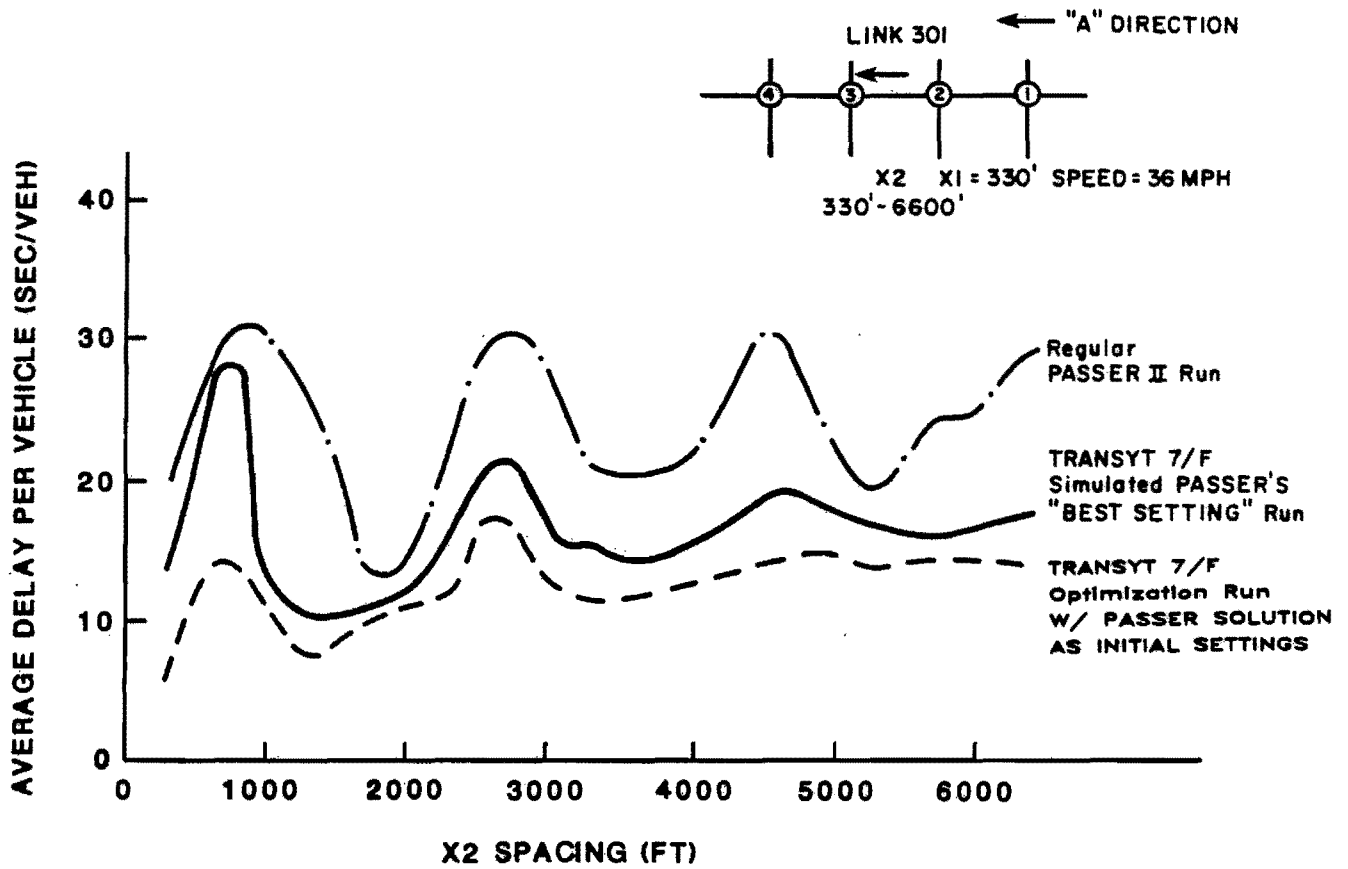
Figure 5.   Synthetic Four-Node Arterial Street.

Figure 6. Selected Link Performance MOE.

Note: PASSER II's Initial Timings and Phase Sequences were used in the TRANSYT-7F Optimization Run.

FIELD STUDY

Two field studies were performed through the travel time and delay study. The first field study was performed using vehicular travel time and delay study on Lamar Boulevard and U.S. 183 in Austin, Texas. Both are high-volume high-type facilities where the former, Lamar Boulevard, operates under low to medium speed and U.S. 183 has medium to high speed operations. Results of this study show good progression exists throughout the two systems regardless of the variance of spacing and saturated operation along two arterials. However, the field study did not provide enough validation of the simulation analysis because the left turn traffic volume percentage and the corresponding traffic volume were not properly identified.

Nevertheless, the travel time/delay study did indicate that a positive relationship did exist between the travel time delay caused by the interconnected signal operation and the travel time/background cycle length used. As indicated in Figures 7 and 8, the travel time delay was plotted against the distance traveled and the travel time/cycle length ratio for both signal system, respectively. These two figures suggest that travel time delay within the interconnected signal system gradually decreases from 0.4 to 0.6 of travel time to cycle length ratio and then increases as travel time increases. These two figures also indicate that the travel time/cycle length ratio can provide a better indicator than distance alone to represent the proper relationships among distance, travel speed, progression speed and traffic volume levels along the arterial street coordination system.

The second detailed field data collection effort was performed on one six-signalized intersection to collect data on signal timing, travel time, delay and queue data. The test network is SDHPT's NASA 1 Facts System, south of Houston illustrated in Figure 9. The cross streets are Kings Row, El Camino, Space Park, Nassua Bay, Point Lookout and Upperbay.

The Specific objectives of this field study were to:

1. Evaluate signal operations under isolated versus interconnected operation by using an offsets and delay study.

2. Calibrate a platoon dispersion (platoon projection) model for Texas driving behavior under both interconnected and isolated traffic operations.

3. Validate simulation study results for offset optimization calculations by: ·

   a. PASSER II-80 and PASSER II-84 programs,
   b. TRANSYT-7F program.

4. Evaluate the possibility of dropping over-saturated intersections from the progression system to provide a control strategy similar to the critical intersection control strategy.

5. Evaluate the signal system operation under Isolated Actuated versus Traffic Responsive Mode.
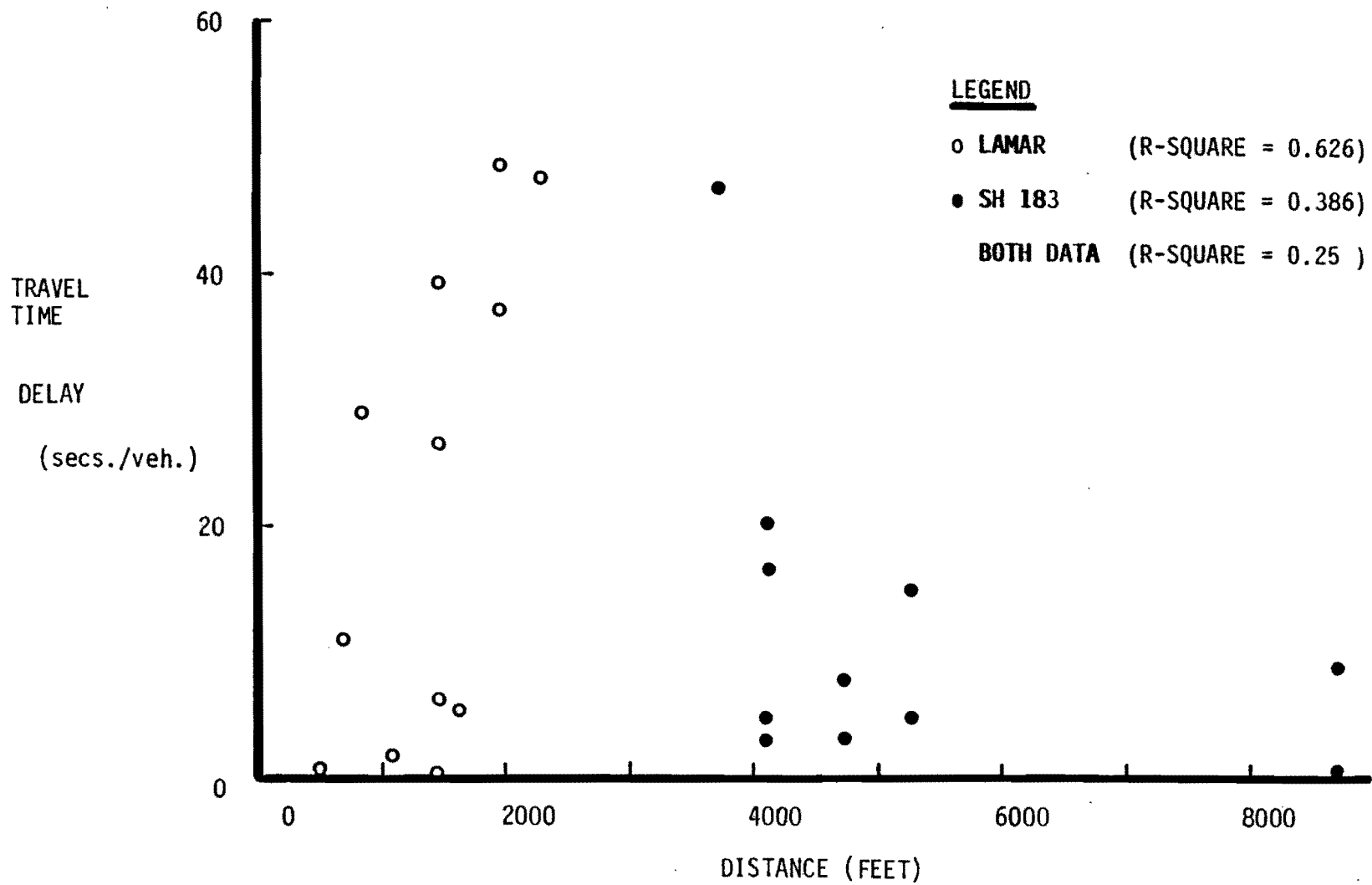
Figure 7. Travel Time versus Distance.

60

TRAVEL
TIME

40

DELAY

(secs./veh.)

20

0

0   0.5   1.0   1.5

LEGEND

o **LAMAR**   (R-SQUARE = 0.97)

● **SH 183**   (R-SQUARE = 0.394)

   BOTH DATA   (R-SQUARE = 0.465)

$$\frac{\text{TRAVEL TIME}}{\text{CYCLE TIME}} \quad \text{RATIO}$$
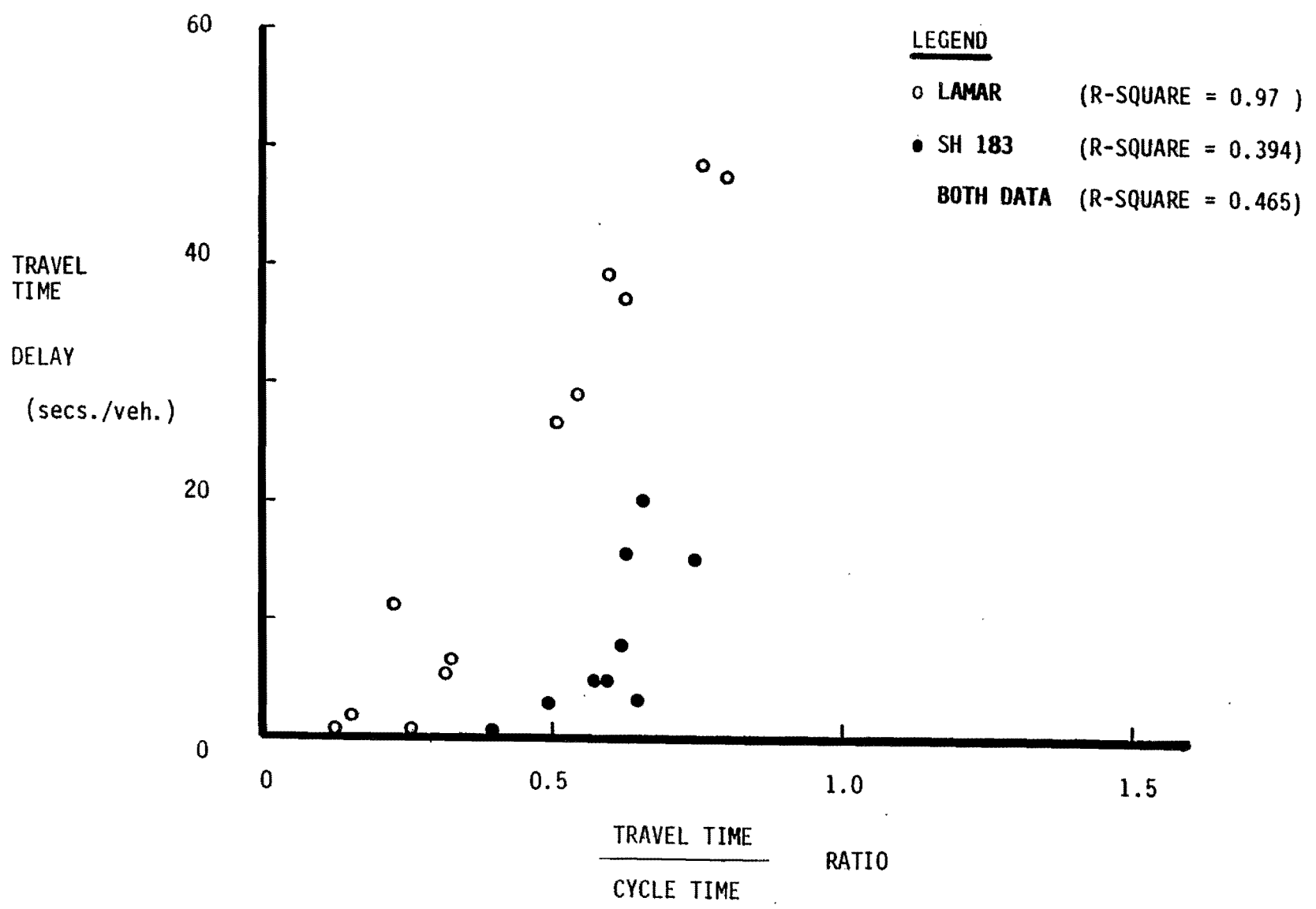
Figure 8.   Travel Time versus Cycle Time.

TEXAS SDPHT NASA 1 FACTS SYSTEM
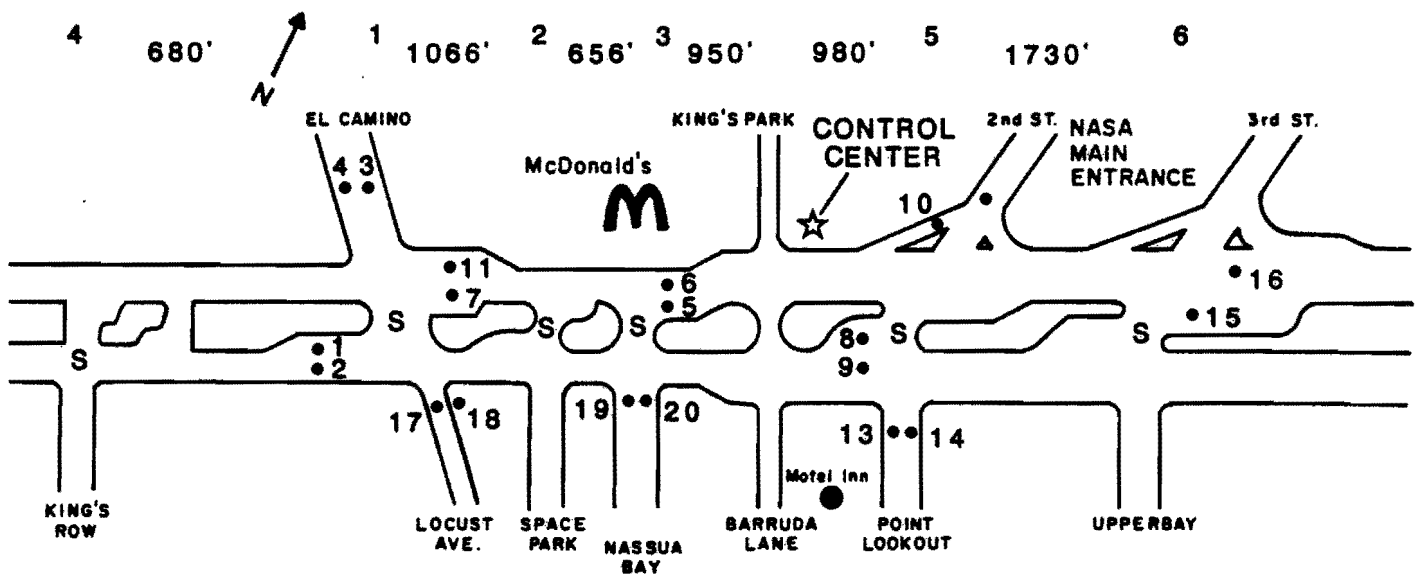
Note - 1. "*" indicates modified "T" intersection
       Westbound traffic has protected green.
    2. "S" indicates signalized intersection.
    3. "•" indicates the location of system detectors.

Figure 9. Texas SDHPT   NASA 1 FACTS System.

Data collected for the test arterial which were sufficient to calibrate and test the operational scenarios and factor levels used in the development of the guidelines for:

1. PASSER II runs;
2. TRANSYT-7F runs;
3. Selected NETSIM runs; and
4. Some selected MOE performance values.

The basic data types collected in this study include: arterial street, arterial link, cross street, intersection, and arterial MOE validation data. The detail items of the basic data types are summarized on the next page.

NASA 1, an arterial computerized traffic control system south of Houston, as shown in Figure 9 was selected to test and calibrate the computer models. The platoon dispersion model in TRANSYT-7F was calibrated to reflect good progression conditions using PASSER II as a front-end preprocessor to study under both isolated and interconnected operations.

Field data were collected on the NASA 1 System during the noon-rush and off-peak periods for use in the calibration of the combined PASSER II and TRANSYT-7F runs and validation of operational measures. Interconnected intersection studies were conducted on Tuesday, Wednesday and Thursday of one week followed by isolated intersection studies on the following week in May 1984. PASSER II optimized phasing was used at all intersections during both simulation and field studies. The detailed study plan is summarized as follows:

INTERCONNECTION STUDY

	Monday,	May 21	Travel to Houston	
1.	Tuesday,	May 22	PASSER II-80 OFFSET	(PII-80)
2.	Wednesday,	May 23	PASSER II-84 OFFSET	(PII-84)
3.	Thursday,	May 24	TRANSYT-7F OFFSET	(T-7F)
			Back to College Station	

ISOLATED STUDY

	Monday,	May 28	Travel to Houston	
1.	Tuesday,	May 29	TRAFFIC RESPONSIVE	(TR)
2.	Wednesday,	May 30	ISOLATED ACTUATED	(ISO)
3.	Thursday,	May 31	TR/DROP EL CAMINO REAL	(CIC)
			Back to College Station	

Arterial Street Data

1. Name of City
2. Name of Arterial
3. District Number
4. Date Data Collected
5. Number of Intersections
6. Operational Cycle Range
7. Minimum "B" Direction Band Split Requirement.

Arterial Link Data

1. Distance, "A" and "B" Directions
2. Average Speed, "A" and "B" Directions
3. Queue Clearance Interval, "A" and "B" Directions

Cross Street Data

1. Street Name
2. Intersection Number

Intersection Data

1. Street Name
2. Intersection Number
3. Number of Lanes for Each Approach
4. Width

   a. Through Lane
   b. Left Turn Lane
   c. Right Turn Lane

5. Presence of Turn Lane and Length of Turn Bay
6. Hourly Approach Traffic Volume (Through, Right Turn, Left Turn) By Time of Day (AM Peak, PM Peak, Off Peak)
7. Saturation Capacity from

   a. Items 3,4 and 5;
   b. Average Minimum Headway; or
   c. Nominal Values

8. Minimum Green Time Requirement for Each Movement
9. Existing Signal Phasing Pattern by Time of Day
10. Permissible Phase Sequences

Arterial MOE Validation Data

1. Floating Car Study
2. Average Queue Size
3. Queue Clearance Time

Field data were used to calibrate computer models and provide real world data in evaluating these models. They were then applied with field data to establish guidelines for interconnecting isolated traffic signals. These data were collected from the stop delay study, the travel time & delay study and the platoon dispersion study. The volume counts were collected with assistance from the D-19 personnel of Texas SDHPT using NASA 1 FACTS System sampling loop detectors. Selected queue counts and stop delay measurements were made at the same time by staff from the Texas Transportation Institute at each signalized intersection location. The platoon dispersion study was performed by using video recording equipment from the window of a hotel near the study site. The data were further reduced for later analysis.

Among these field study methods the stop-delay study was the most time-consuming and detailed activity. It involved the following procedure:

---

5 MINUTES BEFORE EACH STUDY STARTS

1. Set up at appropriate study location.
2. Identify information on the data sheet.

WHEN STARTING TIME ARRIVES

1. Count and record the number of vehicles stopped on the approach for every 15 second interval, counting separately left-turns and through movements.

2. Use a watch to advise proper time intervals.

3. Recount vehicles if they remain stopped during the next time interval.

4. Identify vehicles as "stopped" if they come to the first stop near the signal.

5. Keep counting in spite of any incidents, such as accidents, stalled vehicles, etc., but remark on the data sheet.

BREAK FOR 5 MINUTES EVERY 30 MINUTES AND SUMMARIZE "NUMBER STOPPED"

AM PEAK - THREE (3) 30 MINUTE INTERVALS
OFF PEAK - THREE (3) 30 MINUTE INTERVALS
PM PEAK - FOUR (4) 30 MINUTE INTERVALS

END OF EACH DAY

Summarize and return all data sheets.

STUDY RESULTS

By summarizing the simulation and field data, those factors and conditions that have effects on interconnection feasibility were identified. By combining the simulation and field study results, those elements and warrant conditions for determining where interconnection is an effective alternative were identified for both pretimed and actuated control under both two-phase and four-phase signal operations.

The field and simulation data were used along with guideline elements to determine where interconnection of a series of isolated signals is desired. The field and simulation data previously collected were used to verify the guidelines established. The results of this study provide a simple procedure for analyzing whether interconnection of isolated signalized intersection is necessary with respect to the increasing traffic volume in most urban areas. Guidelines and evaluation procedures were developed to identify conditions where interconnection consideration would be beneficial.

An effective procedure is provided to evaluate whether signal interconnection will be helpful in improving traffic operations through a group of isolated intersections. The guidelines and procedure developed here will assist in designing beneficial signal interconnection and provide better utilization of both the street system and the Department's fiscal resources for traffic operations. The simplified procedure for a traffic engineer to use in evaluating the need for interconnecting a series of isolated intersection developed will be illustrated in the later sections.

This section presents the study results of the simulation analysis and a summary of the field data collection effort devised to develop the effective interconnection warrants and arterial traffic signal control strategies. The major objective is to establish realistic and quantitative relationships among the study factors which have been found to have important influences on operational performance measurements and interconnection decisions. One measure related to the desirability for interconnecting isolated traffic signal is the estimated arterial link delay experienced by the motorists. The other factor used for detecting the potential benefits of traffic signal interconnection is the Interconnection Desirability Index as described in the previous section. The study findings are directed toward two separate discussions: the simulation study and field validation studies.

SIMULATION STUDY

In this study, the simulation model was used as a theoretical test bed to enumerate study conditions and scenarios which cannot be easily reproduced or easily controlled in the field. Emphasis was placed on investigating the generalized relationships among the study factors and their sensitivities with respect to the systemwide performance, especially, the resultant arterial link delay from the traffic signal interconnection. That is, this simulation study was mainly to establish linkage between the estimated arterial link delay and the proposed interconnection guidelines through the usage of test scenarios for reasonably accurate and reliable representation of the candidate application sites.

Three separate analyses were investigated: the interconnection index analysis, the combined PASSER II and TRANSYT-7F analysis and the interconnection warrant study. The first analysis studied the basic variation of the interconnection desirability index as a function of intersection spacings, progression system design speed, intersection volume levels and left turn traffic volume percentages. The second analysis collected estimated arterial street performance statistics by applying the combined approach of PASSER II and TRANSYT-7F programs. The last simulation study presents the relationships between the proposed interconnection guidelines developed and the estimated average delay per vehicle measurement using quick-response type analysis upon the operational performance once the potential interconnection became operational.

Due to the inherent complexity of the problem area and tremendous variability of the candidate field conditions, the major emphases were made on the interconnection guidelines for existing traffic signals operated currently under isolated or coordinated modes for two-way progression operation. That is, the major concern was: "Given existing installed traffic signalized intersection, the decision as suggested by the proposed guidelines will recommend whether the interconnection can provide effective operation without adverse effect and undue delay to the arterial system, as well as, the intersection itself".

Interconnection Desirability Index

The interconnection desirability index, as described earlier, was calculated based on different levels of the study factors. They include:

(1) Distance from 330 ft. to 6600 ft. at every 330 ft. increment,

(2) Left turn percentage from zero percent (0%) to fifty percent (50%),

(3) Progression design speeds of 27 mph, 36 mph and 45 mph to represent candidate arterial progression system ranging from good to fair coordinated operation,

(4) Background cycle lengths at 55, 65, 75, 85 and 90 seconds representing low, median to high traffic volume levels at the most critical intersection under both two-phase and four-phase operations.

The calculations of this Interconnection Desirability Index, as summarized by Statistical Analysis System, is illustrated in Figure 10. The horizontal axis is the intersection spacing in feet from the candidate signal under study to the neighboring signalized intersection, The vertical axis represents the Interconnection Desirability Index (I) for each approach of the traffic signal under analysis. Each line in the diagram represents the Interconnection Desirability Index with respect to intersection spacing up to 6600 feet under individual left turn percentage. The interconnection desirability index could be obtained by following the distance or travel time to cycle length ratio, then intersecting the curve line with the desired left turn percentage perpendicularly on the vertical axis. It should be noted that the intersection spacings which are less than 330 feet are omitted for practical traffic engineering application purposes.

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GUIDELINES OF INTERCONNECTION OF ISOLATED TRAFFIC SIGNAL
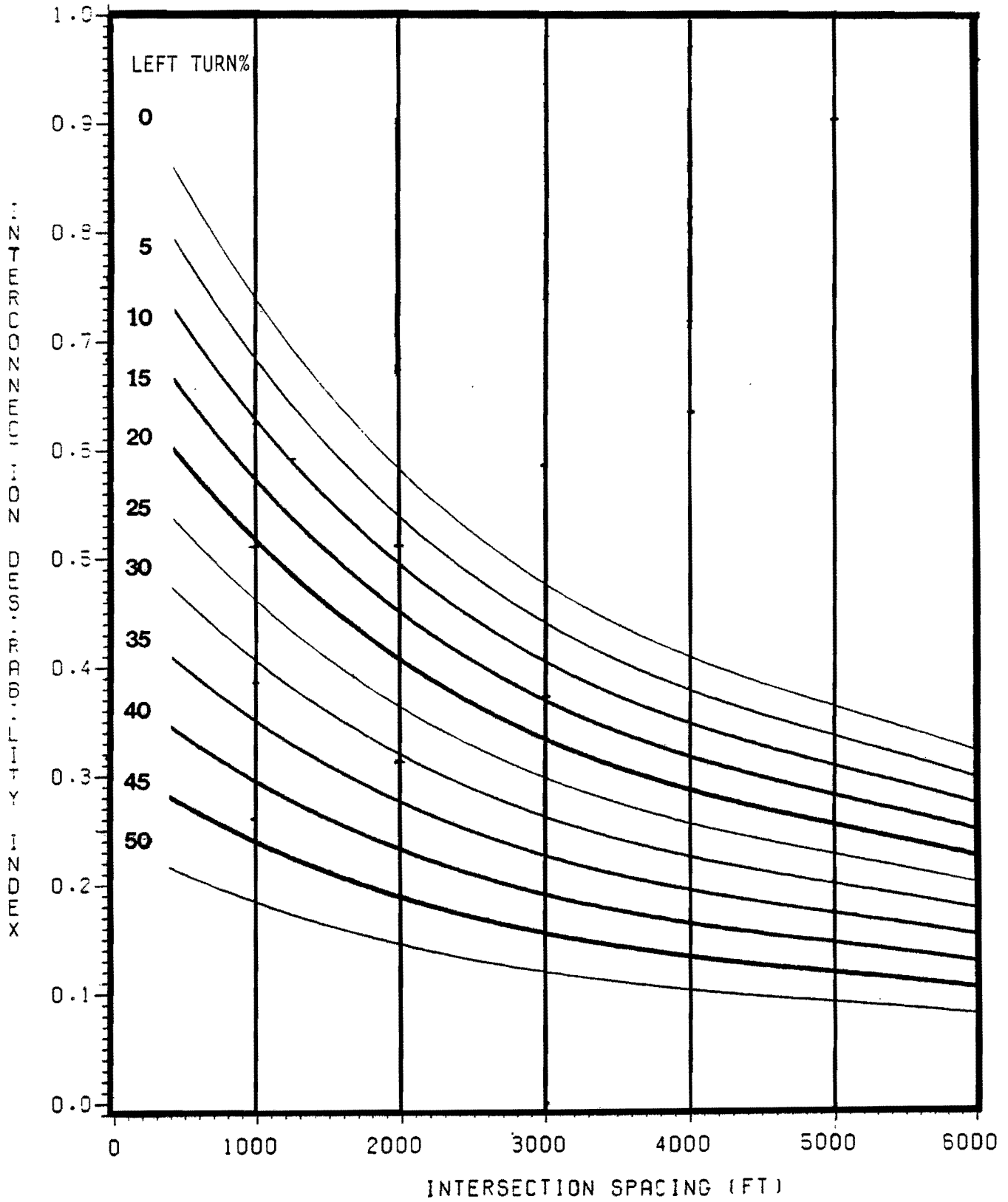### TOTAL = 3 LANES

Figure 10. Interconnection Desirability Index.

PASSER II and TRANSYT-7F Runs

The combined PASSER II and TRANSYT-7F runs were made to study the effectiveness of interconnection versus interconnection with progression phasing under different volume levels. As illustrated in Figure 4, PASSER II was used to generate the basic signal timing parameters for later simulation and optimization analysis by the TRANSYT-7F program. This approach is the benefit from the detailed simulation capability of the TRANSYT-7F program in terms of platoon travel behavior; and the cycle length and phase sequence optimization of PASSER II program.

It was assumed in this simulation study that:

(1) Approach volumes are <u>constant</u> over the study time period;

(2) Platoon structure remains <u>coherent</u> along the arterial;

(3) Link speed remains <u>uniform</u>;

(4) Origin-destination turning traffic volumes are <u>consistent</u>;

      a. All side street left turn traffic flows into through movement,
      b. All main street left turn traffic is originally from the through movement on the main street,
      c. Downstream through traffic on the main street is equal to the arterial through traffic plus side street left turn and right turn, and less the downstream left turn traffic; and

(5) Directional link volumes are <u>balanced</u>.

Three sets of sensitivity analysis were made to investigate the variability of an average link delay per vehicle against the major study variables. These study variables included the intersection spacings, the traffic volume levels and the travel speed used in progression system design. The results of these sensitivities were summarized in Figures 11 through 13. Figure 11 indicates the average link delay variation against effects of intersection, ranging from 330 ft through 2640 ft. in which "QUARTER SPACE" indicates the distance of 330 ft, "HALF SPACE" indicates the intersection spacing of 660 ft, and "FULL SPACE" represents the distance of 2640 ft. In each intersection spacing case, the distance is measured from the second and third study intersections as illustrated previously in the four-node arterial system shown in Figure 4.

Figure 12 demonstrates the average link delay versus different traffic volume levels, which have signal saturation flow ratios ranging from 0.50 to 0.83 representing low, medium and high volume levels. Since there are no separately protected left turn signal treatments in the two-phase operation, all the left turn traffic volumes are added to the through movements in the traffic signal optimization process. The traffic volume levels used are 350 (or 300), 700 (or 750), and 900 (or 1000) vehicles per hour per lane for either the two-phase or four-phase operations. Figure 13 shows the average link delay measurement according to three different progression design speeds of 27 mph, 36 mph and 45 mph. It should also be noted that the intersection spacings which are less than 330 feet were not analyzed for practical traffic engineering application purposes.

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INTERCONNECTION GUIDELINE STUDY
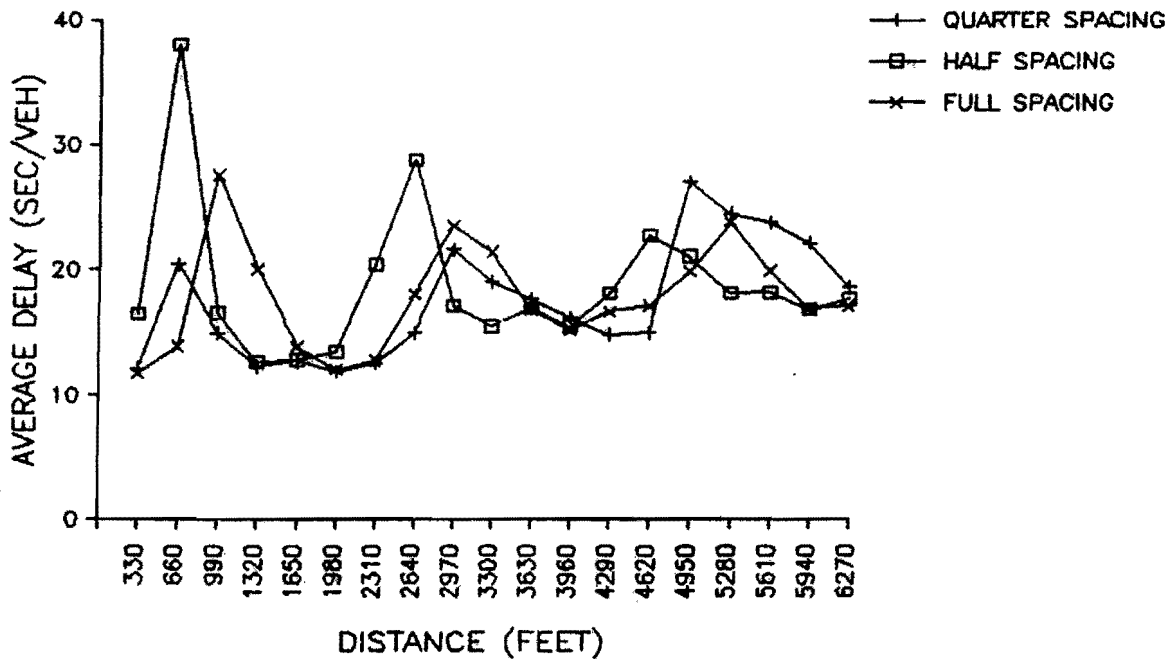## EFFECT OF INTERSECTION SPACING

Figure 11. Summary of Simulation Study Results - Effects
of Intersection Spacing.

INTERCONNECTION GUIDELINE STUDY
EFFECT OF TRAFFIC VOLUME LEVEL
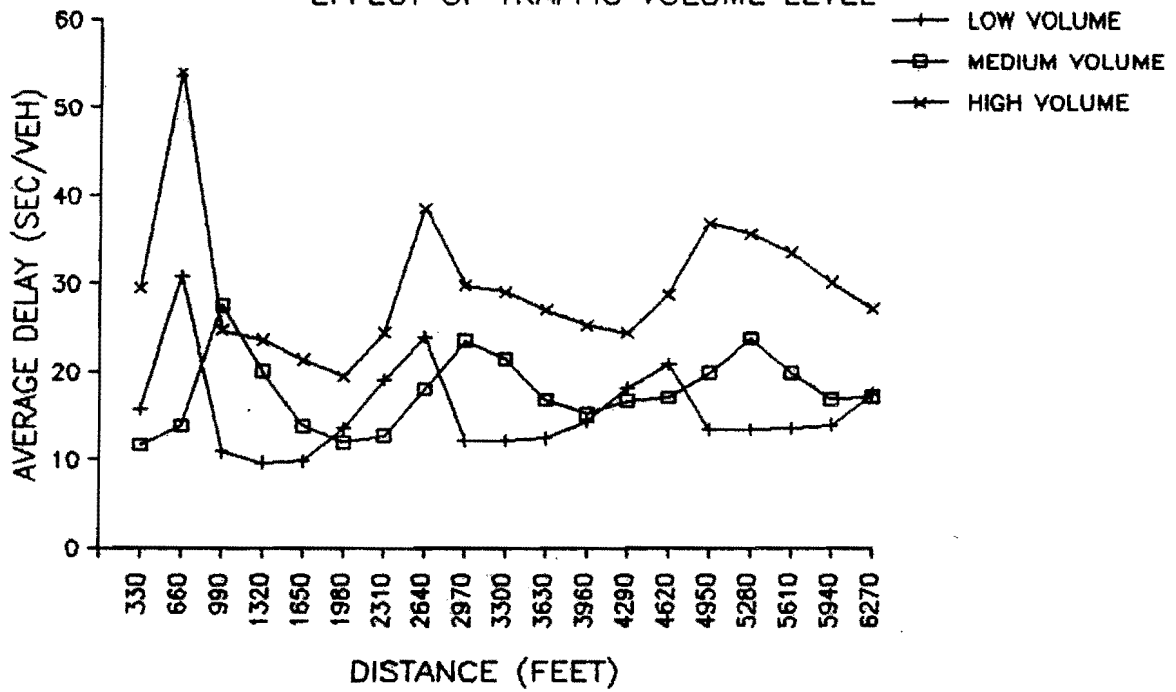
Figure 12. Summary of Simulation Study Results - Effects of Traffic Volume Level.

INTERCONNECTION GUIDELINE STUDY
EFFECT OF TRAVEL SPEED
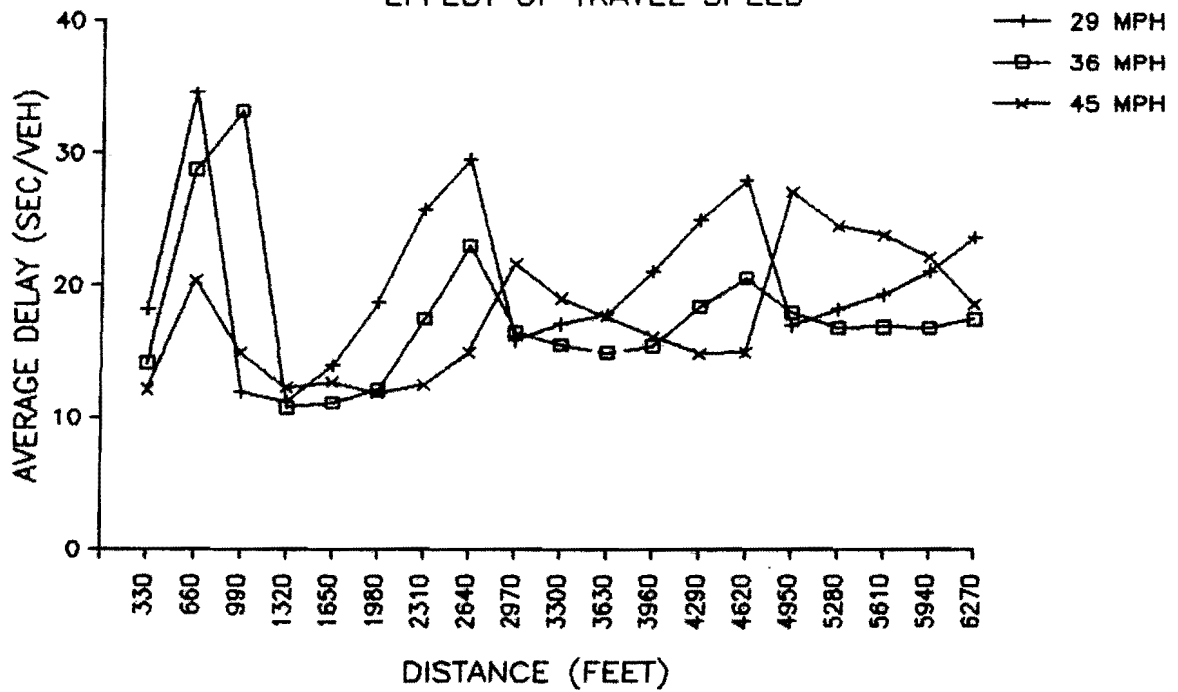
Figure 13. Summary of Simulation Study - Effects
of Travel Speed.

TABLE 1. SUMMARY OF COMBINED PASSER II - TRANSYT-7F SIMULATION STUDY.

HPR 2293 INTERCONNECTION GUIDELINES
SUMMARY OF   SIMULATION TEST CASES

FOUR-PHASE OPERATION

CASE NO	SIGNAL PHASE	TRAFFIC VOLUME	CYCLE LENGTH	LEFTTURN SEQUENCE	INTERSECTION SPACING	SPEED (MPH)
1	F2	LOW	55	2	QR	36
2	F2	LOW	55	2	HF	36
3	F2	LOW	55	2	FL	36
4	F2	MEDIUM	65	2	QR	29
5	F2	MEDIUM	65	2	QR	35
6	F2	MEDIUM	65	2	QR	36
7	F2	MEDIUM	65	2	QR	45
8	F2	MEDIUM	65	2	HF	36
9	F2	MEDIUM	65	2	FL	36
10	F2	HIGH	75	2	QR	36
11	F2	HIGH	75	2	HF	36
12	F2	HIGH	75	2	FL	36

TWO-PHASE OPERATIONS

CASE NO	SIGNAL PHASE	TRAFFIC VOLUME	CYCLE LENGTH	LEFTTURN SEQUENCE	INTERSECTION SPACING	SPEED (MPH)
1	F4	LOW	65	1	QR	36
2	F4	LOW	65	1	HF	36
3	F4	LOW	65	1	FL	36
4	F4	MEDIUM	75	1	QR	29
5	F4	MEDIUM	75	1	QR	35
6	F4	MEDIUM	75	1	QR	36
7	F4	MEDIUM	75	1	QR	45
8	F4	MEDIUM	75	1	HF	36
9	F4	MEDIUM	75	1	FL	36
10	F4	HIGH	90	1	QR	36
11	F4	HIGH	90	1	HF	36
12	F4	HIGH	90	1	FL	36

NOTE -

F4 - FOUR PHASE	F2 - TWO-PHASE	QR - QUARTER SPACING (330 FT)
LOW - 300 VPH	LOW - 350 VPH	HF - HALF SPACING (1320 FT)
MEDIUM - 700 VPH	MEDIUM - 700 VPH	FL - FULL SPACING (2640 FT)
HIGH - 900 VPH	HIGH - 1000 VPH	

The results of all the simulation studies are summarized in Table 1 and illustrated in Figures 14 through 17, indicating that the lower arterial link delay occurs between 1/4 to 1/3 mile distance, or 0.4 to 0.5 cycle length of travel time in two-phase operation, or 0.35 to 0.55 cycle length in four-phase operation. That is, these research findings again confirm that the **"Rule-of-Thumb"** or **"ideal progression spacing"** is approximately travel time of one-third to one-half cycle length times the design speed in any generalized arterial street system once the candidate intersection becomes interconnected.

The results also indicate that highly fluctuated or damped sin-wave type relationships exist between the potential neighboring intersection spacing and the probable arterial link delay under good progression phasing conditions due to the progression platoon dispersed through the distance downstream from the traffic signal under investigation. As indicated, the effectiveness of the signal interconnection relies heavily on the location of the "ideal spacing" for the proper combinations of study design variables, such as volume levels, left turn percentages, intersection spacings of the neighboring intersections, and the design and actual progression speeds for the potential arterial progression system.

A more generalized arterial link delay versus various intersection spacings was summarized for both two-phase and four-phase operations under different volume levels of the candidate signalized intersection as shown in Figures 18 and 19. Figure 18 summarizes the simulation study results of the combined PASSER II and TRANSYT-7F runs for the potential isolated intersection once that possible signal interconnection becomes operational under two-phase operation. On the other hand, Figure 19 illustrates average arterial system delay versus the travel time to tentative cycle length ratio under four-phase operation. The horizontal axis indicates the possible progression travel time versus the tentative cycle length ratio for the study signalized intersection. The vertical axis illustrates the average arterial system delay, expressed in seconds per vehicle. In both cases, three different traffic volume levels are used and simulated. They are labelled and illustrated by "LOW VOLUME", "MEDIUM VOLUME", and "HIGH VOLUME". The traffic volume levels used are 350 (or 300), 700 (or 750), and 900 (or 1000) vehicles per hour per lane for either the two-phase or four-phase traffic signal operations.

Interconnection Guideline Study

Based on the theoretical interconnection desirability index, the guidelines for interconnection of isolated traffic signals were developed as a function of travel time, progression design speed, intersection spacings, left-turn percentage and intersection approach volume level. As shown in Figures 20 and 21, sets of nomographs are developed according to different traffic volume levels. They are provided for quick reference of the possible operational performance after the potential interconnection be made according to different intersection spacings, travel time and tentative cycle length ratios. The user could find out the interconnection desirability index under the given conditions for quick reference to the operational performance under interconnection along with the estimated arterial link delay. Discussion in the next section explains the usage of the Interconnection Desirability Index and the Travel Time to Delay nomographs for determining proper interconnection of particular study intersections in detail for quick-response type reference.

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GUIDELINES OF INTERCONNECTION OF ISOLATED TRAFFIC SIGNAL
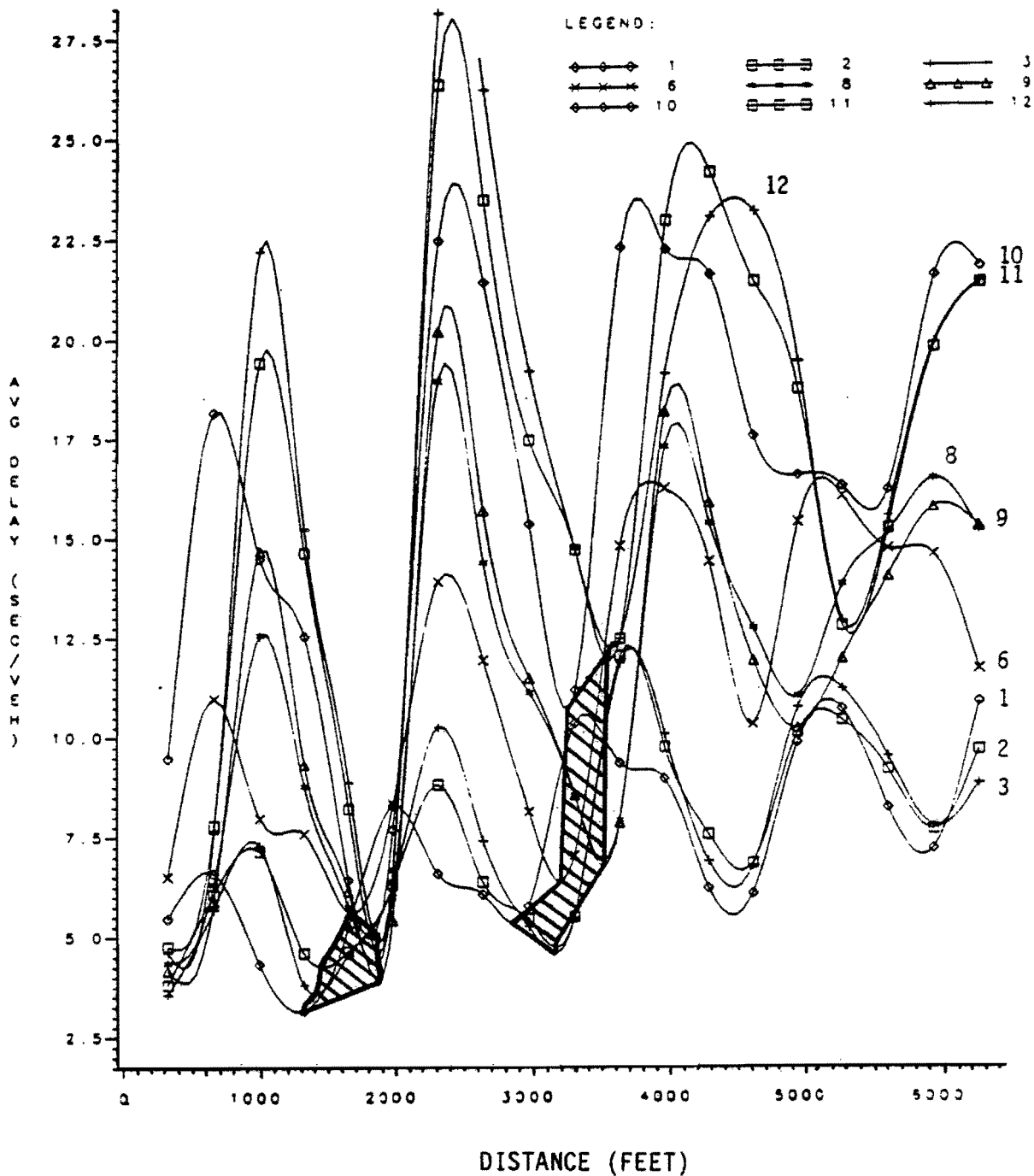
Figure 14.   Summary of Results of Combined PASSER II and
             TRANSYT-7F Runs - Average Link Delay Versus
             Distance under Two-Phase Operation.

GUIDELINES OF INTERCONNECTION OF ISOLATED TRAFFIC SIGNAL

TRAVEL TIME TO CYCLE LENGTH RATIO
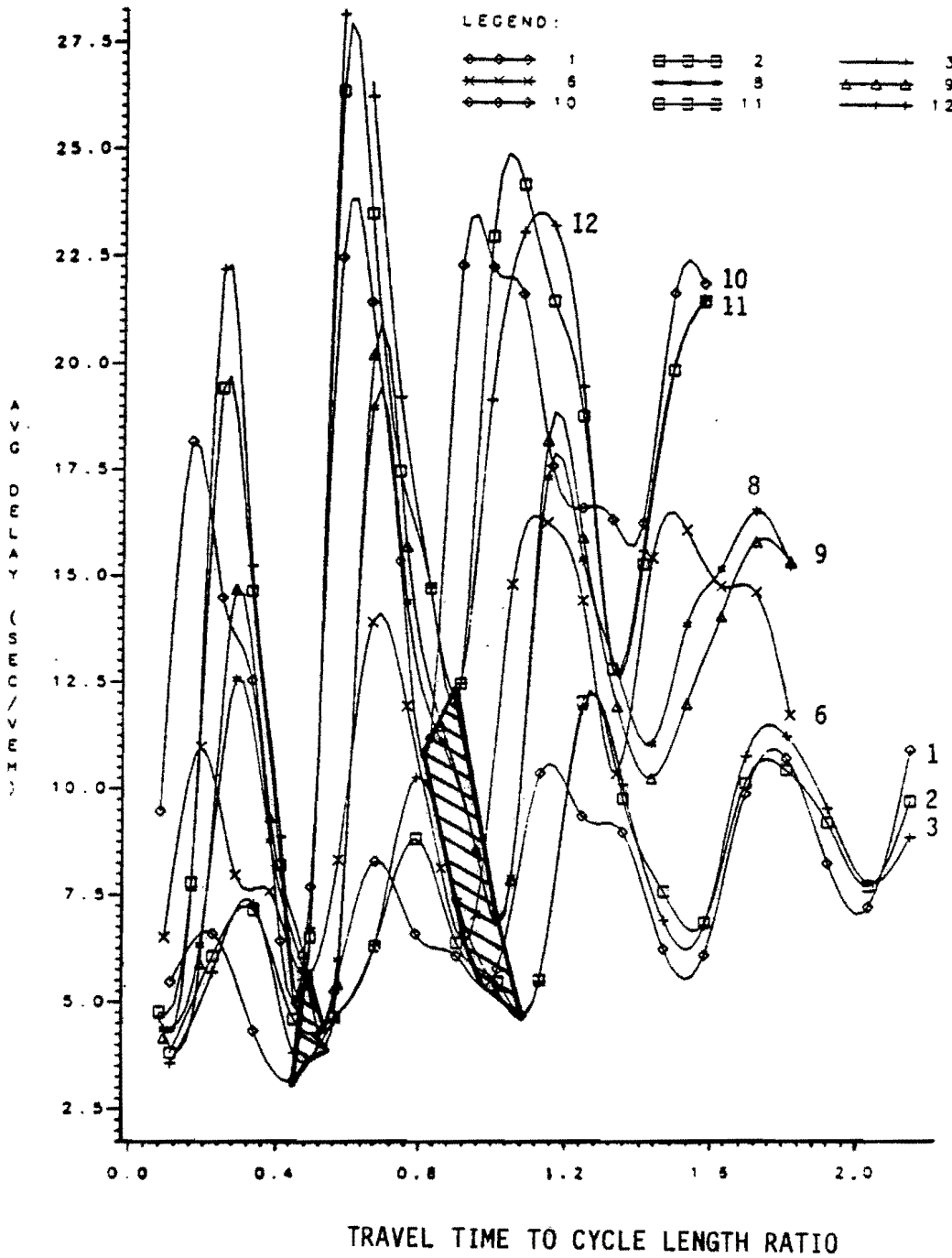
Figure 15. Summary of Results of Combined PASSER II and TRANSYT-7F Runs - Average Link Delay Versus Travel Time to Cycle Length Ratio under Two-Phase Operation.

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GUIDELINES OF INTERCONNECTION OF ISOLATED TRAFFIC SIGNAL
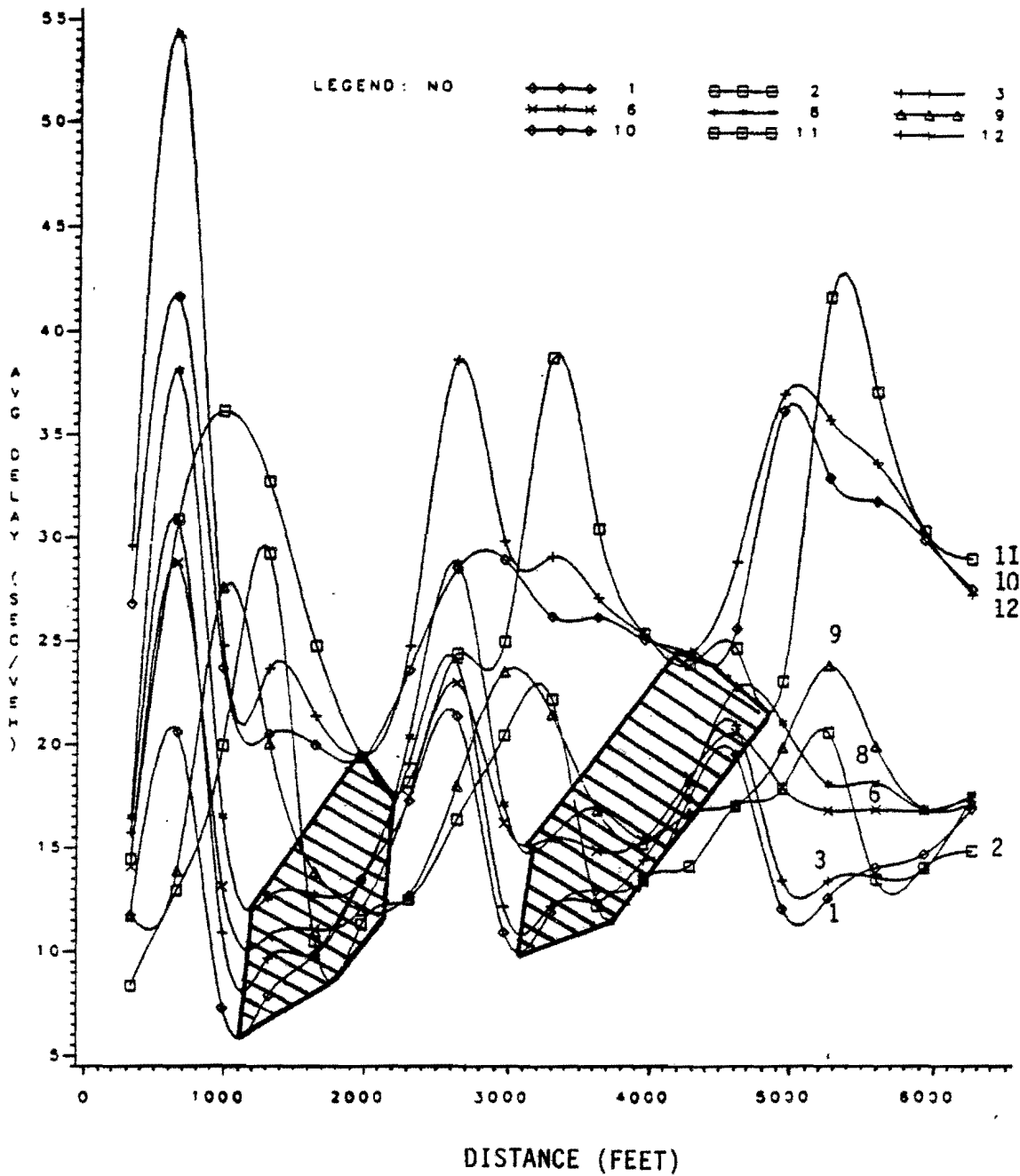
Figure 16. Summary of Results of Combined PASSER II and
TRANSYT-7F Runs - Average Link Delay
Versus Distance under Four-Phase Operation.

GUIDELINES OF INTERCONNECTION OF ISOLATED TRAFFIC SIGNAL

TRAVEL TIME TO CYCLE LENGTH RATIO

Figure 17. Summary of Results of Combined PASSER II and
TRANSYT-7F Runs - Average Link Delay Versus
Travel Time to Cycle Length Ratio
under Four-Phase Operation.

GUIDELINES OF INTERCONNECTION OF ISOLATED TRAFFIC SIGNAL
PHASE=2
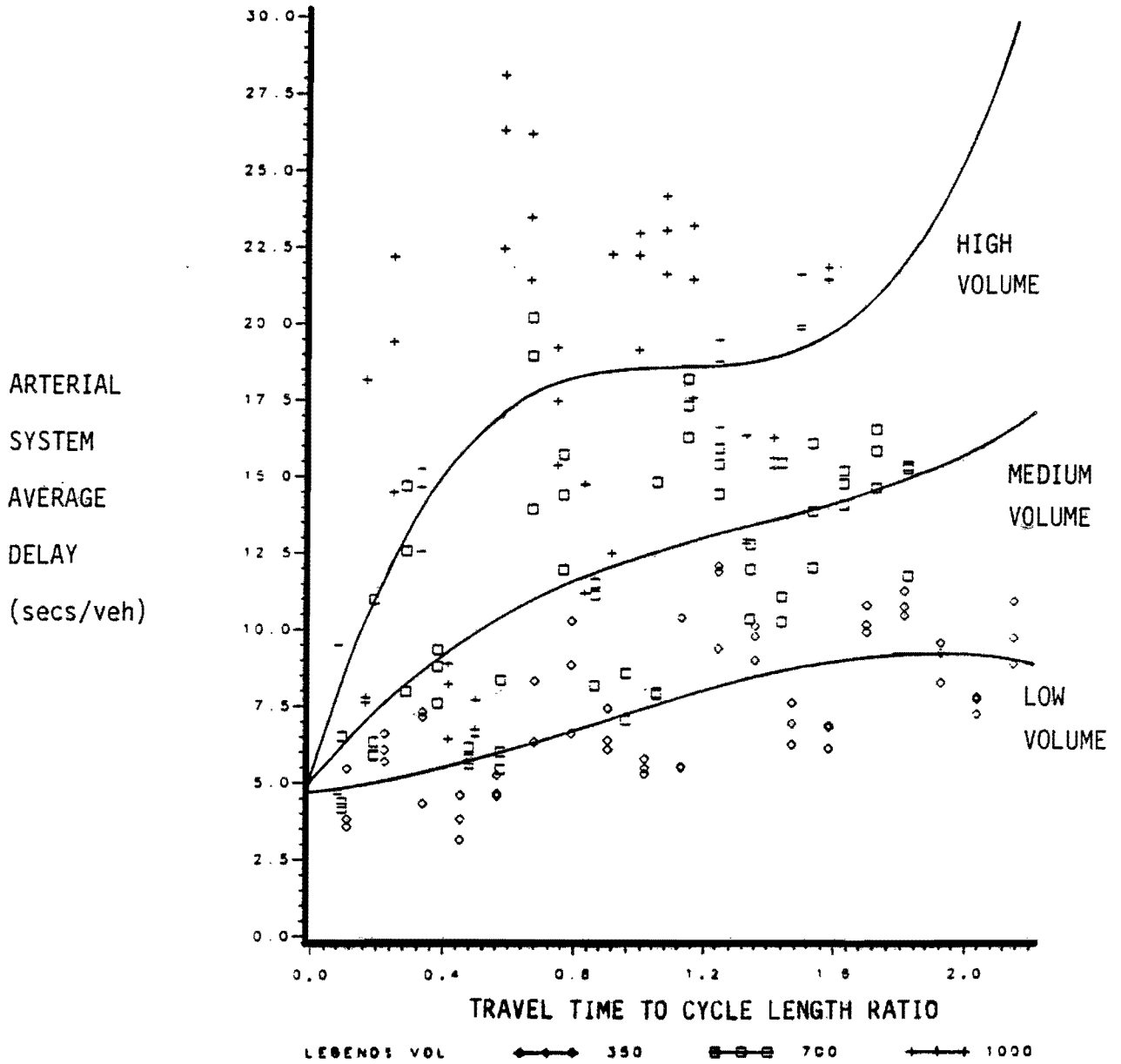
Figure 18.   Summary of Results of Combined PASSER II and
TRANSYT-7F Runs   – Arterial System
Average Delay Versus Travel Time to Cycle
Length Ratio under Two-Phase Operation.

GUIDELINES OF INTERCONNECTION OF ISOLATED TRAFFIC SIGNAL

PHASE=4
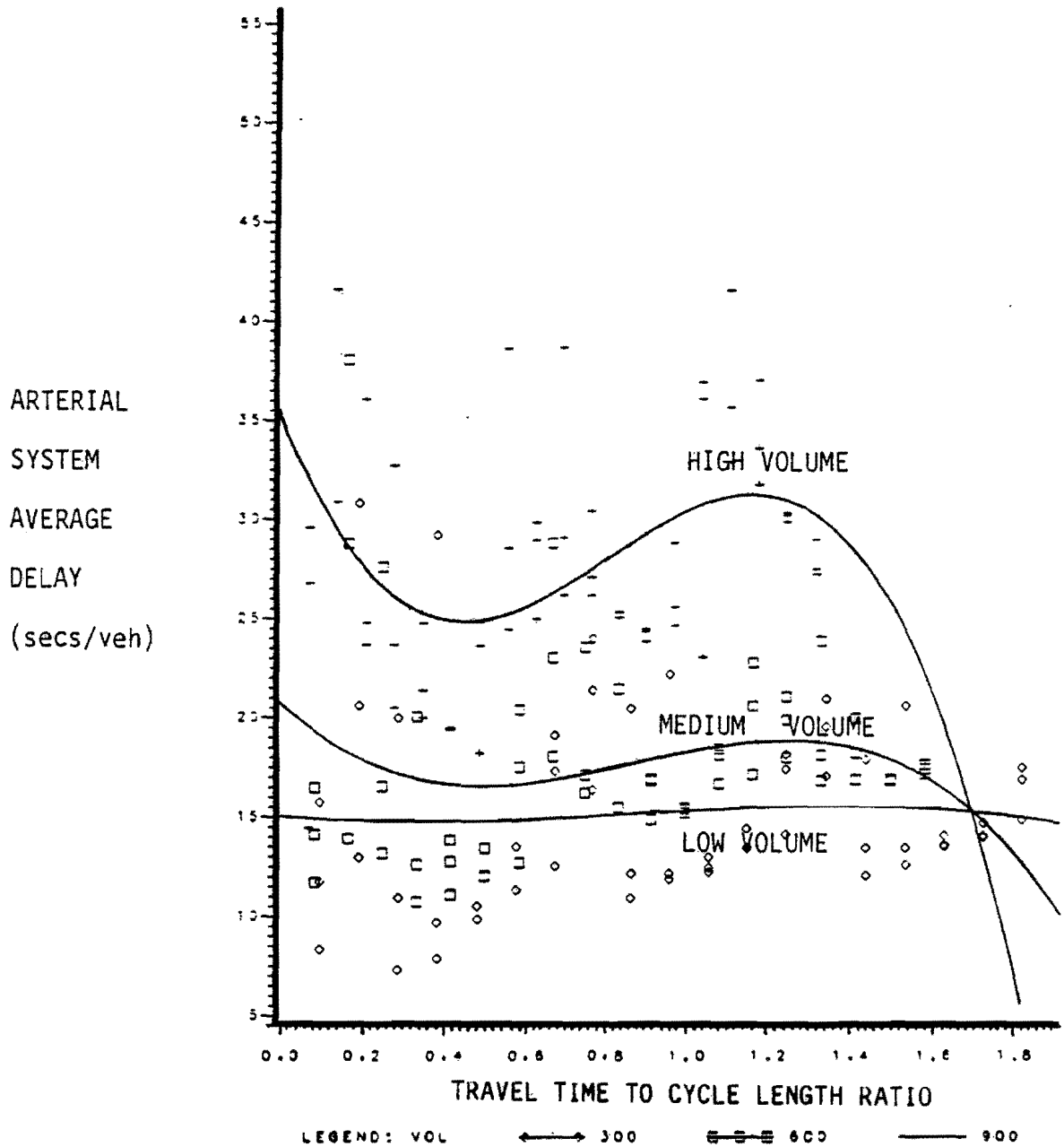
Figure 19.   Summary of Results of Combined PASSER II and
             TRANSYT-7F Runs   - Arterial System
             Average Delay Versus Travel Time to Cycle
             Length Ratio under Four-Phase Operation.

GUIDELINES OF INTERCONNECTION OF ISOLATED TRAFFIC SIGNAL

Figure 20. Extrapolation of Simulation Results - Average Link Delay per Vehicle versus Distance under Four-Phase Operation.

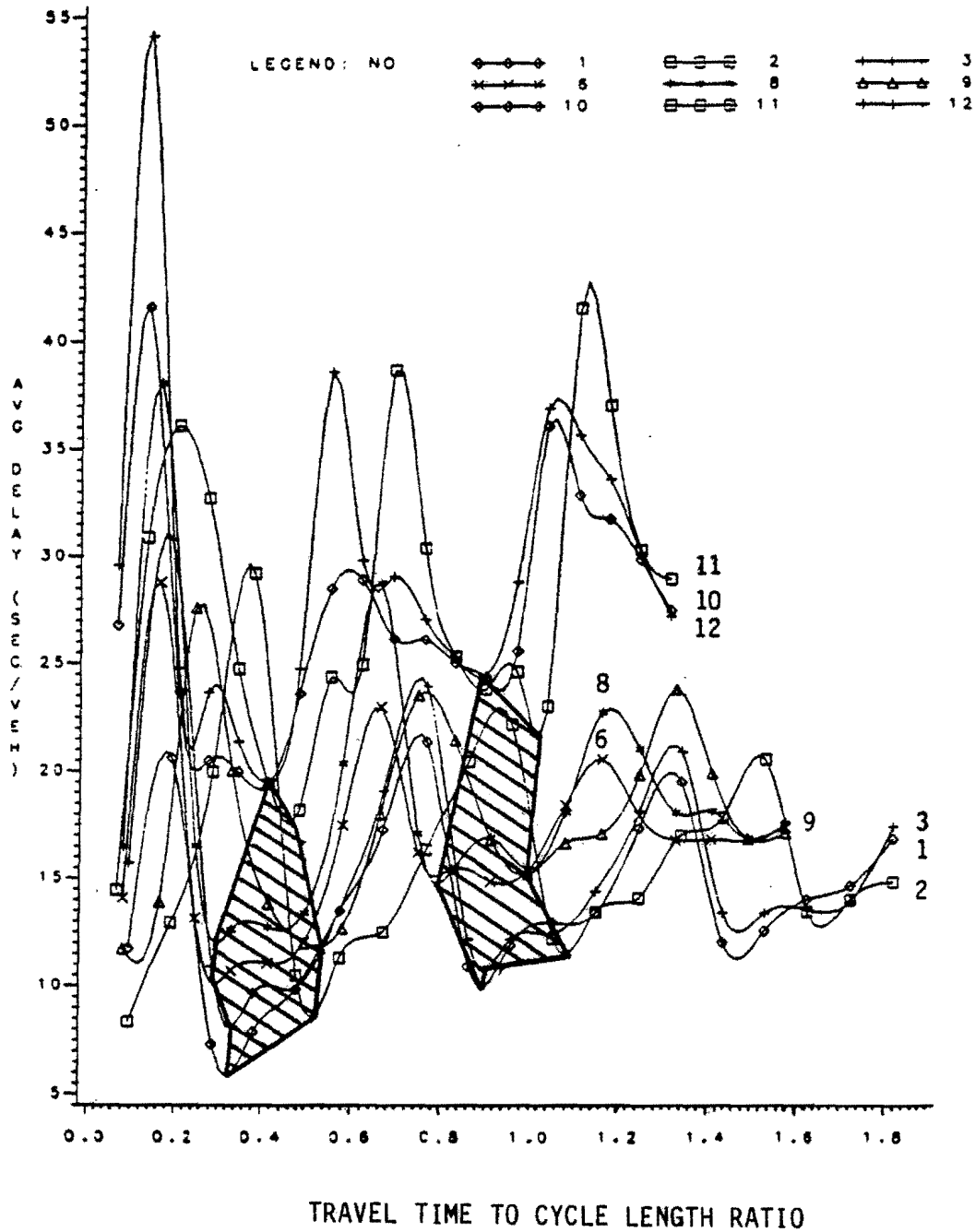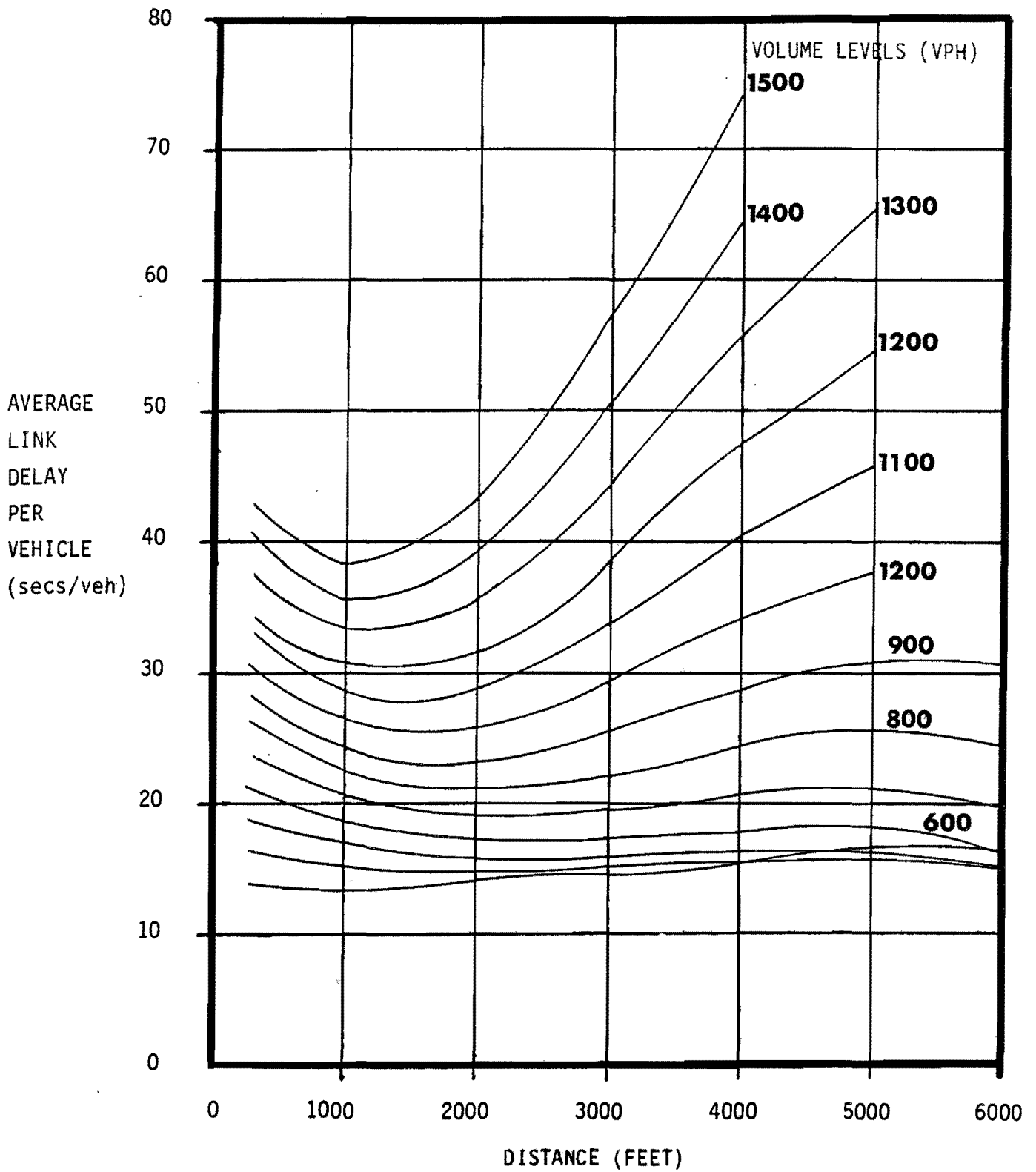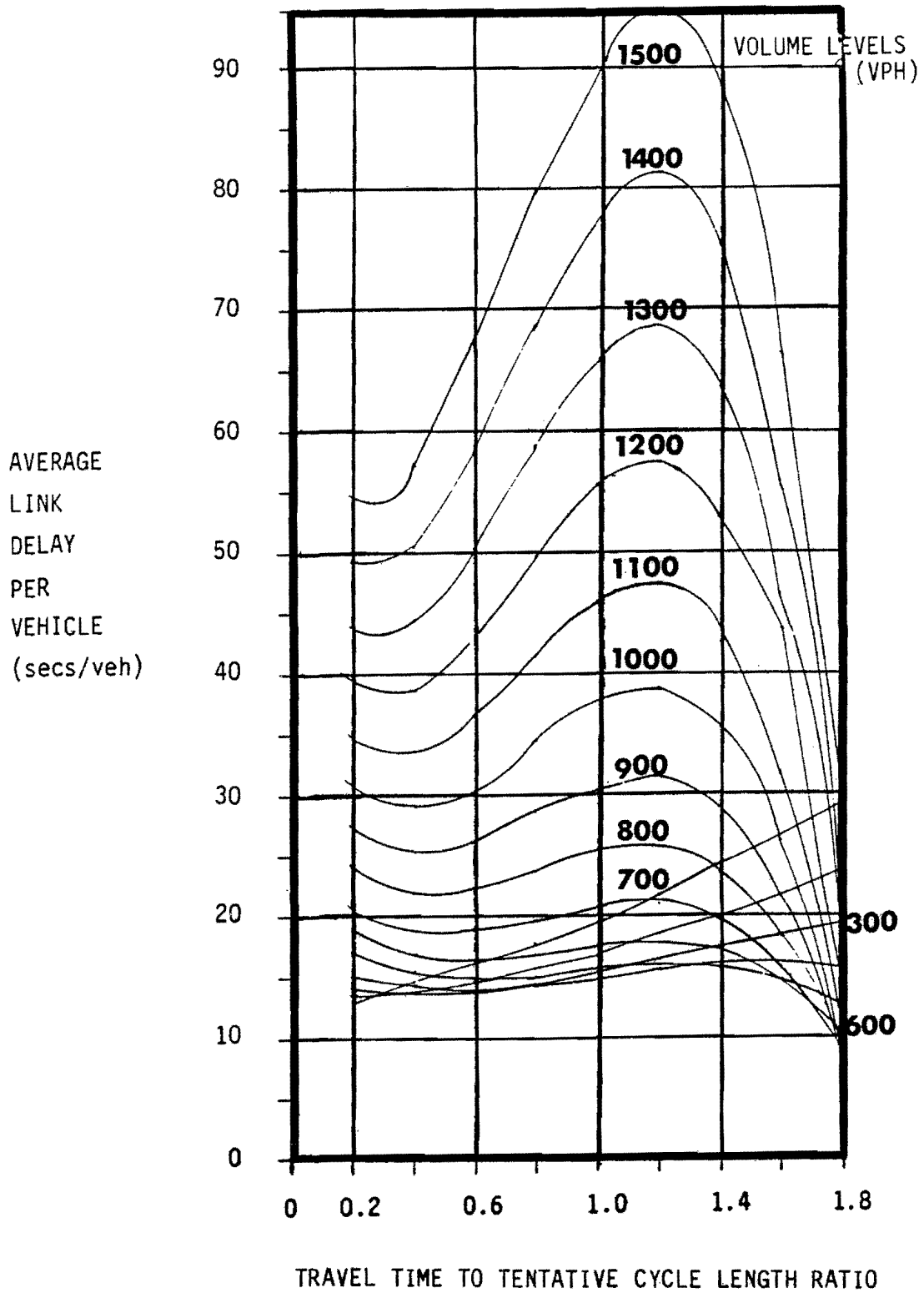GUIDELINES OF INTERCONNECTION OF ISOLATED TRAFFIC SIGNAL

Figure 21. Extrapolation of Simulation Results - Average Link
Delay Per Vehicle Versus Travel Time To Tentative
Cycle Length Ratio under Four-Phase Operation.

FIELD STUDY

This section presents some of the important findings obtained from the second field study of the Texas SDHPT NASA 1 System during the last two weeks in May, 1984.

Basically, four different studies were performed:

(1) Cycle Length Selection Parameter (CLSP) study - to investigate the arterial system loading conditions through the use of the SDHPT D-19 NASA 1 FACTS sampling detectors.

(2) Travel time and delay study - to evaluate the efficiency of arterial traffic signal operations along the arterial travel direction.

(3) Stop delay study - to investigate the effect of various traffic signal timing parameters on the arterial signal system.

(4) Platoon dispersion study - to validate the assumptions used in the simulation study and update the macroscopic travel behavior of vehicular platoons due to the effects of isolated or interconnected traffic operations.

Cycle Length Selection Parameter (CLSP) Study

The results, as illustrated in Appendix A, indicate highly sensitive traffic demand patterns and very obvious peaking phenomenon exist in the study area throughout the time-of-day. The results also demonstrate that the traffic patterns were very sensitive in responding to the various control strategies (treatments) applied in this study. For example, the peaking demand patterns actually shifted from twenty (20) minutes to one half hour earlier between the consecutive study dates in responding to the peak-hour travel experienced by the motorists in different traffic control strategies.

Statistical analysis of the Cycle Length Selection Parameter of the SDHPT NASA 1 FACTS System indicated that all traffic volume loading under each treatment date could be considered to be independent and unbiased even though highly variable conditions exist in all study periods. Therefore, the field validations performed in this study could be considered to be fair and unbiased evaluations against all the control strategies.

Travel Time Study

The results of travel time study are presented in Tables 2, 3, and 4. Tables 2 and 3 indicate the individual mean and standard deviation link travel times between consecutive traffic signals inside the progression system. Table 4 summarizes the results of the statistical analysis of the travel time and delay study using "Floating Car Technique" under each treatment date during the two-week study period. As a group, the treatments under interconnection have better results than do those under isolated operation. This was expected. In addition, the PASSER program generated patterns and had better operating conditions than did the TRANSYT-7F, especially in the arterial travel directions. However, the individual link travel time/delay evaluations indicate mixed results due to the travel time runs not having been made at the same system peak loading conditions.

TABLE 2. SUMMARY OF FIELD STUDY RESULTS –
TRAVEL TIME/DELAY STUDY, EASTBOUND DIRECTION
TEXAS SDHPT NASA 1 SYSTEM.
(MAY 22-24 AND 29-31, 1984).

COL.	TREAT	PERIOD	LINK 1	LINK 2	LINK 3	LINK 4	LINK 5	LINK 6
1	AVERAGE		35.3	17.2	26.0	27.3	29.7	32.0
2	AVERAGE	AM	31.8	14.9	24.1	28.7	30.6	33.5
3	AVERAGE	OFF	35.1	15.8	27.1	26.9	28.7	30.5
4	AVERAGE	PM	41.2	20.6	25.8	26.8	30.3	32.7
5	1	AVERAGE	34.7	17.7	25.0	28.1	29.2	33.9
6	2	AVERAGE	37.4	15.1	23.3	30.7	31.5	35.0
7	3	AVERAGE	34.8	18.5	24.2	29.7	30.7	34.2
8	4	AVERAGE	35.8	21.0	32.4	25.8	31.7	33.4
9	5	AVERAGE	35.8	10.2	25.5	19.9	24.0	21.4
10	6	AVERAGE	32.7	19.0	25.1	26.6	28.9	29.8
11	1	AM	31.9	19.9	29.6	30.8	36.6	41.0
12	1	OFF	36.4	16.6	27.6	26.5	30.0	33.2
13	1	PM	.	17.8	.	28.7	22.9	30.2
14	2	AM	41.2	.	26.3	36.4	37.1	40.6
15	2	OFF	34.2	14.9	28.3	31.7	33.9	37.1
16	2	PM	41.1	17.8	18.4	28.2	28.0	31.5
17	3	AM	29.7	17.5	.	26.0	21.8	29.3
18	3	OFF	38.5	15.4	28.2	34.9	31.6	35.0
19	3	PM	39.5	.	25.8	27.0	34.6	36.1
20	4	AM	32.8	15.7	27.6	33.2	34.0	38.2
21	4	OFF	34.2	23.4	26.6	.	26.5	28.0
22	4	PM	39.5	22.6	43.8	27.3	37.3	36.7
23	5	AM	32.3	.	26.2	21.6	26.7	21.7
24	5	OFF	36.3	10.3	26.4	20.6	22.7	21.2
25	5	PM	45.7	13.7	22.2	.	23.9	21.7
26	6	AM	26.7	18.2	24.1	25.9	31.7	31.9
27	6	OFF	30.4	12.3	24.5	26.6	26.0	26.7
28	6	PM	43.5	30.2	27.4	27.8	30.0	32.0

NOTE - 1. (1) PII-80 - PASSER II-80 PROGRAM
　　　　　(2) PII-84 - PASSER II-84 PROGRAM
　　　　　(3) T-7F　 - TRANSYT-7F　 PROGRAM
　　　　　(4) T.R.　 - TEXAS SDHPT'S FACTS TRAFFIC RESPONSIVE SYSTEM
　　　　　(5) ISO.　 - ISOLATED INTERSECTION OPERATIONS
　　　　　(6) CIC.　 - CRITICAL INTERSECTION CONTROL

　　　2. "." - INDICATES THE MISSING DATA CELL OR THE INVALID DATA
　　　　　DUE TO THE EXTREME LONG STANDING QUEUES.

TABLE 3.   SUMMARY OF FIELD STUDY RESULTS -
           TRAVEL TIME/DELAY STUDY, WESTBOUND DIRECTION
           TEXAS SDHPT NASA 1 SYSTEM.
           (MAY 22-24 AND 29-31, 1984).

COL.	TREAT	PERIOD	LINK 1	LINK 2	LINK 3	LINK 4	LINK 5	LINK 6
1	AVERAGE		43.2	37.1	19.7	29.4	33.2	29.1
2	AVERAGE	AM	44.5	37.8	24.6	33.0	35.0	29.6
3	AVERAGE	OFF	41.9	36.8	17.5	27.6	31.1	28.2
4	AVERAGE	PM	44.3	36.0	12.9	25.2	35.5	31.4
5	1	AVERAGE	45.1	44.1	20.4	28.5	32.1	31.4
6	2	AVERAGE	46.6	37.4	23.2	30.7	34.4	33.0
7	3	AVERAGE	45.7	38.6	20.2	30.4	34.7	31.9
8	4	AVERAGE	40.3	37.7	25.1	29.5	30.4	27.2
9	5	AVERAGE	41.6	32.4	12.3	27.9	32.2	21.1
10	6	AVERAGE	38.1	35.8	15.6	27.9	33.0	26.7
11	1	AM	50.1	37.6	31.9	28.0	32.6	28.3
12	1	OFF	43.1	48.1	18.4	25.9	31.0	31.5
13	1	PM	.	40.2	10.7	38.3	35.1	35.7
14	2	AM	50.5	43.8	31.0	28.6	31.6	40.4
15	2	OFF	44.7	31.8	25.0	32.9	35.0	29.3
16	2	PM	44.3	40.9	.	29.2	36.0	32.2
17	3	AM	44.9	35.7	25.8	41.2	37.2	31.7
18	3	OFF	46.7	41.8	17.6	27.8	32.3	33.6
19	3	PM	.	37.1	14.9	14.6	35.1	28.5
20	4	AM	46.0	41.3	34.4	29.9	35.6	32.5
21	4	OFF	34.5	32.0	15.5	29.4	28.5	24.2
22	4	PM	.	39.8	25.5	29.3	27.1	25.0
23	5	AM	44.3	34.2	12.7	34.8	36.1	20.7
24	5	OFF	39.2	30.8	12.0	21.9	28.9	21.4
25	6	AM	36.4	36.0	15.2	28.9	33.4	25.5
26	6	OFF	41.4	35.3	16.2	26.0	32.1	29.1

NOTE - 1. (1) PII-80 - PASSER II-80 PROGRAM
          (2) PII-84 - PASSER II-84 PROGRAM
          (3) T-7F   - TRANSYT-7F   PROGRAM
          (4) T.R.   - TEXAS SDHPT'S FACTS TRAFFIC RESPONSIVE SYSTEM
          (5) ISO.   - ISOLATED INTERSECTION OPERATIONS
          (6) CIC.   - CRITICAL INTERSECTION CONTROL

       2. "." - INDICATES THE MISSING DATA CELL OR THE INVALID DATA
              DUE TO THE EXTREME LONG STANDING QUEUES.

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TABLE 4. SUMMARY OF FIELD STUDY RESULTS - TRAVEL TIME/
DELAY STUDY, TEXAS SDHPT NASA 1 SYSTEM.

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TRAVEL TIME/DELAY STUDY

OVERALL CONCLUSIONS FOR SAS ANALYSIS WITH ANOVA AND SCHEFFE'S TEST

	WITH QUEUE		WITHOUT QUEUE	
	EASTBOUND	WESTBOUND	EASTBOUND	WESTBOUND
AM	No significant difference at 0.05 level	(1,2,3) (6) (1,4) (5)	(1) (5,6)	(1,2,3,4) (6) (1,4) (5)
OFF	(1,3) (5,6)	(1,2,3) (6)	(1,3,4) (5,6)	No significant difference at 0.05 level
PM	No significant difference at 0.05 level	(1,2,3,4) (5) (1,2,3,4) (6)	No significant difference at 0.05 level	No significant difference at 0.05 level among 1,2,3,4

Note - 1. (1) PII-80 - PASSER II-80 PROGRAM
           (2) PII-84 - PASSER II-84 PROGRAM
           (3) T-7F   - TRANSYT-7F PROGRAM
           (4) T.R.   - TEXAS SDHPT'S FACTS TRAFFIC RESPONSIVE SYSTEM
           (5) ISO.   - ISOLATED OPERATION
           (6) CIC.   - CRITICAL INTERSECTION CONTROL

       2. "WITH QUEUE"   - REPRESENTS THE TRAVEL TIME/DELAY STUDY INCLUDING
                             THE MEASURES OF QUEUE DELAY.
           "WITHOUT QUEUE" - REPRESENTS THE TRAVEL TIME/DELAY STUDY NOT
                             INCLUDING THE MEASURES OF QUEUE DELAY.

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Stop Delay Study

Table 5 represents the results from the stop delay study collected from the 5 major intersections of the NASA 1 System by varying the treatments as generated by different traffic signal control strategies. Those intersections were the crossings of NASA 1 Road with Kings Row, El Camino Real/FM 270, Space Park Drive, Nassau Bay Drive, Point Lookout (2nd Street) and Upperbay Road (3rd Street).

Study results were similiar to those found in the previous travel time and delay study. First, the interconnection patterns as calculated from the PASSER II-80, PASSER II-84, and TRANSYT-7F programs, and the previously operated SDHPT FACTS traffic responsive system provided better system performance than either isolated actuated operation or critical intersection control treatment. Secondly, the offset patterns, as generated by the PASSER program and implemented by either the Texas SDHPT traffic responsive system or through the PASSER II-80 and PASSER II-84 programs under fixed-time mode, had less filed-measured stop delay than did those generated by the TRANSYT-7F program. However, no statistically significant study results were found due to the large variation in field conditions and the highly responsive traffic volume fluctuations on the study site throughout the study period.

Finally, the Critical Intersection Control (CIC) experiment was made by dropping off the first and most congested intersection--El Camino Street--from the NASA 1 FACTS System and letting it operate separately as one isolated actuated intersection. The main objective of this CIC experiment is to test whether this local optimization strategy by disconnecting a heavily loaded major critical intersection in an existing arterial progression network operating by itself while leaving the rest of the arterial street operated through the traffic responsive mode to alleviate the heavily loaded intersection and provide better systemwide operation. However, the result of this extreme case of interconnection warrant study has indicated that even though much less delay was found in that major critical intersection, the system performance under this CIC control was not as good as the original interconnected progression system according to total systemwide stop delay evaluation. The progression of the rest of the arterial system was severely damaged by the long queue on the main street waiting to pass through that critical intersection. This resulted from heavy traffic movements on the cross street that took the green time originally available for progression movements away from the major arterial street direction.

Platoon Dispersion Study

A set of platoon dispersion studies was made in this field study by measuring the platoon size, travel time and vehicular platoon travel behavior from video tape recordings. Table 6 presents the platoon dispersion results as those reduced from the video tapes recorded in the second week study. Basically, the results provide the travel time measured from the stop line of the upstream intersection to the locations of 500, 1000, and 1500 feet downstream from the candidate intersection. The travel time relationship was expressed as a function of the number of vehicles in the platoon, distance and the signal controlled treatments provided in the second week during the field study.

TABLE 5. SUMMARY OF FIELD STUDY RESULTS - STOP DELAY
STUDY, TEXAS SDHPT NASA-1 SYSTEM.

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STOP DELAY STUDY

TREATMENT	1	2	3	4	5	6
DATE	MAY 22	MAY 23	MAY 24	MAY 29	MAY 30	MAY 31
WEEKDAY	TUESDAY	WEDNESDAY	THURSDAY	TUESDAY	WEDNESDAY	THURSDAY
PROGRAM	PII-80	PII-84	T/7F	T.R.	ISO.	CIC.
AM	32.09	32.00	40.60	33.46	36.45	45.30
OFF	44.37	42.38	43.02	43.60	54.73	85.38
PM	83.03	70.12	74.75	75.20	112.91	113.82

NOTE -

1. COMPUTER CONTROL TRAFFIC PATTERN EXAMINED -

   (1) PII-80 - PASSER II-80 PROGRAM
   (2) PII-84 - PASSER II-84 PROGRAM
   (3) T-7F   - TRANSYT-7F   PROGRAM
   (4) T.R.   - TEXAS SDHPT'S FACTS TRAFFIC RESPONSIVE SYSTEM
   (5) ISO.   - ISOLATED OPERATIONS
   (6) CIC.   - CRITICAL INTERSECTION CONTROL

2. THE COMPUTER CONTROL TRAFFIC PATTERN SETTINGS USED FOR STUDY
   CONDITIONS '(4)TR' AND '(6)CIC' WERE DEVELOPED AND IMPLEMENTED FIVE
   YEARS PRIOR TO THE DATE OF THE FIELD STUDY. UPDATED TRAFFIC PATTERN
   SETTINGS MAY HAVE PROVIDED LOWER STOP DELAY RESULTS.

TABLE 6. SUMMARY OF FIELD STUDY RESULTS - PLATOON DISPERSION STUDY
WITHOUT QUEUE DATA, TEXAS SDHPT NASA-1 SYSTEM.

HPR 293 INTERCONNECTION GUIDELINES

PLATOON DISPERSION STUDY

TEXAS SDHPT'S NASA 1 FACTS SYSTEM

TRAVEL TIME AT DISTANCE OF 500,1000,1500 FT	TRAFFIC RESPONSIVE (T.R.) DAY 29		ISOLATED OPERATION (ISO.) DAY 30		CRITICAL INTERSECTION (CIC.) DAY 31	
	MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION
VEHICLES IN PLATOON	4.94	2.09	6.08	2.66	7.24	1.99
H2 (HEAD 500 FT)	9.14	1.64	7.80	1.50	7.71	1.26
T2 (TRAIL 500 FT)	14.41	9.61	12.84	3.48	15.07	2.92
H3 (HEAD 1000 FT)	16.67	2.36	15.48	2.01	15.16	1.65
T3 (TRAIL 1000 FT)	21.67	3.82	21.83	4.19	23.81	3.22
H4 (HEAD 1500 FT)	24.17	2.49	22.56	2.68	22.38	2.30
T4 (TRAIL 1500 FT)	29.59	4.87	29.72	4.97	32.41	3.65

NOTE -   1. TR   - TEXAS SDHPT'S FACTS TRAFFIC RESPONSIVE SYSTEM
            ISO - ISOLATED INTERSECTION CONTROL
            CIC - CRITICAL INTERSECTION CONTROL
          2. ALL DISTANCE REFERS TO THE DISTANCES FROM THE STOP LINE
             OF THE UPSTREAM SIGNAL INTERSECTION.
          3. "Hi" - INDICATES THE TRAVEL TIME MEASURED FOR THE HEADING VEHICLE.
             "Li" - INDICATES THE TRAVEL TIME MEASURED FOR THE TRAILING VEHICLE.

The purpose of this platoon dispersion study was to identify whether there are differences which exist between the platoon travel behavior and the traffic signal control strategies. The controlled field experiments were made by measuring the platoon travel time versus the distance travelling downstream from the stop line of the upstream traffic signals under both interconnected and isolated signal control operations. Three traffic signal control scenarios were used in this field study. They were the Traffic Responsive mode (T.R.), Isolated Intersection Operation (ISO.) and the Critical Intersection Control mode (CIC.). The data were collected twice in the morning--AM peak and OFF peak--and once in the afternoon--PM peak.

The results of this particular platoon dispersion study are summarized in Table 6. The numbers of vehicles in the progression platoons were first identified using the recorded video tape. Then the travel times of the heading and trailing vehicles were separately identified for each available progression platoon at the locations of 500, 1000 and 1500 feet downstream of the stop line at the upstream intersection. Next, the numbers of vehicles and their corresponding travel times were summarized were summarized for inclusion in Table 6. Unfortunately, the results of this platoon dispersion study were not such that statistically significant conclusions could be drawn. After careful reexamination of the available photographic video record, it was found that the interferences were heavily influenced by the large variation in field data and by difficulty in identifying the proper number of vehicles in the platoon. However, this study did indicate the potential implications of using platoon identification techniques in evaluating the progression signal system performance. This platoon dispersion study also illustrated the importance of platoon analysis using permanent photographic records in the evaluations of isolated versus interconnection operations.

GUIDELINES AND PROCEDURES

The effects of traffic signal operations are the most complex among traffic control devices. Traffic signals have major impacts on motorists and pedestrians, such as safety, delay, and transportation costs. A traffic signal could affect the movements of motorists and pedestrians far downstream from the traffic signal location. These effects become much more complex due to overlapped influence areas especially when traffic signals are operated within close proximity to each other.

Traffic signal interconnection is warranted when the net effect can improve the safe, convenient and economical movement of persons and goods. Past experience has demonstrated that a traffic signal may decrease accidents, but, at the same time, increase delay and user costs. Therefore, all factors of signal operation must be warranted to perform effectively. It is desirable to establish a priority for interconnection, to predict at what conditions at a given intersection will satisfy the warrant, and to determine the best allocation of funds available for traffic signal interconnections.

The application of a warrant system will help the development of a geometrically efficient traffic signal system with efficient traffic patterns. The benefits from this approach over an incoherent traffic signal system are that it compacts random and arbitrary traffic flows to pass through the whole traffic signal system. In order to determine whether or not a traffic signal is appropriate for interconnection, the following three approaches are recommended:

   1. Physical suitability of the intersection,
   2. Quick-response analysis, and
   3. Applications of computer models.

PHYSICAL SUITABILITY OF THE INTERSECTION

The physical characteristics of the approaches to the intersection must be evaluated to determine whether a traffic signal can be operated safely and effectively. Examples of factors which might suggest isolated instead of interconnected signal control include:

   a) Steep grades on one approach could make the stopping or starting of motor vehicles difficult or impracticable, especially during adverse road and weather conditions.

   b) A severe skewed angle of intersection could result in excessively long vehicle and pedestrian clearance phases, and resultant inefficient signal operation.

   c) An offset intersection approach could result in excessively long vehicle and pedestrian clearance phases and undue conflict between vehicles and pedestrians unless an inefficient multi-phase signal operation could be provided.

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QUICK-RESPONSE ANALYSIS

Data Requirements

The following data are required for each approach on both sides of the intersection in the arterial street directions, in order to determine the "interconnection desirability index" (8,9,10):

a) Distance from the nearest existing or proposed future traffic signal.

b) Likelihood that good progression between the nearest existing or proposed future traffic signal and the study intersection is attainable (for one-way streets only). In order to determine this factor, it is necessary to evaluate whether the offset of a traffic signal at the study location would result in the stopping of vehicles which otherwise would flow unhindered through the intersection. In the case of a variable system offset operation throughout the day, the offset operation which would accommodate the majority of daily vehicle movements should be used.

c) Length of the system background cycle (for two-way streets only). The background cycle length which would be in operation for all day during which the greatest total volume of vehicle movements would be accommodated should be used. This is usually the "peak hour" cycle length. In cases where an isolated actuated traffic signal operation is proposed for the future, care should be taken to make sure that there will be no other traffic signals close enough to result in overlapping areas of influence.

d) Desirable progression speed along the link (for two-way streets only).

e) Average Annual Daily total vehicular volume should be representative for the twenty-four hour volume of vehicular traffic using the study intersection during the part of the year the proposed traffic signal would be operated. Normally, a traffic signal would operate all year long, and the appropriate figure would be the Average Annual Daily Total. These figures are derived by expanding short-term traffic counts to a twenty-four hour total, and then modifying this total further by the use of day-of-the-week and month-of-the-year adjustment factors. For this purpose, the short-term counts should be at least 7 hours long, and should include both the morning and evening rush hour periods. The appropriate expansion factors should be determined from data derived from permanent counting stations at key locations.

In areas having abnormal seasonal fluctuations, such as resort areas and their connecting roadways, it may be appropriate to operate a traffic signal for only a few months of the year, in which case representative figures for those few months should be used.

f) The expansion factor to account for the increase in vehicular volume which, due to the interconnection of a traffic signal, would occur on the street of the study intersection within one year.

The Expansion Factor should reflect the probable increase in vehicular volume on each street of the study intersection, due to an anticipated re-routing of motorists to use the newly signalized route. These factors may also be used to account for predictable increases in volume due to projected roadway widenings, new connections, etc. A catalogue of past experience should be compiled in order to improve judgment for future proposed traffic signal interconnections. The following general conditions should be noted:

i) Traffic volumes on the former "through" street will not usually increase except for normal growth, and the factor for the "through" street is usually close to 1.0.

ii) In cases in which the former "stop" street had no undue delay problems or was the only alternative for motorists on the route, the factor for the "stop" street may range from 1.0 to 1.3.

iii) In cases in which the former "stop" street motorists experienced appreciable delay, and other alternative routes suffered the same problems, the factor may range from 1.5 (low) to 2.0 (average) to 2.5 (high).

Examples of the quick-response analysis is illustrated in Figures 22 and 23.

Satisfaction of Interconnection Warrants

The interconnection of traffic signals at a study intersection is warranted when the total priority points equal or exceed 0.35. The relative need or priority for traffic signal interconnections at a number of possible locations is indicated by the relative number of the interconnection desirability index on both sides of the study intersection.

While the interconnection warrant rating system provides a realistic technical analysis of the net effect of the interconnection of a traffic signal at a specific location, it is recognized that it can serve only as a tool to aid the judgment of the traffic engineer, and not as an absolutely complete and final answer which would overcome the need for experienced and objective analysis.

At intersections which satisfy the interconnection warrant for only part of the year, such as those at seasonal recreation areas, the traffic signal should be operated only during that part of the year during which conditions meet the interconnection warrant. At other times of the year, the traffic signal should be either taken out of the interconnected progression service, by removing or bagging the signal heads.

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(Example) Assume all the street sections have two through lanes
and one left turn lane. The Interconnection Desirability
Index (I) is:

$$I = \frac{0.5}{1+t} * \left[\frac{q_{max}}{\bar{q}} - (x-2) \right]$$

CROSS STREET	CENTRAL	GREENVILLE	SKILLMAN	ABRAMS
DISTANCE	2740 ft.			2650 ft.
SPEED	26 mph (38 fps)			30 mph (44 fps)
PEAK HOUR VOLUMES				

CASE I.

$t = \dfrac{2740}{38}$ = 72.1 sec. ≑ 1.2 min.

q_{max} = through = 1038 vph

$\bar{q} = \dfrac{1038 + 514}{3}$ = 517 vph

X = 2+1 = 3 lanes

$I = \dfrac{0.5}{1+1.2} * \left[\dfrac{1038}{517} - (3-2) \right]$

= 0.227

Interconnection may **not** be warranted.

CASE II.

$t = \dfrac{2650}{44}$ = 60 sec. ≑ 1 min.

q_{max} = through = 1623 vph

$\bar{q} = \dfrac{1623+36}{3}$ = 533 vph

X = 2+1 = 3 lanes

$I = \dfrac{0.5}{1+1} * \left[\dfrac{1623}{553} - (3-2) \right]$

= 0.484

Interconnection is warranted.

Figure 22. Example Calculation of Interconnection Desirability Index.

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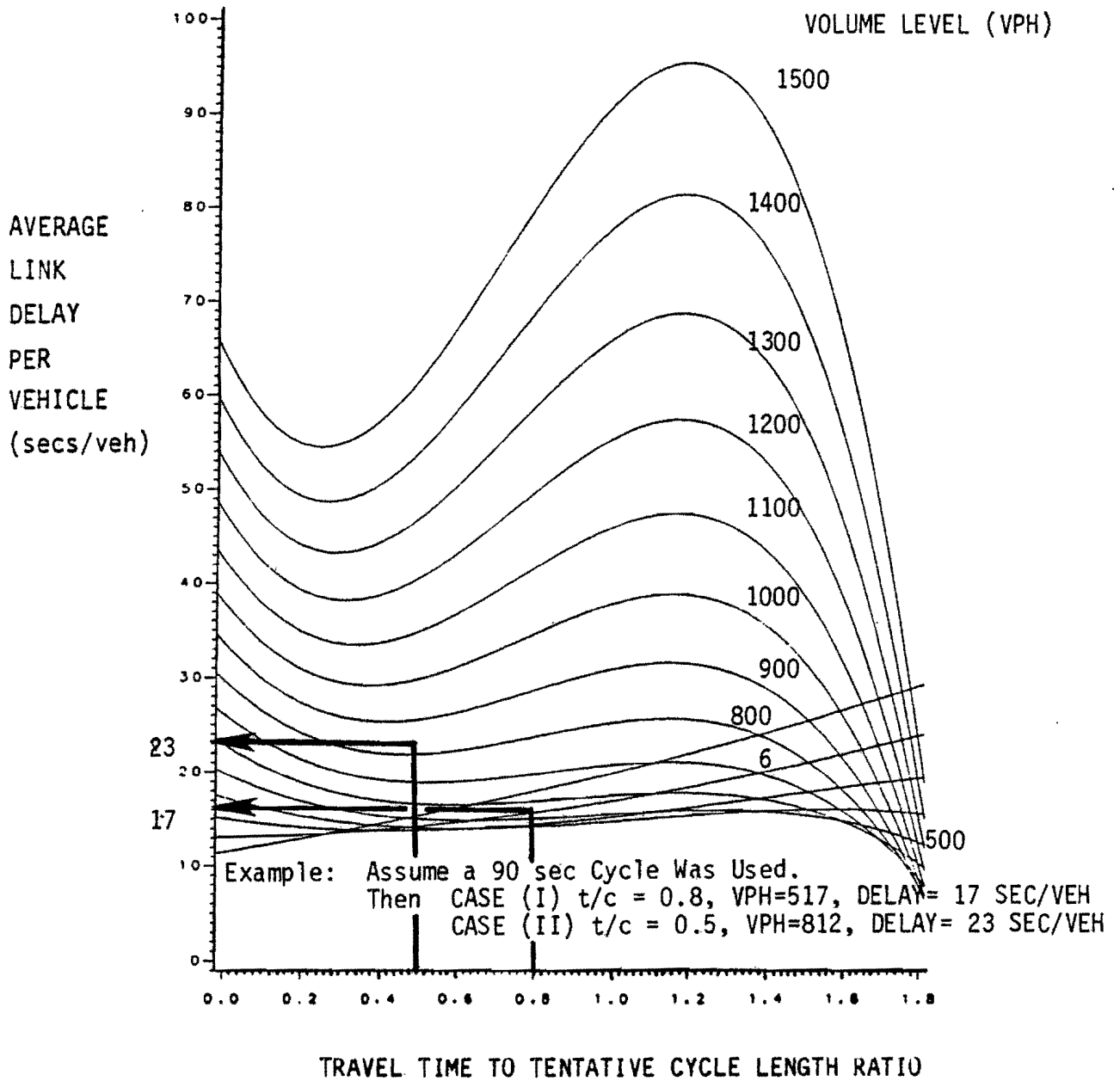## WARRANTS OF INTERCONNECTION OF ISOLATED TRAFFIC SIGNAL

Figure 23. Example of Quick Response Analysis.

APPLICATION OF COMPUTER MODELS

Bandwidth programs, such as PASSER II and MAXBAND, can produce good combinations of the traffic control variables for optimal interconnected traffic signal operations. Concurrent usage of the program can provide modest additional improvements for the detailed arterial studied in traffic operational performance, compared to the single use of the TRANSYT program. The most promising strategy is combined use of the PASSER II programs to establish the system cycle length and phase sequences, followed perhaps by TRANSYT-7F runs to validate flow profile and provide final optimization of the traffic signal control parameters.

Computer programs can assist traffic engineers to develop as well as evaluate alternative solutions and select the final optimal timing plan for field implementation of interconnected traffic signal operations. Substantial benefits can be achieved in signal management using improved computerized techniques. However, efficient use of these tools depends highly upon the users to provide correct field data and interpret the final results.

Microcomputers can be very helpful in signal retiming and deciding proper signal interconnection combinations. They are low cost and more user friendly than mainframe computers. Portable microcomputers are especially useful, allowing traffic engineers easy access to field data collection and analysis. As compared to mainframes, microcomputers have the disadvantages of lower processing speed and storage capabilities, especially for larger scale applications. Integrated software in one package--including data reduction, analysis calculations, and output--is highly desirable to reduce the time consumed for individual program applications.

It is recommended that traffic signal timing parameters be collected after quick-response analysis has indicated the feasibility of interconnection was described in Figure 23. Then, the combined PASSER II/TRANSYT-7F runs can be performed, as indicated using the combined coding form in Figure 24. After obtaining the performance index, a decision can be made on interconnection. However, care should be taken to examine the situation for either one-way or two-way street operation.

ONE WAY STREETS

For each one-way approach of an intersection, consideration must be given to the net effect which the operation of a traffic signal would have upon:

a) The availability of crossing gaps at the intersection and at points remote from the study intersection.

b) The progression of vehicles along the street to or from other existing or proposed traffic signals.

c) The delay to vehicles on the street.

d) The number of stops to which vehicles are subjected by signal operation.

T.7F. LINK. VOL. DIAGRAM

RUN NO	CITY NAME			ARTERIAL NAME			DATE			NO # SIGNAL			ARTERIAL NAME			DATE			NO # SIGNAL	SPEED VAR.
CROSS STR. NAME	A		CROSS STR. NAME	A		CROSS STR. NAME	A		CROSS STR. NAME	A		CROSS STR. NAME	A		CROSS STR. NAME	A		CROSS STR. NAME	A		
	B			B			B			B			B			B			B		
	A			A			A			A			A			A			A		
	B			B			B			B			B			B			B		

← B

→ A

54

2
3
6 7
1
4 5 8

SIGNAL
PHASE

MAJOR
ART. GREEN

MINOR
CRS. GREEN
CYCLE

OFFSET   OFFSET   OFFSET   OFFSET   OFFSET   OFFSET   OFFSET

Figure 24.   Coding Form for Combined PASSER II-TRANSYT-7F Analysis.

TWO WAY STREETS

For each two-way approach of an intersection, consideration must be given
to the net effect which the operation of a traffic signal would have
upon:

a) The availability of <u>crossing gaps</u> at the study intersection and at
    points remote from the intersection.

b) The progression of vehicles along the street, to and from other
    existing or proposed traffic signals.

c) The delay to vehicles on the street.

d) The number of stops to which vehicles are subjected by signal
    operation.

CONCLUSIONS AND RECOMMENDATIONS

The continued demand for urban mobility requires that the highest degree of traffic service be obtained from existing urban arterial streets and intersections. The ability of signalized intersections to move traffic is determined by the physical features of the intersections as well as the type of signalization used. Thus, total system design of a signalized arterial involves concurrently evaluating existing traffic control devices and proper signal timing settings as they function together in the field either as one integrated unit or several isolated subsystems.

The purpose of this study was to find an efficient and usable procedure for practicing traffic engineers to use in deciding warrants for interconnecting isolated arterial traffic signals to optimize traffic operations. This study developed fundamental procedures and guidelines for interconnection warrants to minimize the arterial systemwide delay measurement and preserve the convenience of progression movement in multiphase traffic signal timing optimization. This report provides documentation of research conducted and material developed for the Texas SDHPT and U.S. DOT, FHWA.

CONCLUSIONS

Traffic signal optimization depends heavily on the relative relationships among cycle length, roadway capacity, speed of traffic, distances between signalized intersections, and side friction along the arterial. Effective interconnected traffic signal operations can not only provide safe crossing gaps for the cross street traffic and accommodate different turning traffic movements, but also develop randomly arriving traffic through the whole network into compact platoons. Warrants should be used in helping traffic engineers to decide time and locations for proper arterial traffic signal interconnection. The guidelines and procedures developed herein should become the warranting conditions included in the Texas MUTCD in the future.

Despite highly fluctuated arrival traffic patterns, well-designed cycle length, phase and offset patterns can tailor the arterial traffic signal control to suit particularly sensitive traffic demand patterns, such as the Texas SDHPT NASA 1 FACTS system. It has also been found that a proper compromise between the directional bandwidths and efficient interconnections can, to a certain extent, further alleviate total system traffic loading conditions without having to sacrifice good progression operation. However, care should be taken to monitor traffic speed variations against progression design speeds as well as traffic demand growth along the arterial to maintain the proper data base for assuring successful signal timing implementations.

It is difficult to compare the impacts of improvements in the traffic signal timing parameter on the total arterial system operation without the aid of traffic simulation calculations or a thorough survey of the stops, delay and concurrent traffic volumes on the study site. It was also found that close monitoring of the traffic flow in the field is necessary to minimize delay from the maximum progression calculation. Green time can be used more efficiently if special attention is given to the comparison of the progression platoon size with the progression bandwidth. This effort can further minimize total arterial system delay.
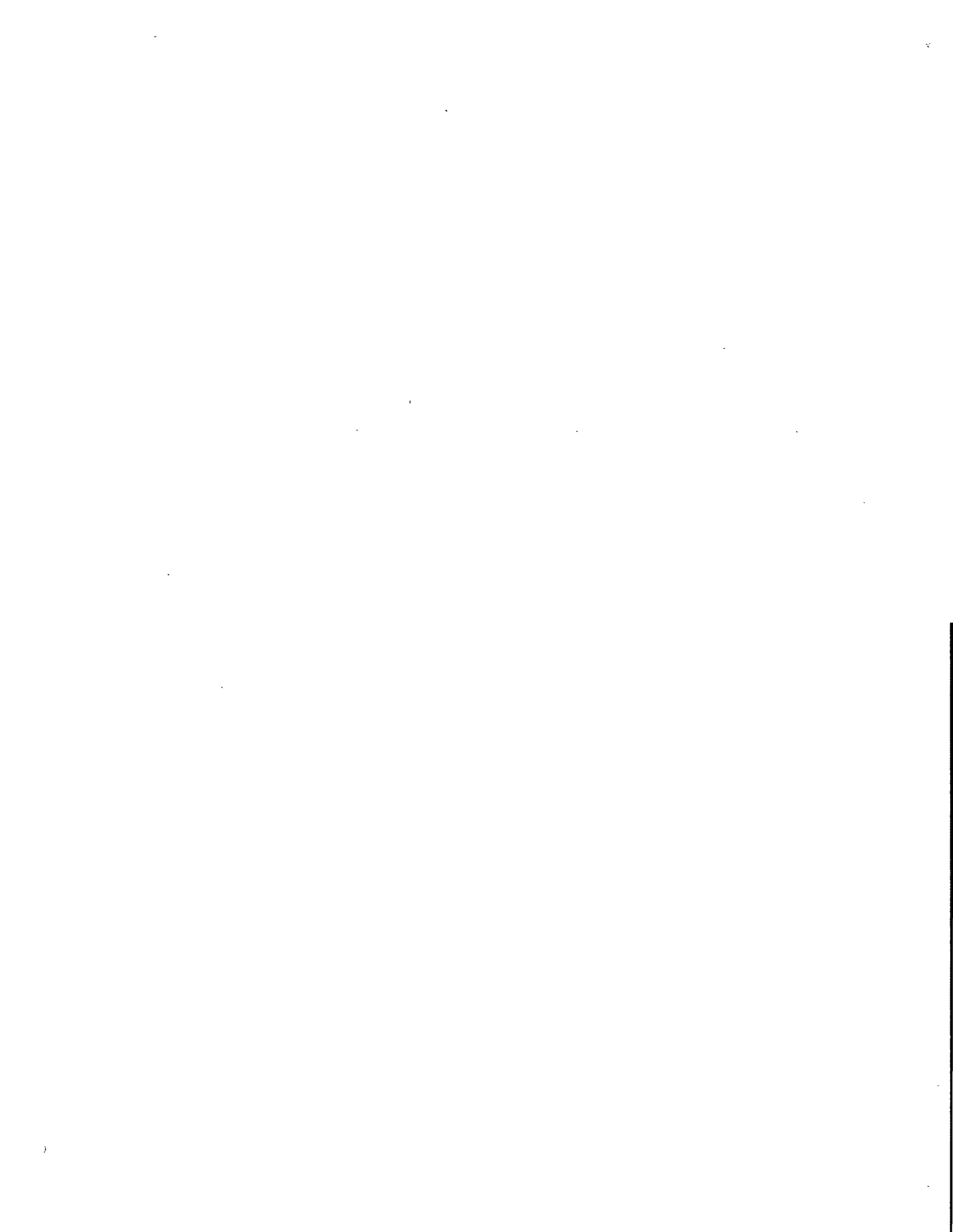
RECOMMENDATIONS

Further research is recommended in: the calibration of platoon dispersion models used in various traffic signal control timing programs, field validation of the interconnection warrants in actual study sites, evaluation of the traffic progression impact on the arterial street operations, alternative strategies in allocating the directional bandwidths, and the local and system optimization tradeoffs in arterial signal optimization. Further studies are needed to extend this research to permit on-line network configuration of the traffic signal control systems so as to control "open" rather than "closed" networks.

Since the proper study tool for evaluating traffic actuated controller operation under either isolated or interconnected operation is lacking, it is highly recommended that the internal simulation mechanism of the NETSIM program be revised to reduce the step size in order to reduce the existing cost for simulating combined coordination of fixed-time and actuated signal operations. Especially, attention should be given to compare the progression platoon size with the progression bandwidth in order to use the green time more efficiently without having to sacrifice the progression solution to further minimize total arterial system delay measurements.

ACKNOWLEDGEMENTS

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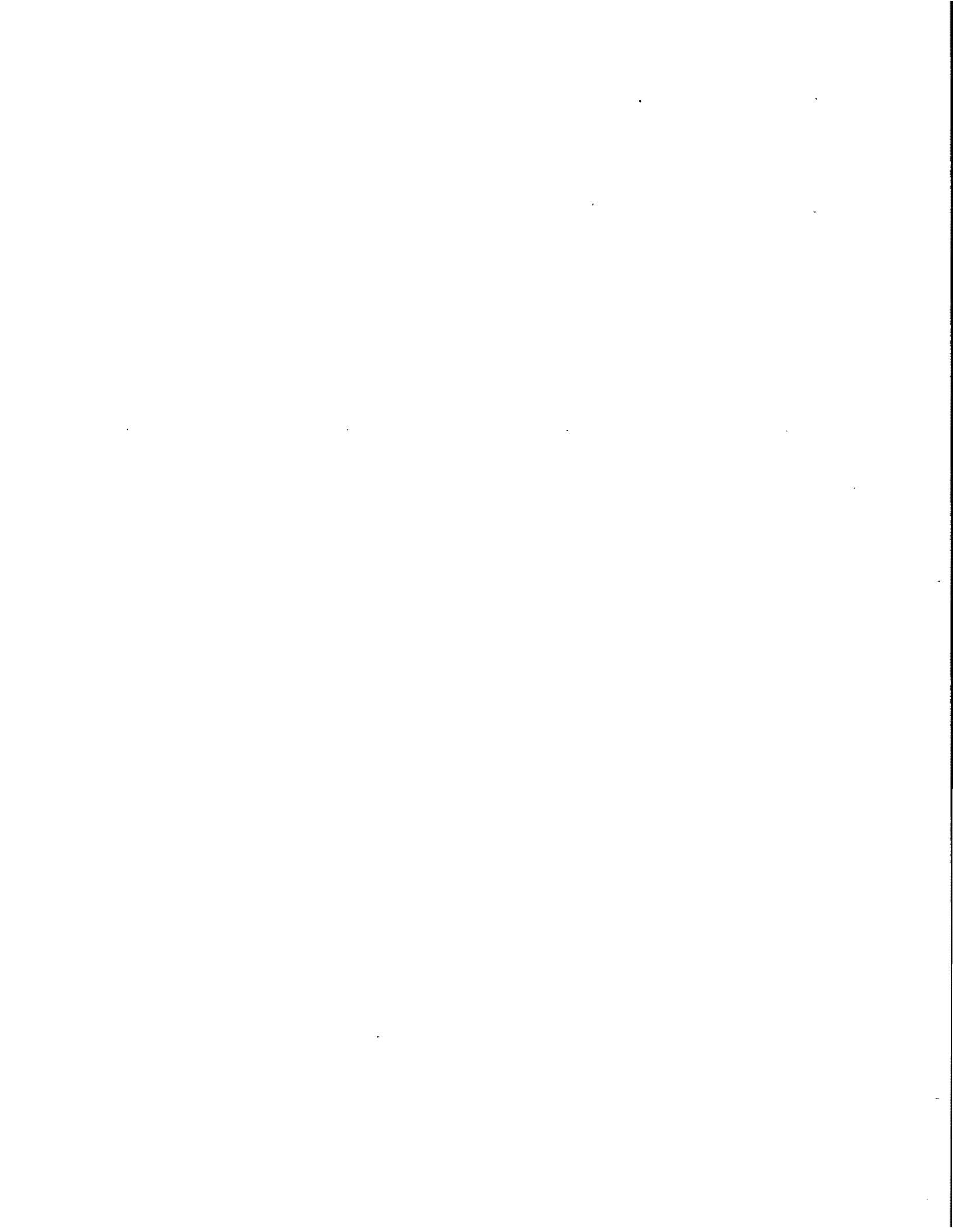
Appendix A.

Summary of Traffic Volume Variations in Field Study,

Texas SDHPT NASA 1 Road, Houston, Texas.

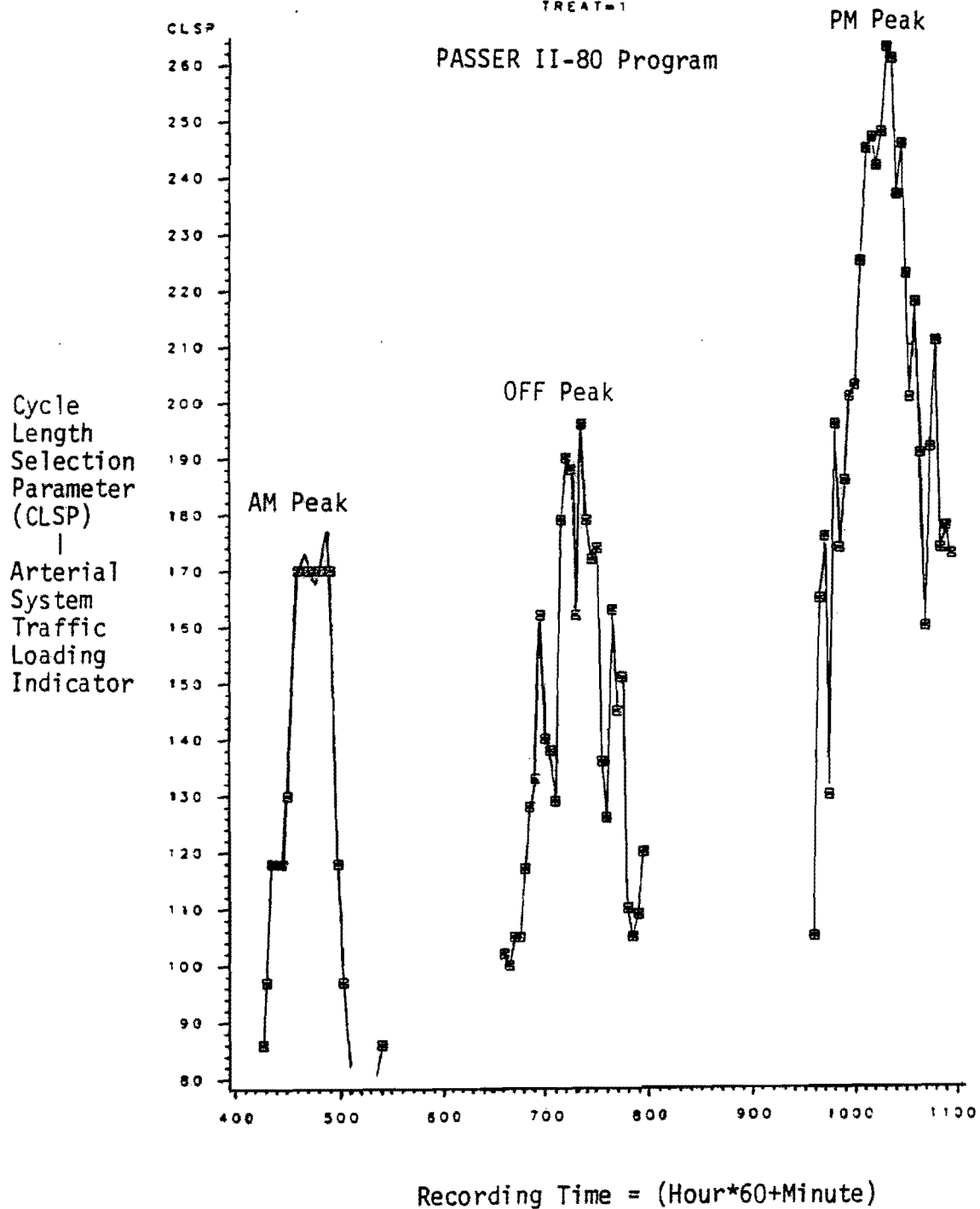### (May 22-24 and 29-31, 1984)

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Figure A-1.   Summary of Field Study Result -
Traffic Volume Variation - PASSER II-80 Program
NASA 1, Houston, Texas
(May 22, 1984)

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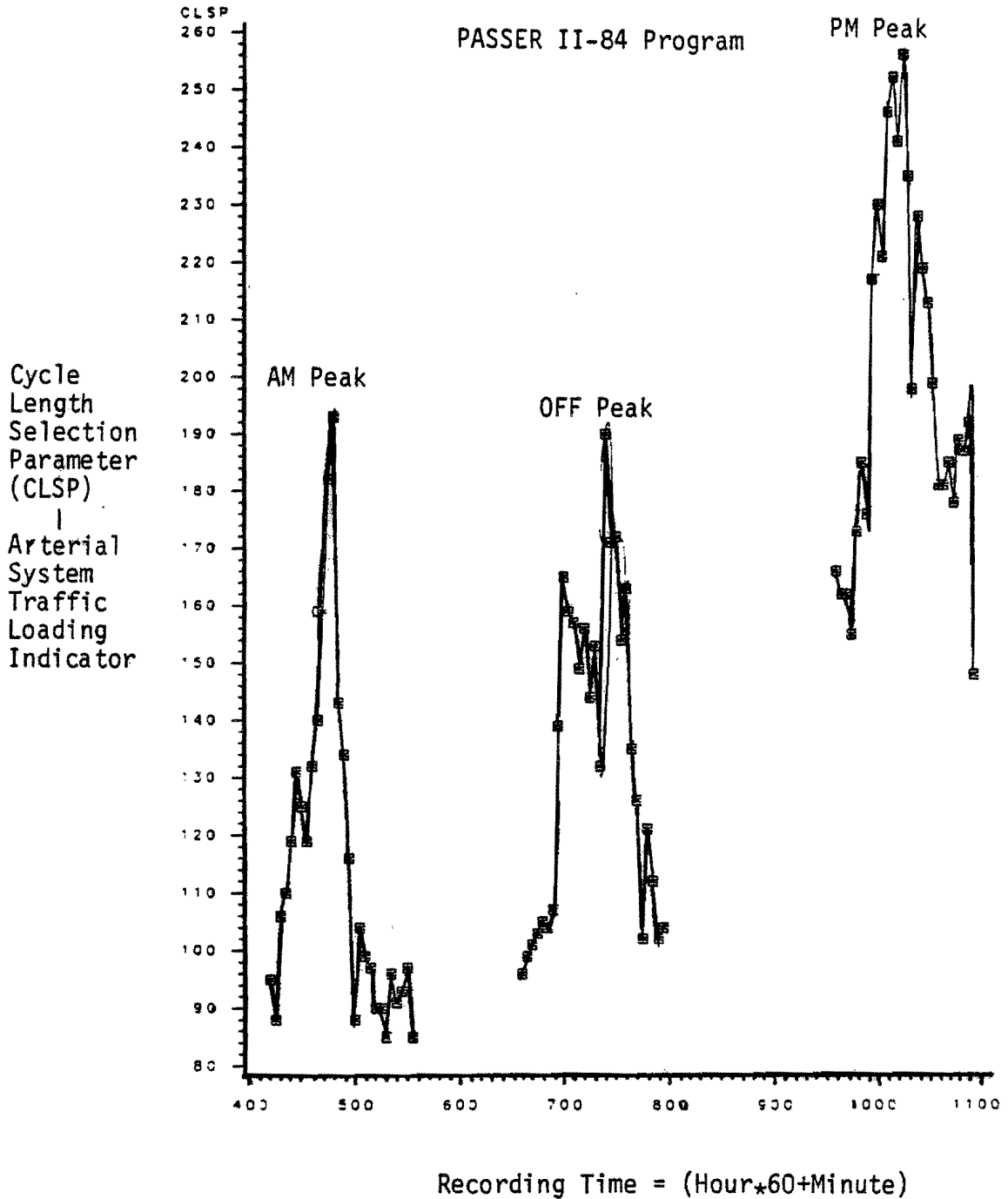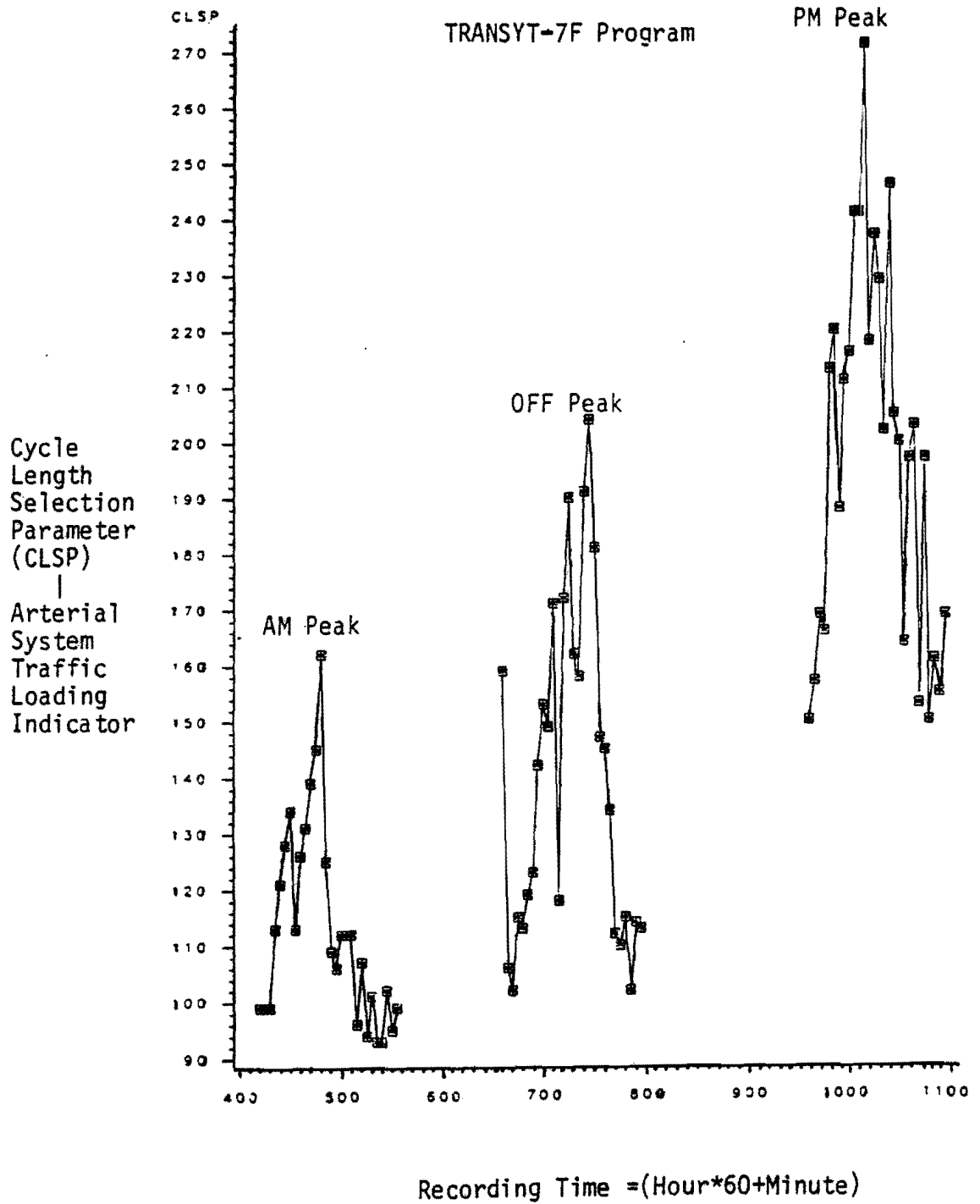WARRANTS OF INTERCONNECTION OF ISOLATED TRAFFIC SIGNAL
TREAT=2

Recording Time = (Hour*60+Minute)

Figure A-2. Summary of Field Study Result -
Traffic Volume Variation - PASSER II-84 Program
NASA 1, Houston, Texas
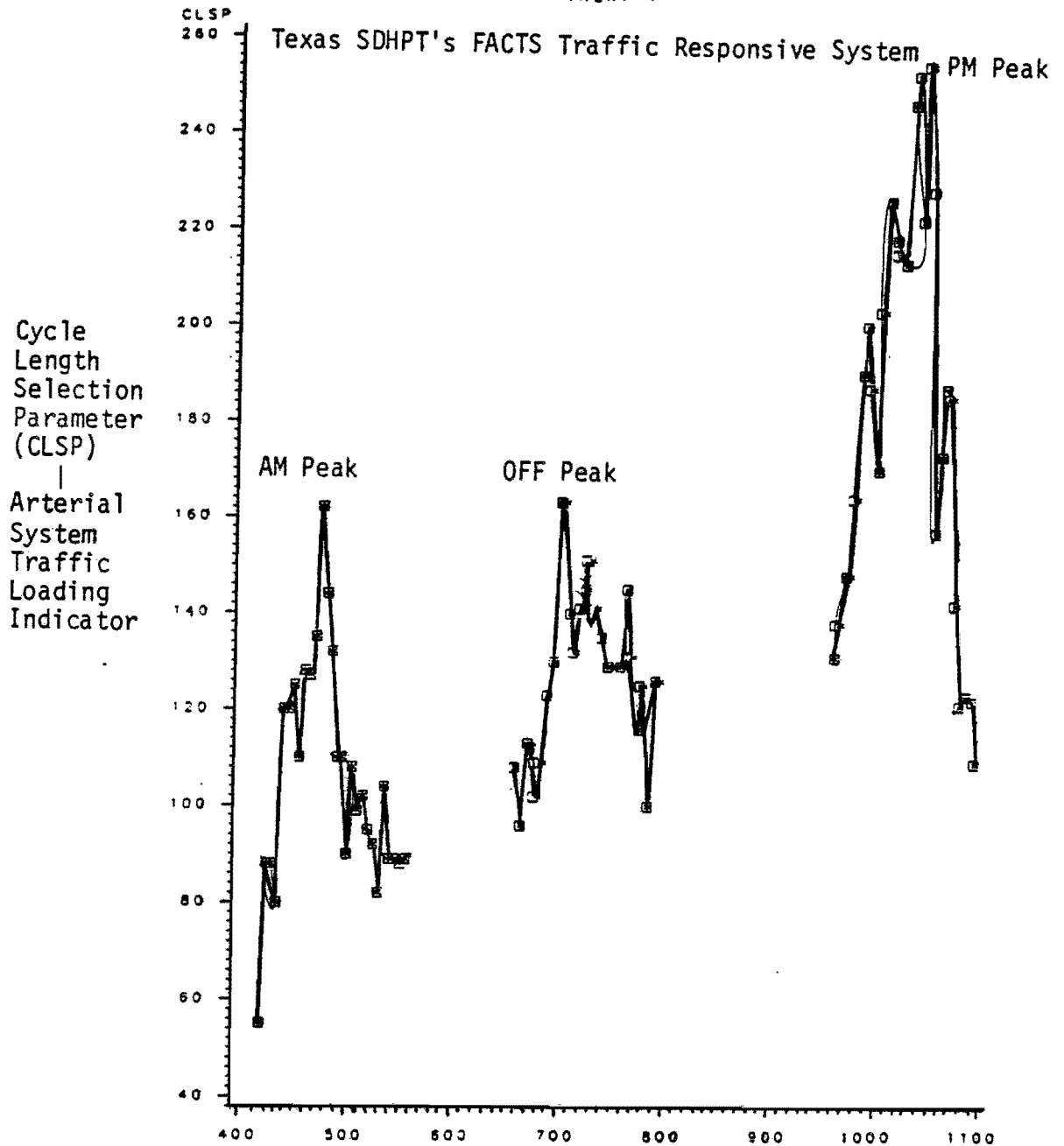(May 23, 1984)

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Figure A-3. Summary of Field Study Result -
Traffic Volume Variation - TRANSYT-7F Program
NASA 1, Houston, Texas
(May 24, 1984)

HPR 2293 STUDY

WARRANTS OF INTERCONNECTION OF ISOLATED TRAFFIC SIGNAL
TREAT=4

Recording Time = (Hour*60+Minute)

Figure A-4. Summary of Field Study Result -
Traffic Volume Variation - Texas SDHPT's FACTS Traffic
Responsive System
NASA 1, Houston, Texas
(May 29, 1984)

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HPR 2293 STUDY
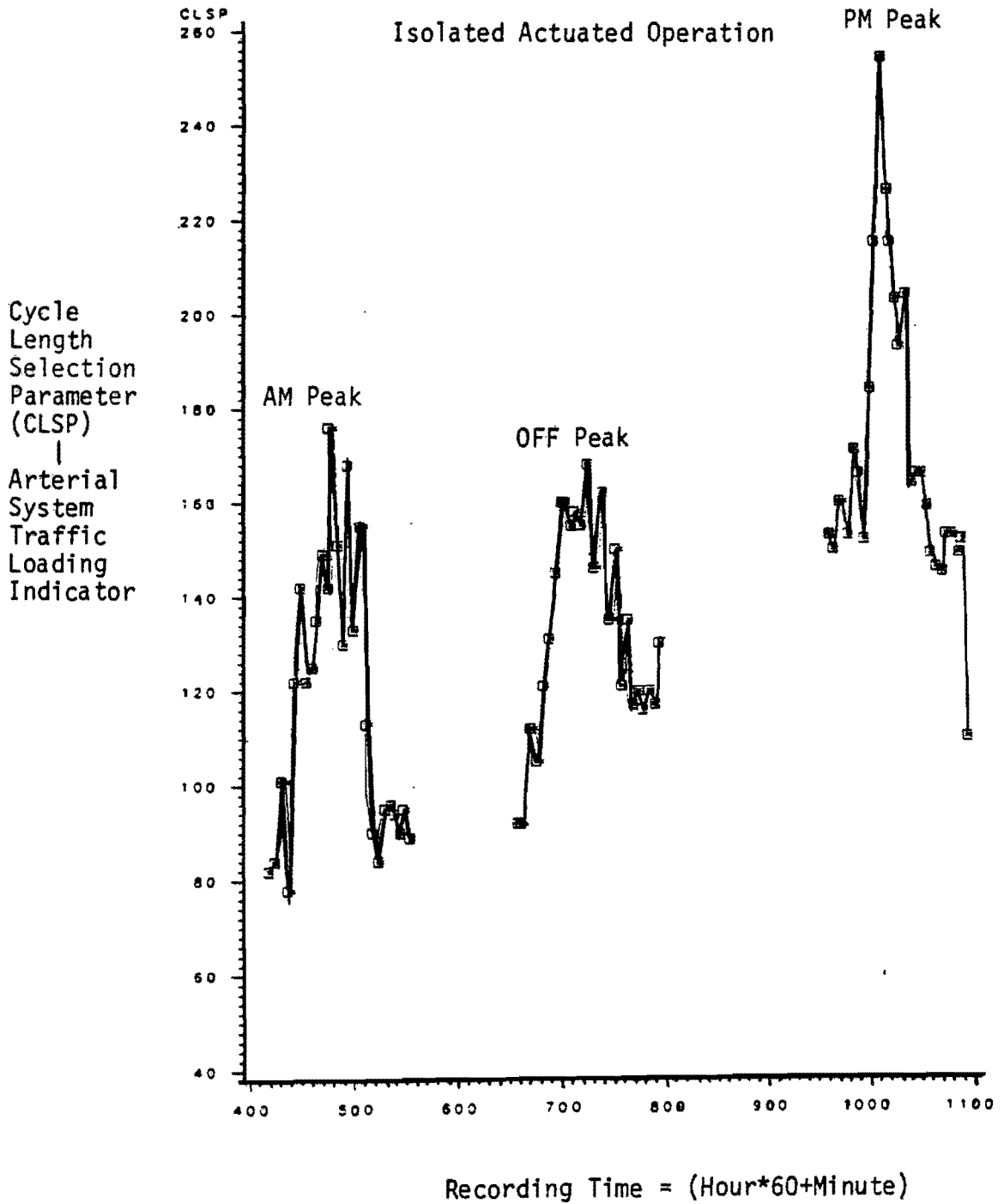
Recording Time = (Hour*60+Minute)

Figure A-5.   Summary of Field Study Result -
Traffic Volume Variation - Isolated Actuated Operation
NASA 1, Houston, Texas
(May 30, 1984)

HPR 2293 STUDY

WARRANTS OF INTERCONNECTION OF ISOLATED TRAFFIC SIGNAL
TREAT=6

Cycle
Length
Selection
Parameter
(CLSP)
|
Arterial
System
Traffic
Loading
Indicator

Critical Intersection Control

OFF Peak

PM Peak

AM Peak

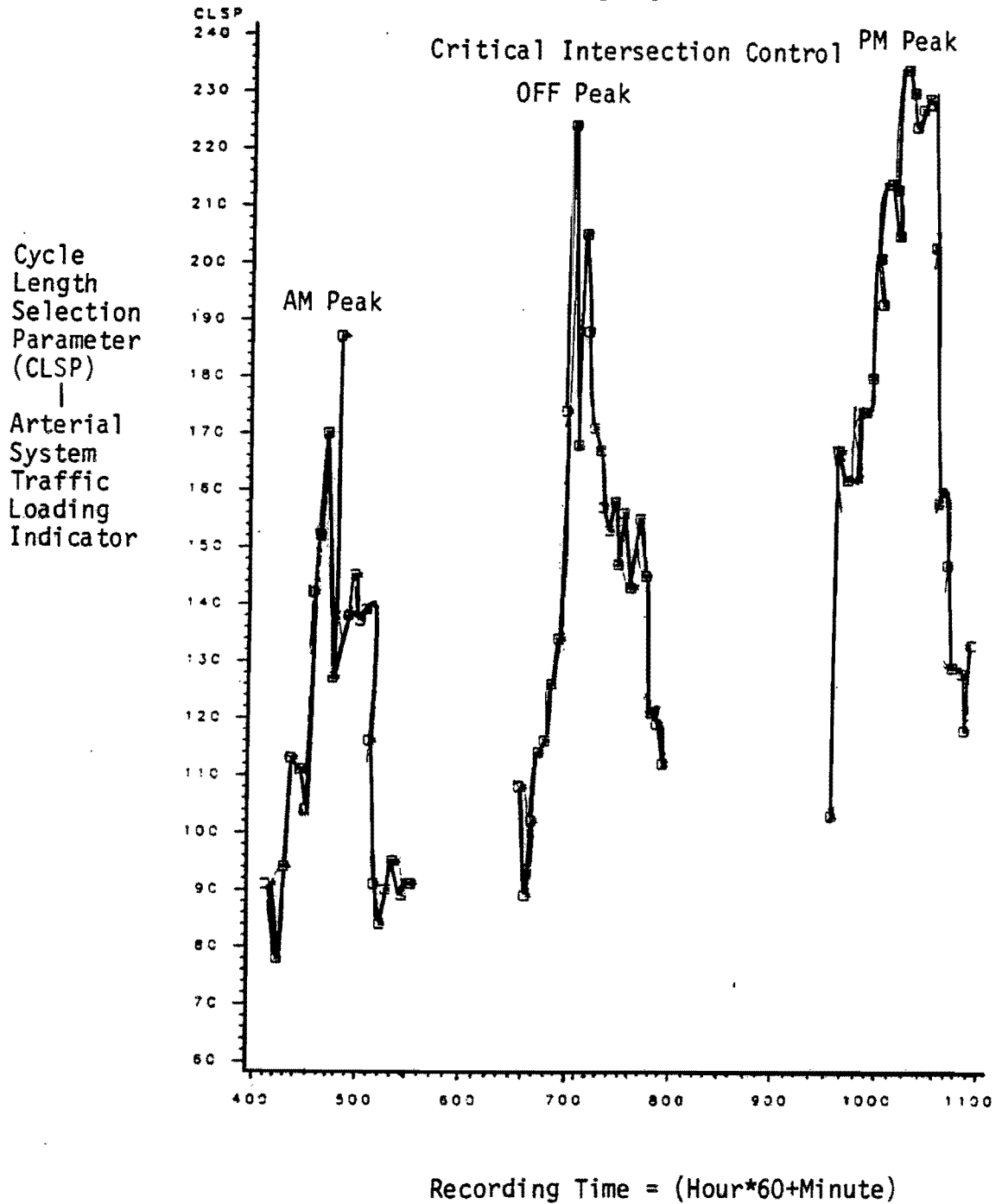Recording Time = (Hour*60+Minute)

Figure A-6. Summary of Field Study Result -
Traffic Volume Variation - Critical Intersection Control
NASA 1, Houston, Texas
(May 31, 1984)

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