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16. Abstract

This document provides guidelines and procedures for the retiming of arterial streets, including procedures for data collection, and the types and amount of data to be collected; the analytical procedures and software packages that are available for signal retiming projects; and examples of step-by-step applications for each type of signal retiming project.

Section One, Introduction, provides background information and discusses how to determine if a signal should be retimed. Section Two, Arterial Streets, discusses the characteristics of an arterial street, including the types of phasing, controllers, measures of effectiveness, and signal timing methods. Section Three, Data Requirements, discusses the procedures and requirements for data collection along an arterial.

Section Four, Evaluation, provides information needed for the simulation of existing arterial operations, including the use of currently available software programs. Section Five, Optimization, provides the guidelines to optimize timings along a typical arterial. Section Six, Implementation, explains the interpretation of optimized signal plans and implementation in the field. Section Seven, Documentation, explains how the benefits of signal retiming can be calculated, and provides examples of possible benefits.

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IMPLEMENTATION GUIDELINES FOR

RETIMING ARTERIAL STREETS

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

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	2.54	centimeters	cm
ft	feet	0.3048	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	6.452	centimeters squared	cm^2
ft^2	square feet	0.0929	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
mi^2	square miles	2.59	kilometers squared	km^2
ac	acres	0.395	hectares	ha
		MASS (weight)		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		VOLUME		
fl oz	fluid ounces	29.57	millimeters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.0328	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

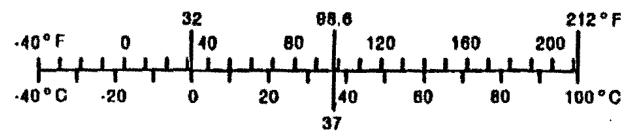
Note: Volumes greater than 1000 L shall be shown in m^3.

These factors conform to the requirement of FHWA Order 5190.1A

*SI is the symbol for the International System of Measurements

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
yd	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
yd^2	kilometers squared	0.39	square miles	mi^2
ha	hectares (10,000 m^2)	2.53	acres	ac
		MASS (weight)		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME		
mL	millimeters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



IMPLEMENTATION STATEMENT

The objective of this study is to place in a single set of documents, implementation guidelines for traffic signal retiming projects in Texas. These documents include the types and amounts of data to be collected, and the procedures for doing so; the analytic procedures and software packages that are available and the types of projects for which they are suited; and examples featuring step-by-step applications for several typical signal retiming projects in Texas. This set of documents also includes field implementation and evaluation guidelines. Specific types of signal retiming projects addressed by this study are as follows:

1164-1 Implementation Guidelines for Retiming Isolated Intersections;

1164-2 Implementation Guidelines for Retiming Arterial Streets;

1164-3 Implementation Guidelines for Retiming Diamond Interchanges;

1164-4 Implementation Guidelines for Retiming Arterial Networks; and

1164-5 Implementation Guidelines for Retiming Freeway Corridors.

The objective of this document is to provide implementation guidelines and procedures for retiming signalized arterial streets.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation and is NOT INTENDED FOR CONSTRUCTION, BIDDING, OR PERMIT PURPOSES.

ACKNOWLEDGEMENTS

The research reported herein was performed as part of a study entitled "Implementation Guidelines for Traffic Signal Retiming Projects" by the Texas Transportation Institute and sponsored by the Texas Department of Transportation. This study was conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration. Dr. Daniel B. Fambro, P.E. No. 47535 (Texas) of the Texas Transportation Institute served as the research supervisor, and Mr. Herman H. Haenel and Mr. Charles Riou of the Texas Department of Transportation served as technical coordinators.

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1.0 INTRODUCTION

1.1 Background

With both urban congestion increasing and available funding decreasing in Texas cities, Texas Department of Transportation (TxDOT) engineers face a growing problem of developing low-cost solutions to increase the capacity of their signalized intersections and arterial streets. The state's assumption of the maintenance of those traffic signals in cities between 15 and 50 thousand in population and at freeway interchanges, together with the initiation of the Primary Arterial Street System (PASS) program for larger cities, adds to the magnitude of the problem.

Some of the lowest cost methods of dealing with capacity problems are traffic signal retiming projects. Signal optimization and retiming projects have received increased attention as cost-effective and transportation systems management (TSM) measures. Results from several studies demonstrate that substantial energy savings can be achieved through the development of improved timing plans on existing signal systems. Also, unnecessary delays and stops at traffic signals are eliminated, resulting in travel time savings for the public.

The development of efficient signal settings requires detailed data collection of traffic and geometric conditions, application of improved methods to optimize the signal timing plan, and field implementation and evaluation of the improved signal timings. Several techniques and computer programs have been developed, and are available to traffic signal analysts to analyze existing conditions and optimize signal timing to minimize delays and stops and improve traffic progression.

Because of the diversity of retiming project types and the number of techniques and tools available, however, there exists no single procedure or set of guidelines that applies to all projects. Field implementation and evaluation guidelines also are virtually nonexistent in the literature. In addition, most districts do not undertake such projects on a routine basis. For these reasons, it would prove beneficial if a set of guidelines and procedures for several types of typical traffic signal retiming projects were available to each district. These guidelines should cover not only the development of new timing plans, but also their subsequent implementation and evaluation.

1.2 Objectives

This study places implementation guidelines for traffic signal retiming projects in a single set of documents. These documents would include the types and amounts of data to be collected, and the procedures for doing so; the analytic procedures and software packages available, and the types of projects for which they are suited; and examples featuring step-by-step applications for several typical traffic signal retiming projects in Texas. This set of documents also includes field implementation and evaluation guidelines. Specific types of retiming projects addressed are as follows:

1164-1	Implementation Guidelines for Retiming Isolated Intersections;
1164-2	Implementation Guidelines for Retiming Arterial Streets;
1164-3	Implementation Guidelines for Retiming Diamond Interchanges;
1164-4	Implementation Guidelines for Retiming Arterial Networks; and
1165-5	Implementation Guidelines for Retiming Freeway Corridors.

This document seeks to provide implementation guidelines and procedures for retiming signalized arterial streets. It will include the types and amounts of data to be collected, and the procedures for doing so; the analytical procedures and software packages available for a particular project and examples of step-by-step applications for each type of arterial street signal retiming project.

1.3 Organization

This document provides guidelines and procedures for implementing traffic signal retiming plans for coordinating signalized intersections along an arterial street. Separate documents address other types of traffic signal retiming projects. The guidelines and procedures for arterial street traffic signal retiming projects are organized as follows:

- 1.0 Introduction
  - 1.1 Background
  - 1.2 Objectives
  - 1.3 Organization
  - 1.4 When to Retime Signals Along an Arterial Street

- 2.0 Arterial Streets
  - 2.1 Characteristics
  - 2.2 Types of Phasing
  - 2.3 Types of Control
  - 2.4 Signal Timing Methods
  - 2.5 Coordination Methods
  - 2.6 Measures of Effectiveness

- 3.0 Data Requirements
  - 3.1 Traffic Data
  - 3.2 Signal Data
  - 3.3 Geometric Data

1.4 When to Retime Signals Along an Arterial Street

Public complaints are usually the first signs of traffic signal operational problems. Signal retiming cannot address all complaints, but the number of complaints indicate a need for at least a field observation and/or an engineering study. Some common complaints include: excessive approach delay, left turn delay, excessive queues, and poor progression (i.e., stoppages at every intersection). Traffic signal analysts can make field observations to determine the legitimacy of the complaints. Major problems will be obvious to the observer, such as long queues, ineffective use of green times and excessive cycle lengths (greater than 150 seconds). In some cases, equipment such as detectors may need repair. If one rules out these problems, retiming may be a solution to improving the signal's operational efficiency. As a rule of thumb, one should make field observations or studies every three to five years to determine if signal retiming is necessary.

Changes in traffic flow caused by land use and population changes, addition or deletion of signals in the area, changes in major traffic generators, and for changes in the geometry of the roadway or intersections may create the need for retiming signals. Some jurisdictions recommend yearly inspection and documentation (field data and/or video data) of signal operations. This type of documentation will help identify operational problems before they become severe.

2.0 ARTERIAL STREETS

2.1 Characteristics

A series of signalized intersections along an arterial street comprise an arterial street system. Such systems provide mobility from Point A to Point B by efficiently moving vehicles along the street segment. Given adequate design and access features, signal coordination can provide mobility along an arterial street that allows vehicles to progress through a series of signals without stopping. Some of the problems that occur along arterial streets as a result of poor or outdated signal timing and increasing or changing traffic demand include:

1. Lack of progression, causing excessive stops and low average travel speed;

2. Inadequate phase capacity at intersections, causing an additional amount of overflow traffic delay to occur and creating a bottleneck in the system; and

3. Overflow demand at turn bays and intersection approaches, causing blockage of through lanes and upstream intersections.

The following sections describe the types of phasing and controllers used at arterial street intersections; methods of timing intersections and coordinating the signals along an arterial street; and the measures of effectiveness used to evaluate arterial operations.

2.2 Types of Phasing

Descriptions of the type of phasing at each intersection along the arterial can be divided into three parts: the individual movement numbers, the type of left-turn treatment, and the phasing sequence. The following paragraphs describe each of these components.

Movement Numbers. Most methods of signal timing analysis use the NEMA configuration for numbering movements, as shown in Figure 2-1. Each NEMA movement corresponds to a separate phase in an 8-phase dual-ring NEMA controller. Combinations of these movements are also considered as phases. To number the movements, start with Movement 1, (usually a left-turn movement) and move clockwise numbering each left-turn 3, 5, and 7. Movement 2 (usually a through movement) always lies across from Movement 1, and is usually chosen to represent the forward direction (i.e., the direction in which the intersections are numbered or sequenced) along the arterial. After selecting the direction for Movement 2, proceed clockwise to number the remaining through movements 4, 6, and 8.

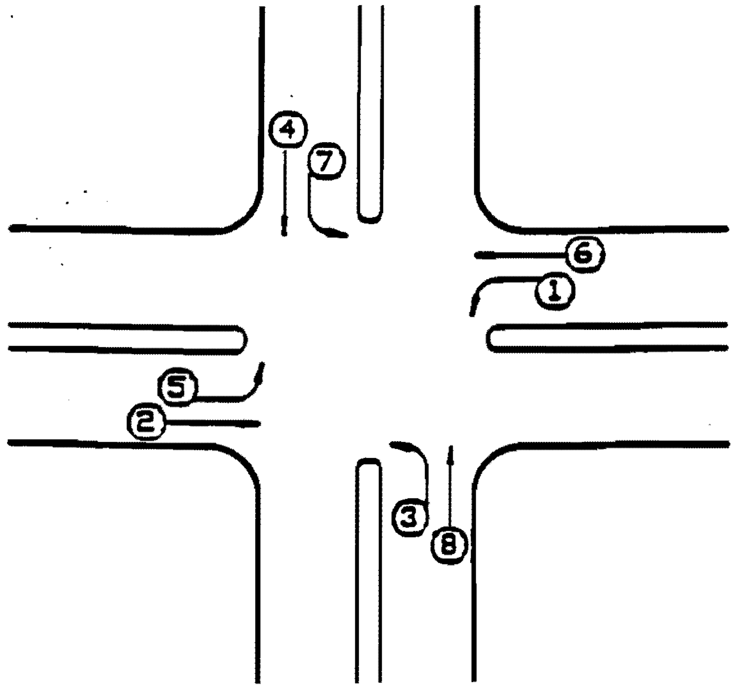


Figure 2-1. Movement Numbering Scheme for an 8-Phase NEMA Controller

Note that Movement 1 conflicts with Movement 2, Movement 3 conflicts with Movement 4, Movement 5 conflicts with Movement 6, and Movement 7 conflicts with Movement 8. These movement pairs are known as conflicting movements, and as a result of this conflict, they cannot have a green indication at the same time. This general rule serves as the basis for the signal timing methodologies and hardware described in this report.

Left-Turn Phasing. One can classify phasing schemes by the type of left-turn treatment that exists at the intersection. Left-turn movements can be permitted only, protected only, or protected-plus-permitted (combined), as illustrated in Figure 2-2 and described below:

Permitted - Left turns must yield to opposing traffic. They may proceed on a green ball after yielding to oncoming traffic.

Protected - Left turns proceed separately from opposing traffic. They may proceed either during a green left-turn arrow or during the time that opposing movements are stopped (i.e., during the split phase).

Geometry	Permitted Phasing	Protected Phasing	Combined Phasing
No Bay	1	2	3
Bay	4	5	6

Phasing

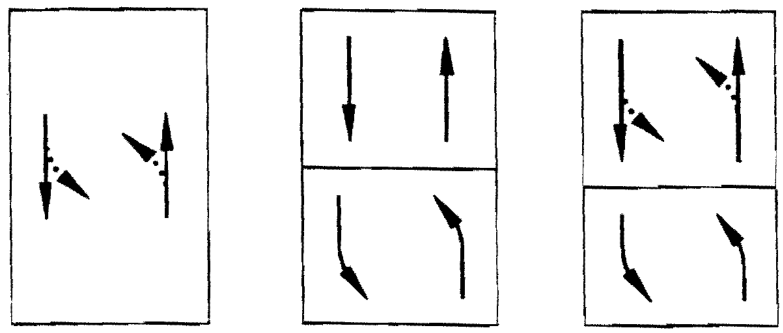


Figure 2-2. Left-Turn Treatment Alternatives

Protected/Permitted - Left turns are protected during part of the cycle and permitted in another part of the cycle. They may proceed either during the protected left-turn phase and on a green ball after yielding to oncoming traffic.

Phase Sequence. The phase sequence represents the order in which the phases are displayed at a signalized intersection. Protected left-turn phases may be leading, lagging, lag-lead, or lead-lag for the arterial and cross streets. It is not unusual for the phasing sequence on the arterial street to be different from the phasing sequence on the cross street. It also is not unusual for different intersections to have different arterial phasing sequences in order to improve progression along the arterial.

Leading Lefts - Both protected left-turn movements proceed before the through movements.

Lagging Lefts - Both protected left-turn movements proceed after the through movements.

Lag-lead/lead-lag - One protected left-turn movement and its adjacent through movement proceed before or after the opposing protected left-turn movement and its adjacent through movement.

If the duration of the phases serving the two concurrent movements equal one another (i.e., the concurrent phases start and end at the same time), analysts describe the phasing as "without overlap" phasing. If the duration of the phases serving the two concurrent movements do not equal one another (i.e., the concurrent phases start at the same time, but end at a different time), the description is "with overlap" phasing. Respectively, these two phasing sequence descriptors are analogous to single and dual ring control. One should note that the terminology for describing phase sequences may vary between signal timing software and traffic controller hardware. Figure 2-3 illustrates one set of guidelines for selecting the type of left-turn phasing sequence to implement at a signalized intersection.

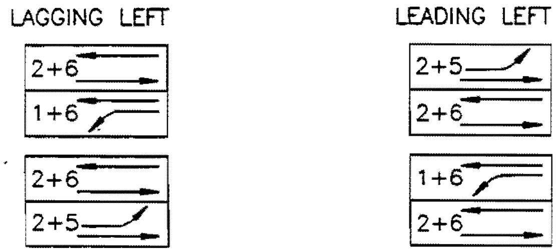
2.3 Types of Control

The type of controllers at intersections along an arterial street affect the number of timing plans that can be implemented, as well as the number of allowable phases and sequences. Analysts typically operate a coordinated arterial system in one of two ways. First, one may control the system by predetermined signalization schemes designed to accommodate the anticipated traffic demands on the system. This type of control is referred to as pretimed operation. Second, one may control the system by signalization operations that maintain progression but are responsive to the current traffic demands in the system. This type of control is referred to as actuated or semi actuated operation.

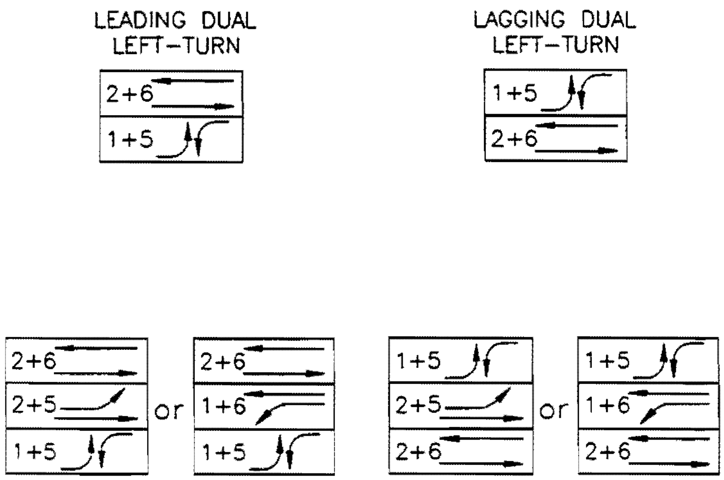
Pretimed Coordinated Control. Under pretimed control, analysts assign right-of-way in a predetermined manner and coordinate the signal timings at intersections along the arterial to provide for progression. Fixed cycle length, fixed phase sequence, fixed phase length, and fixed offsets compose the major elements of pretimed control. Depending on equipment, one may use several timing plans; the appropriate phase is implemented automatically at fixed times of the day, usually with one timing plan for the a.m. peak period, one timing plan for the p.m. peak period, and one timing plan for the off-peak period.

Pretimed coordination are recommended for certain types of design and operational conditions. Design conditions that benefit from coordination are predominantly associated with intersection spacing. Generally, as the distance between signals decreases, the need for coordination increases. Signal spacing may range from 150 to 5000 feet, but spacings between 800 and 1000 feet prove ideal for coordination.

LEFT-TURN PHASING	GUIDELINES

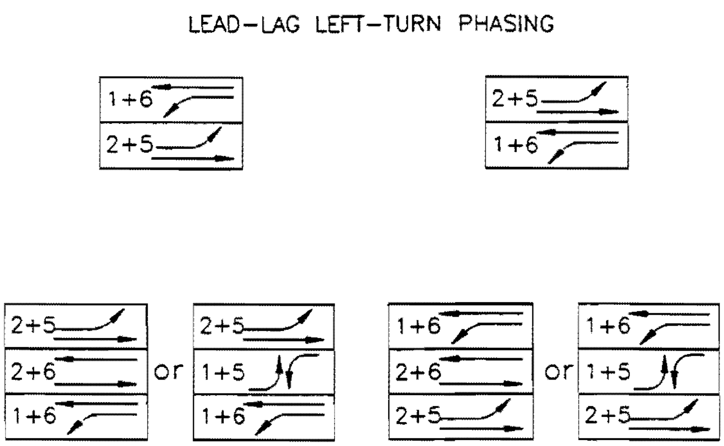


SPECIAL PHASING
* Applicable for T-intersections or where opposing left-turns are prohibited.
* Can be used with either pretimed or actuated control.
* Use should be kept to a minimum where no left turn lane exists due to possibility of one movement blocking the other.



NO OVERLAP PHASING
* Simple and inexpensive.
* Can be provided with pretimed or single ring actuated controllers.
* Should be kept to minimum since both left-turns receive exactly the same green time.
* Lagging left should only be used when system operation needs dominate safety consideration.

OVERLAP PHASING
* Applicable for dual ring actuated controllers.
* An efficient method of providing protected only left-turn phase.
* Through movement is allowed to move when there is no opposing left-turn traffic.



SPLIT PHASING (NO OVERLAP)
* Applicable when left-turn volume is very heavy in both directions and is equal or greater than the companion through movement.
* Effective when one of the through lanes must be used as an optional left-turn lane or where a separate left-turn lane can not be provided.

OVERLAP PHASING
* Either pretimed or dual ring actuated controller can be used.
* As efficient as dual left with overlap phasing.
* Should be used only for interconnected signals where its use will increase the width of the progressive band.

Figure 2-3. Guidelines for Selecting Left-Turn Phasing Sequences

Traffic conditions that benefit from pretimed arterial coordination include circumstances where there are a limited number of traffic patterns, and there is no significant changes in these traffic patterns. Peak periods with heavy directional traffic volumes are additional conditions where pretimed coordinated control proves advantageous. If more than three phases are required, however, pretimed control is not generally recommended.

For pretimed operations, two types of controllers exist: electromechanical (no longer being manufactured) and solid state. The electromechanical controller is comprised of one or more (usually no more than three) dials driven by a synchronous motor. Each dial corresponds to a different cycle length; for example, one dial for the a.m. period, one dial for the p.m. period, and one dial for the off-peak period. A solid state controller is similar to an electromechanical controller, except solid state components replace the mechanical parts (the dial units, camshafts, and keys). A microprocessor controls operations. For more details about the hardware, refer to the *Traffic Control Systems Handbook* (1). One should note, however, that the Texas Department of Transportation (TxDOT) no longer purchases pretimed controllers. Rather, they purchase fully actuated controllers and then use them as pretimed controllers when conditions warrant.

Semi-Actuated Coordinated Control. Semi-actuated coordinated control is suited for arterial streets where traffic is unpredictable and demand varies. Traffic actuated control attempts to adjust green times, and in some cases skip minor phases to provide additional green time where vehicular demand warrants it; i.e., along the arterial street. Detectors placed in the approach lanes provide demand information to the controller. The basic timing parameters are yellow plus red clearance times, minimum green times, green extension interval, and maximum green interval. Definitions for these basic timing parameters follow:

Yellow plus red clearance time -	The portion of time that occurs at the end of the phase and provides adequate time for all vehicles to safely exit the intersection. This parameter is based upon the speed of the vehicles traveling through the intersection, the width of the intersection, and driver expectancy.
Minimum green time -	The length of time considered as the shortest amount of time that a phase is allowed to be green. This parameter is usually based upon pedestrian walk time or the location of the detector. The actual green time cannot equal less than the "minimum green" time.
Extension interval -	The portion of time that the green interval can be extended is based on detector location. A minimum extension time should allow a vehicle

sufficient time to travel from the point of detection to the stop line, or, in the case of multiple detection, time to travel from the point detection to the next detector.

Maximum green interval - The maximum green interval is the longest time a green indication will be displayed in the presence of a call on a conflicting phase.

When specifying controller settings for coordinated semi-actuated controllers, the following signal timing parameters may be encountered:

Yield Point - The yield point is the earliest point at which the coordinated phase may end to give right of way to one or more of the conflicting phases. The yield point normally occurs at the beginning of the yellow interval (end of the green interval) of the coordinated phase.

Force-off - The force-off point is the fixed point/points in the background cycle length used to give right of way to one or more of the conflicting phases. One calculates force-off points by adding the splits for each phase beginning with the start of the interval to which the yield point is referenced.

Figure 2-4 illustrates the above definitions of yield and force-off points.

There are two basic hardware designs for actuated controllers: the type 170 and the NEMA standard. The states of California and New York jointly developed Type 170 controllers, which require software to operate. Changes in traffic conditions are accommodated by updating the software. NEMA (National Electrical Manufacturers Association) controllers meet specifications whose standards reflect input from traffic engineers, installers of traffic signal equipment, and professionals in the field of traffic control. The NEMA specifications describe physical and functional requirements for fully actuated signal controllers. For more information on these controllers, refer to the *Traffic Control Systems Handbook* (1). It should be noted that TxDOT only purchases actuated controllers conforming to NEMA standards, and that they have developed a set of standard specifications for their controllers.

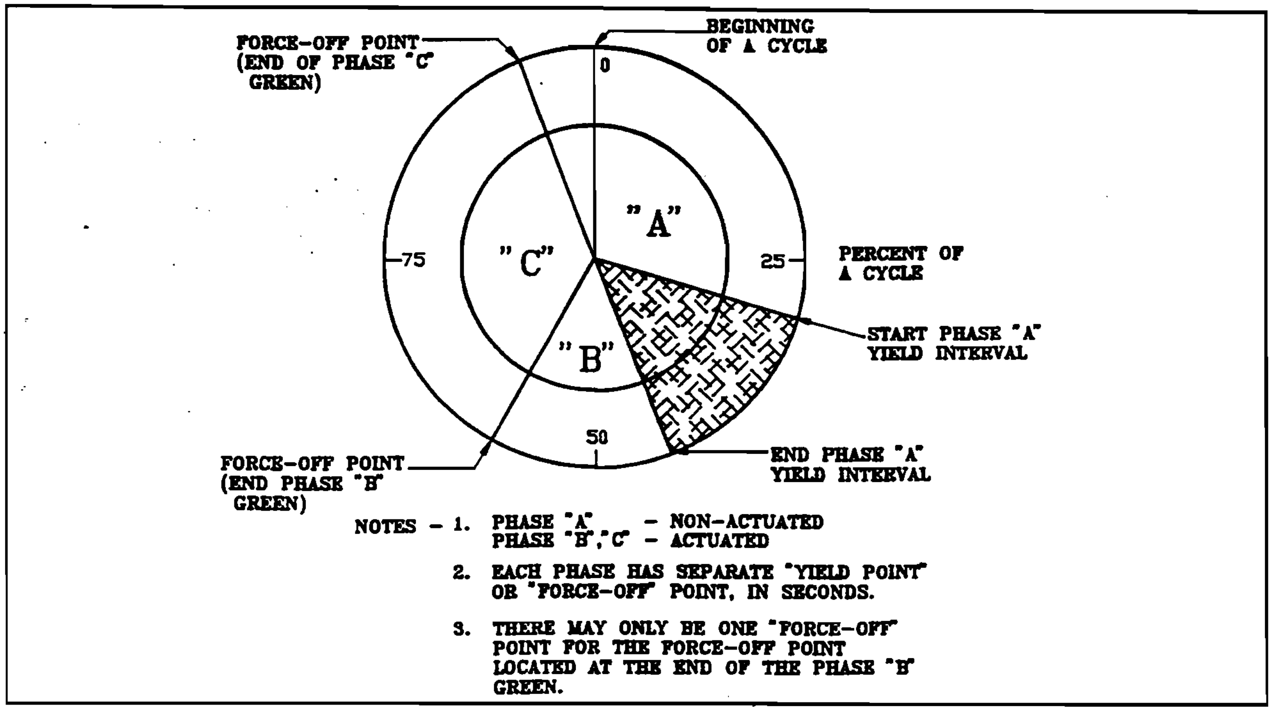


Figure 2-4. Yield Point and Force-Off Point for Semi-Actuated Controller

Actuated coordinated control of arterial street systems is predominantly at the semi-actuated operational level. Semi-actuated arterial control provides the main street with as much green time as possible and only services the intersecting cross streets in response to traffic demand. Actuated arterial signals operate on a common background cycle and force-off points provide synchronization. Coordination is provided for the arterial street phase (sync phase), which is commonly not actuated. Actuated phases consist of those serving the cross street and the main street left-turn movements.

Actuated controllers can either be single-ring (sequential) or dual-ring (concurrent) and can provide different combinations of phase sequences. Single-ring controllers are four-phase controllers that handle each phase sequentially and return to the first phase at the end of the series. A specific preferred phasing sequence is used, and phases cannot occur simultaneously (i.e., overlap cannot be used). Figure 2-5 illustrates single-ring control with leading lefts on both the arterial and cross streets.

Dual-ring controllers can accommodate eight-phases corresponding to eight movements at the intersection. Concurrent timing may be used, which allows a traffic phase to be selected and timed simultaneously and/or independently with another phase. One may skip phases and use overlap phasing. Figure 2-6 illustrates dual-ring control, with leading lefts on both the arterial and cross streets. Note that any phase to the left of the barrier in Ring 1 can be displayed simultaneously with any phase to the left of the barrier in Ring 2; i.e., they are non-conflicting phases. The same relationship is true for phases in Ring 1 and Ring 2 to the right of the barrier.

The type of control selected may affect intersection operation. At low to moderate volume to capacity ratios, actuated controllers are almost always more efficient than pretimed controllers because of the capability of adjusting green times and/or skipping phases in response to variations in vehicular demands. In fact, even at conditions approaching capacity, there is still enough variation in vehicular demands, particularly relative to left-turn phases, that actuated controllers can be more efficient than pretimed controllers. In addition, actuated controllers are more responsive to high volume conditions because their maximum cycle lengths are generally longer than optimal pretimed controller cycle lengths.

2.4 Signal Timing Methods

For an arterial street to operate effectively, analysts must optimize the signal timing at the individual intersections along the arterial facility. Signal timing at individual intersections seeks to find a "best" solution, characterized by a cycle length and green splits that accomplish a traffic engineering objective, such as minimizing delay, fuel consumption, or excessive queuing, or increasing the capacity of an intersection. One must then coordinate the timing for the individual intersections to achieve the traffic engineering objective for the entire arterial (i.e., an optimum timing plan for all intersections on the arterial). One should note that the best cycle length for all intersections may not equal the best cycle length for each individual intersection.

The optimum solution must consider coordinating the signals along the arterial to minimize stops, delays, and fuel consumption. One also must consider the traffic characteristics at different times of the day when coordinating the signals. During peak hours, a directional distribution of the traffic may occur; i.e, during the morning peak, most of the traffic could move in one direction, while in the afternoon peak, most of the traffic could move in the opposite direction. In such cases, one can provide progression exclusively for the traffic moving in the peak direction. During off-peak conditions, balanced progression can be provided in both directions, or intersections can be operated in an isolated mode. The best solution depends on the characteristics of the intersections along the arterial, intersection spacing, development along the arterial, traffic characteristics, and the objective of the traffic signal analyst.

One signal timing method often used for retiming intersections is based on equations developed by Webster (2). Equations for estimating delay, minimum delay cycle length, and green splits are based on Webster's original work. The following sections discuss each of these equations.

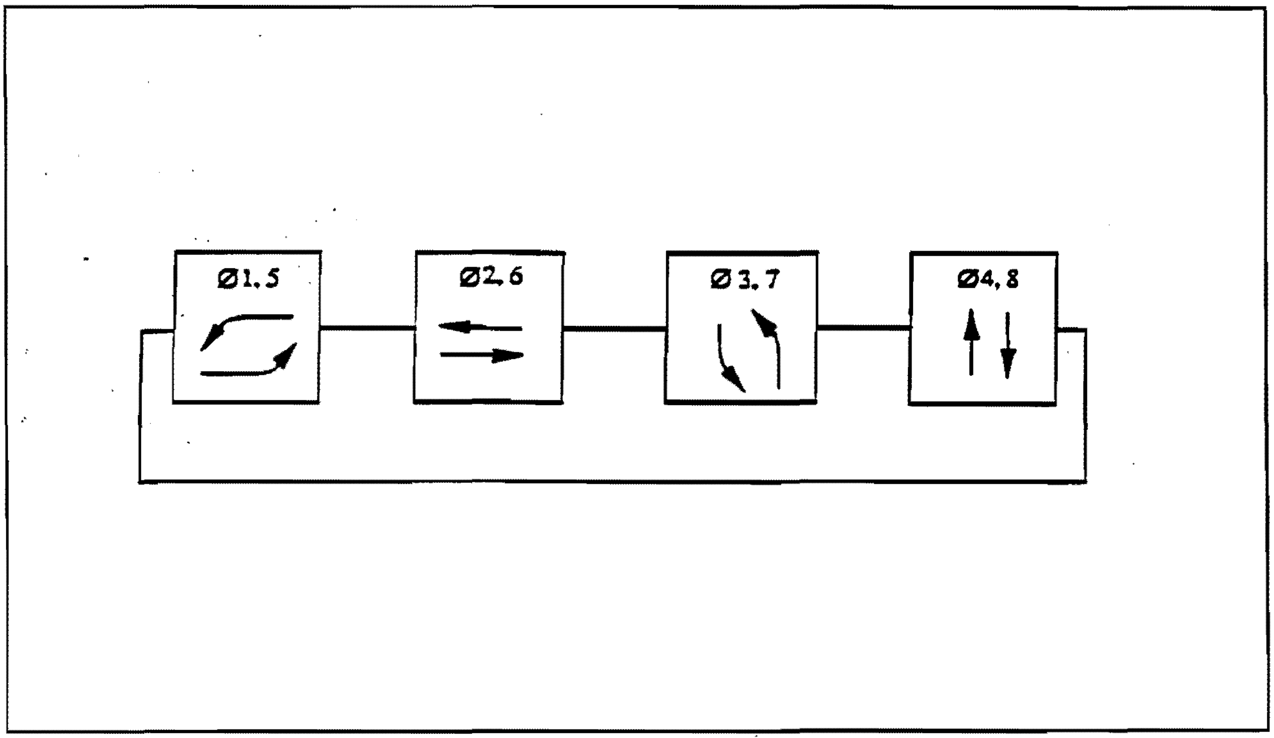


Figure 2-5. Phase Sequence for Single-Ring Control

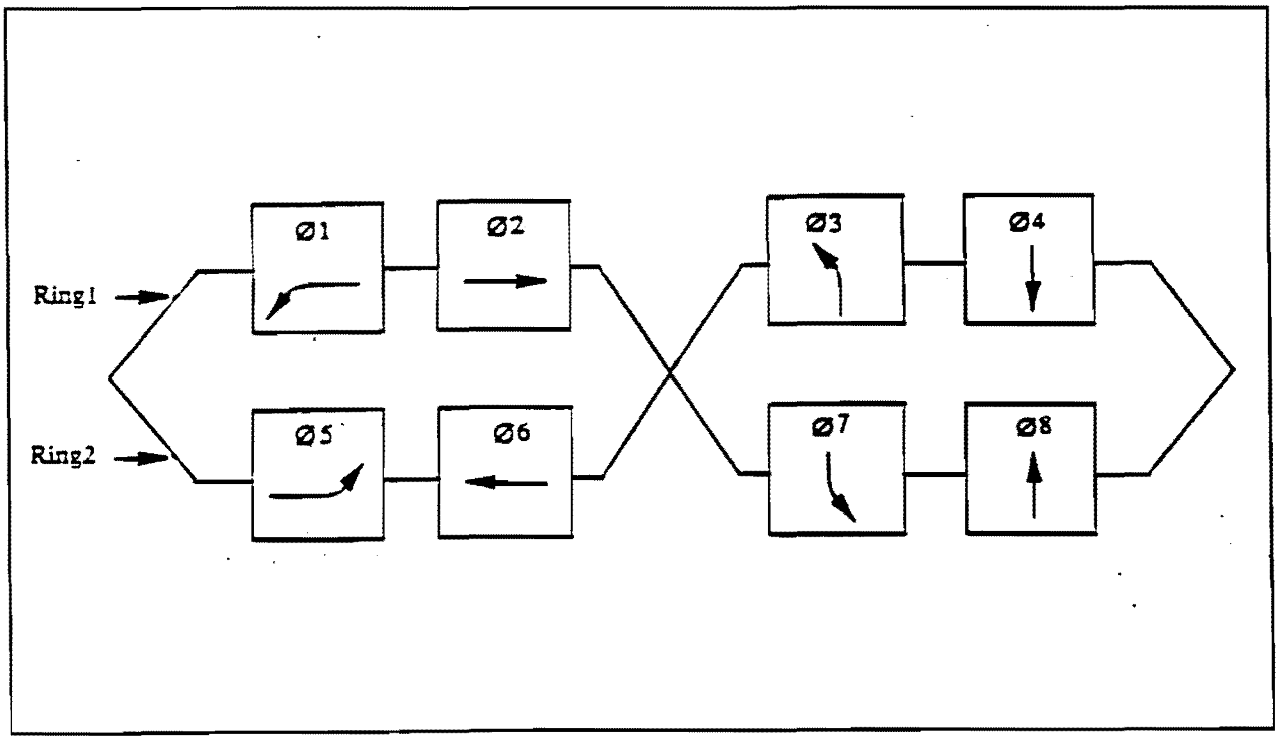


Figure 2-6. Phase Sequence for Dual-Ring Control

Minimum Delay Cycle. Analysts often use delay as a measure of effectiveness to determine the efficiency of a signalized intersection's operation. Figure 2-7 illustrates the variation in delay with cycle length, and the equation and location for Webster's minimum and minimum delay cycle lengths. Figure 2-8 illustrates the variation in minimum delay cycle lengths at various volume levels. Note that, a minimum delay cycle exists for each and every volume level, and if traffic volumes fluctuate during the day, an intersection may have a different minimum delay cycle and phasing sequence during different time periods. Note also that adjacent intersections with different traffic volumes may have different minimum delay cycle lengths. Webster's equation for calculating the minimum delay cycle is as follows:

$$C_o = (1.5\,L + 5) \ / \ (1 - \Sigma Y) \qquad [2\text{-}1]$$

where:

	C_o	=	minimum delay cycle length (seconds);
	L	=	total lost time (seconds); and
	ΣY	=	sum of the critical flow ratios, $y_1 + y_2 + \ldots + y_i$ (y_i = volume for critical movement i divided by the saturation flow rate for critical movement i).

The range of cycle lengths that provides acceptable average delays (near minimum delay) at a typical intersection is $0.8\,C_o < C < 1.3\,C_o$. Cycle lengths shorter than this range generally prove too short to handle the traffic volumes and cycle failures (oversaturation) will occur. Cycle lengths longer than this range generally prove longer than necessary to handle the traffic volumes, and wasted time resulting in long delays will occur.

After calculating the minimum delay cycle length for all intersections along the arterial, one selects the largest minimum delay cycle length (the maximum of the minimums) as the shortest cycle length for the system. Although this cycle length may be too long for the other intersections in the system, shortening the cycle length at the critical intersection may result in oversaturation and a bottleneck on the arterial. The longest allowable cycle length should be no more than 10 to 15 seconds longer than the shortest allowable cycle length to minimize the excess delay at the non-critical intersections.

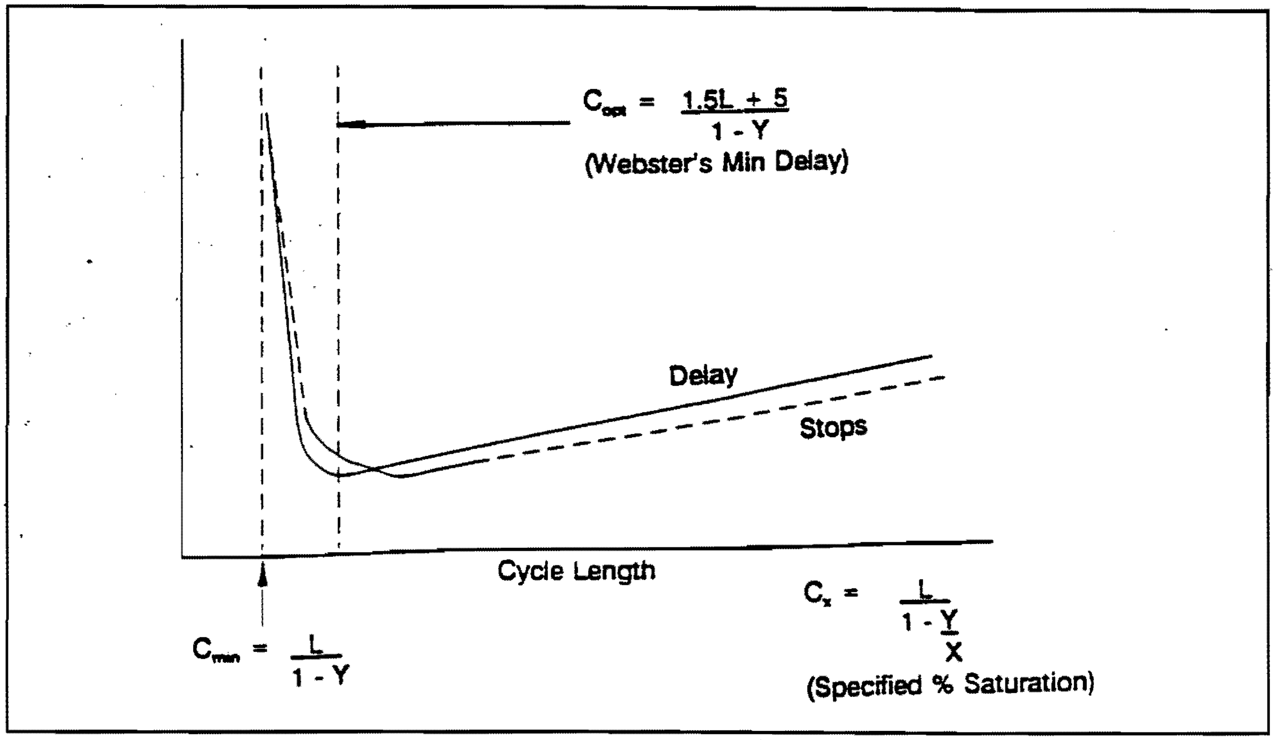


Figure 2-7. Minimum Delay Cycle Length

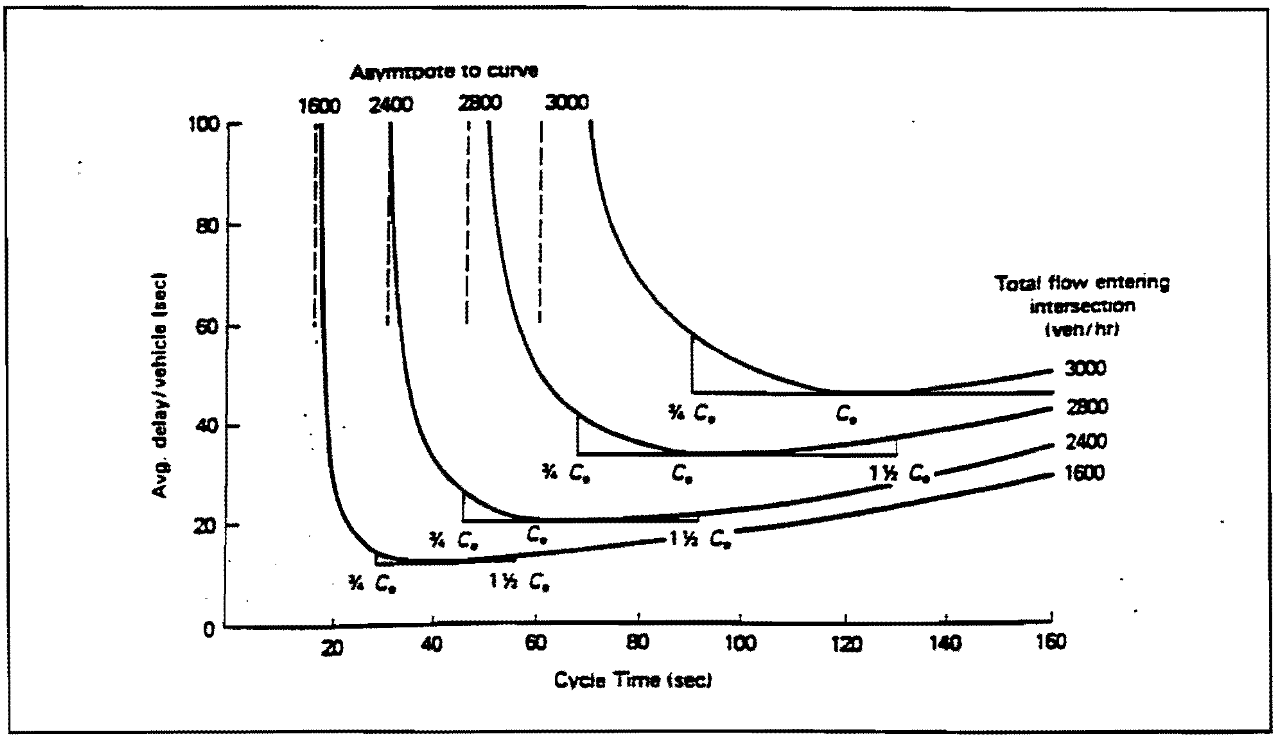


Figure 2-8. Variation in Delay with Cycle Length

Green Splits. After determining the cycle length, green time must be allocated to each phase. To determine the optimum green splits at a particular intersection, identify the critical movements and calculate their flow ratios. The sum of the critical flow ratios is denoted by the variable Y. The first step in calculating the green splits is the calculation of the overall volume to capacity ratio, X_I. Webster's method assumes X_I to equal the volume to capacity ratio for each critical movement (the volume to capacity ratio is the same for each movement, as well as for the entire intersection). The equation for calculating the intersection volume to capacity ratio is as follows:

$$X_I = (Y * C) / (C - L) \qquad [2\text{-}2]$$

where:

	X_I	=	intersection volume to capacity ratio;
	Y	=	sum of the critical flow ratios;
	C	=	cycle length (seconds); and
	L	=	total lost time at the intersection (seconds); the lost time per phase generally ranges from 3 to 5 seconds.

The equation for determining the green time for each critical movement is as follows:

$$g_i = (y_i * C) / X_I \qquad (2\text{-}3)$$

where:

	g_i	=	phase time G + Y + RC - lost time (seconds);
	y_i	=	flow ratio for movement i;
	C	=	cycle length (seconds); and
	X_i	=	intersection v/c ratio.

2.5 Coordination Methods

To provide an efficient coordinated system, one must develop cycle lengths, phase sequences, and green splits for each intersection in the system, and determine offsets to progress vehicles along the arterial. Coordination is achieved by altering the initiation of green phases at each intersection, such that the phase changes correspond with the arrival of a platoon of vehicles. Many of the objectives of arterial system coordination are similar to the objectives for intersection signal timing, such as minimizing overall delay, stops, and fuel consumption. A coordinated solution should also attempt to maximize the average travel speed along the arterial by providing progression (minimizing stops and delay) along the arterial.

One must determine optimal values for the following components to develop a coordinated arterial signal plan.

System cycle length - This cycle length is based on the intersection within the system that has the longest cycle length required to satisfy the demand for that intersection. For coordinated operation, the system must operate at one cycle length and is usually constrained by the individual intersection with the maximum (longest) minimum delay cycle length.

Phasing and splits - One must determine the phase sequences and lengths for each intersection in the system.

Offsets - One must calculate offsets relative to a master intersection for each intersection. Offsets also can be defined as the difference between the green initiation times at two adjacent intersections, and are usually expressed as a positive number between zero and cycle length.

Time-Space Diagram. A time-space diagram is simply a plot of signal indications as a function of time for two or more signals. One scales the diagram with respect to distance in order to plot the vehicle positions as a function of time. Figure 2-9 shows a time-space diagram for four intersections (3).

The time-space diagram in Figure 2-9 depicts a northbound vehicle travelling at a speed of 40 feet per second. Using standard conventions to illustrate the various indications of the signals, a simple line indicates a green signal, a shaded line indicates the amber (yellow) signal, and a thick solid line indicates a red signal.

Offset, as defined earlier, is the green initiation time (of the phase of interest) at the downstream intersection, minus the green initiation time (of the phase of interest) at the master intersection. *Ideal offset* is defined as the offset that will cause the specified objective to be best satisfied. Often, the ideal offset is the offset such that, as the first vehicle of a platoon arrives at the downstream signal, the downstream signal turns green. One can calculate the ideal offset by using Equation 2-4:

$$o_{id} = \frac{L}{v} \qquad [2\text{-}4]$$

where:
o_{id} = ideal offset (seconds);
L = block length (feet); and
v = vehicle speed (feet per second).

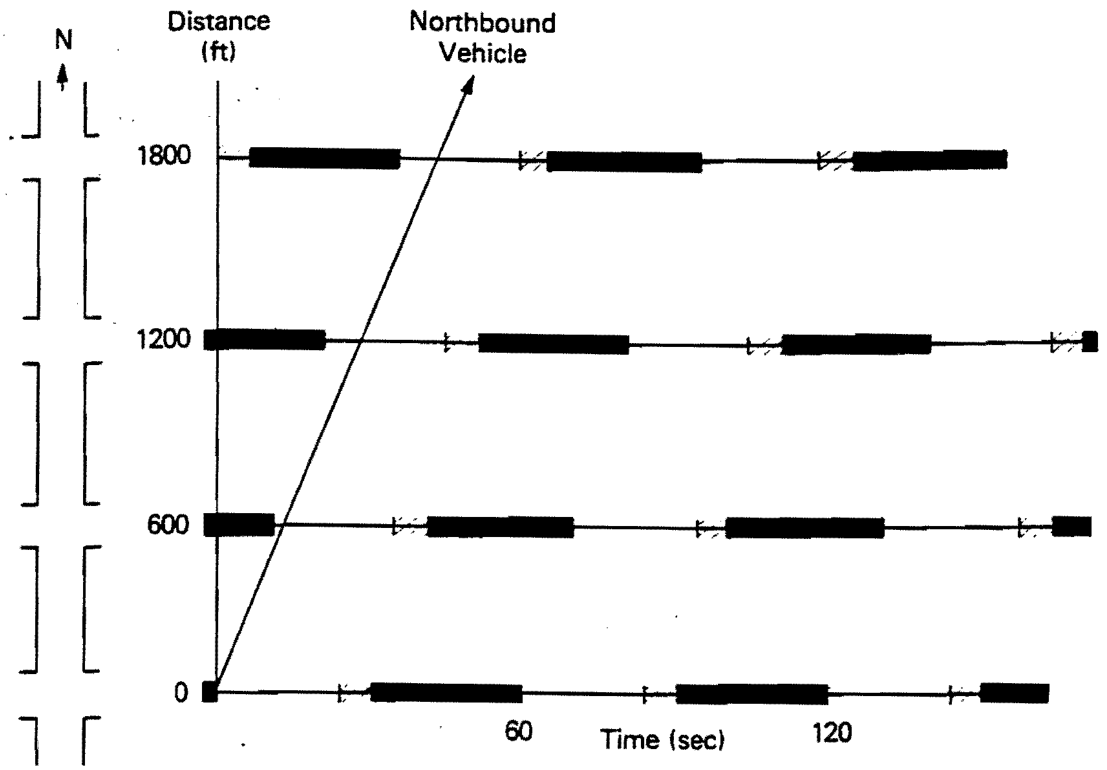


Figure 2-9. Typical Time-Space Diagram

If vehicles had to stop and then accelerate after some initial start-up delay, the ideal offset could be represented by the above equation plus some term representing start-up lost time at the first intersection; however, one generally uses Equation 2-4 without an added term.

Bandwidth. From Figure 2-9, one can see that a window (or band of green) exists for the movement of through vehicles. The size of this window, called the bandwidth, measures how large a platoon of vehicles can pass through the arterial system without stopping. The bandwidth is limited by the minimum green in the direction of interest. Traffic signal analysts like the concept of bandwidth, since it provides easy visual images of the signal system; however, a significant shortcoming of designing offset plans to maximize bandwidth is that one may overlook internal queues. When internal queues exist, bandwidth-based solutions can prove misleading and erroneous.

Maximizing the bandwidth in the direction of the peak traffic movement provides good progression for the through movement. For off-peak periods, emphasis is placed on providing equal bandwidth for both directions. One may achieve this latter objective by the process of half-integer synchronization. Half-integer synchronization generally assumes that the speeds remain equal in both directions and results in equal bandwidths for both directions. Analysts maximize bandwidth by centering either the green indications or the red indications, and by minimizing bandwidth reduction effects known as interferences (4).

Alternative Methodologies. The different methodologies for developing optimal arterial timing plans can be divided into one of two categories, those that minimize delay or other traffic performance measures, and those that maximize bandwidth. Each of these alternatives is discussed in the following sections.

Delay-Offset Method. Hilliar of the Transport and Road Research Laboratory in the United Kingdom developed the delay-offset method of selecting optimal offsets for pretimed signals (5). This method minimizes the overall delay but does not necessarily provide uninterrupted progression or minimize stops. The delay-offset method also does not exclusively favor the arterial through movement or a maximum progression solution. The method attempts to minimize the overall delay of the system, and, therefore, individual movements as well as the overall system performance are of concern (6). Figure 2-10 illustrates the variation in delay with change in offset.

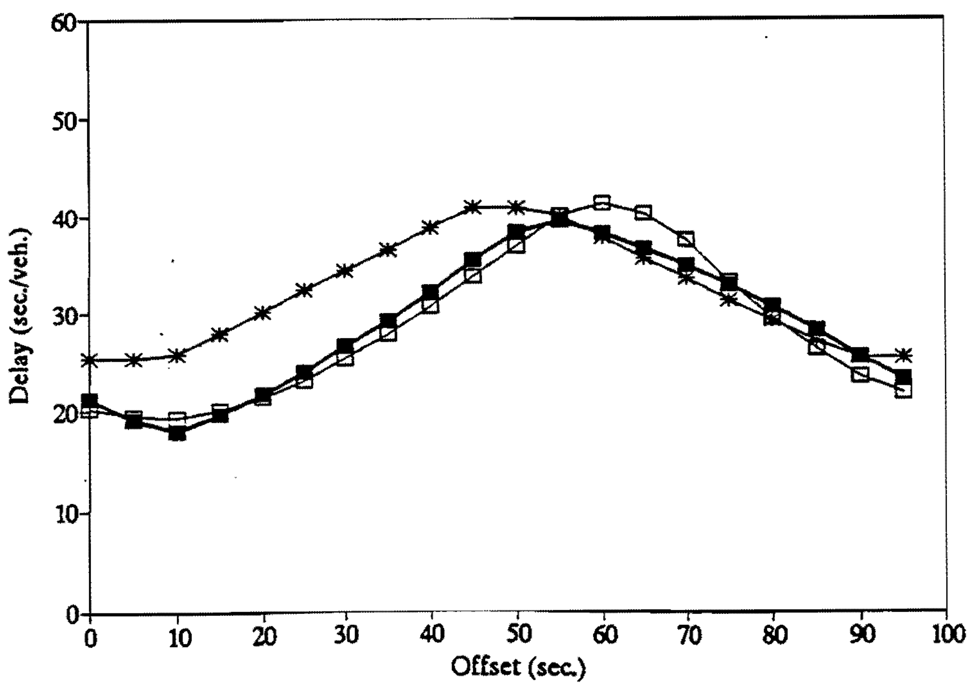


Figure 2-10. Variation in Delay with Change in Offset

Maximum Bandwidth Method. One of the most popular methods of timing arterial systems uses the philosophy of maximizing the progression bandwidth. Analysts give preference to the through movements on the arterial streets, which may cause more delay to the cross streets. The maximum bandwidth solution attempts to develop a signal timing plan which allows a queue of vehicles to leave a downstream intersection and progress through the green of downstream intersections without stopping. The maximum bandwidth possible depends on the minimum green times for the inbound and outbound directions, and the minimum interference. The maximum bandwidth is calculated as follows (7):

$$B_{max} = G_{o\ min} + G_{i\ min} - I_{i\ min} \qquad [2\text{-}5]$$

where:

B_{max} = maximum bandwidth, (seconds);
$G_{o\ min}$ = minimum green in the outbound directions, (seconds);
$G_{i\ min}$ = minimum green in the inbound directions, (seconds); and
$I_{i\ min}$ = minimum inbound interference (seconds).

Efficiency and attainability compose the primary measures of effectiveness for evaluating arterial progression. Efficiency (E) describes the proportion of the cycle length used for progression of through movements. Attainability (A) is the ratio between the sum of the bandwidths and the sum of the minimum green times in both direction; that is, it equals the percentage of the shortest arterial through green time in each direction occupied by the band. Several documented studies discuss the theory of maximum bandwidth; for further reference, see Little et al. (8), Brooks (4), and Messer (7). Efficiency and attainability are calculated as follows:

$$E = \frac{B_a + B_b}{2C} \qquad [2\text{-}6]$$

where:

E = progression bandwidth efficiency ratio;
B_a = progression bandwidth in "A" direction, (seconds);
B_b = progression bandwidth in "B" direction, (seconds); and
C = cycle length, (seconds).

$$A = \frac{B_a + B_b}{G_{min(a)} + G_{min(b)}} \qquad [2\text{-}7]$$

where:
A = progression bandwidth attainability ratio;
$G_{min(a)}$ = minimum green time in "A" direction, (seconds); and
$G_{min(b)}$ = minimum green time in "B" direction, (seconds).

2.6 Measures of Effectiveness

The measures of effectiveness (MOEs) analysts use in the evaluation of signal timing alternatives on arterial streets include average travel speed, critical volume to capacity ratio, total system delay, queue length, and fuel consumption. The sections below discuss each of these MOEs.

Average Travel Speed. The *1985 Highway Capacity Manual* (HCM) (9) uses average travel speed as the basic measure of effectiveness for arterial streets. Such factors as the number of signalized intersections per mile and the average delay at these intersections greatly influence the average travel speed on an arterial segment. Table 2-1 presents the arterial level of service ranges in terms of the average travel speed of all through vehicles on the segment. The "arterial classification" concept utilized in Table 2-1 is based upon the functional and design category of the arterial under evaluation, and the 1985 HCM describes it further (9).

Table 2-1. Level of Service Ranges for Arterial Streets

ARTERIAL CLASS	I	II	III
Range of Free Flow Speeds (mph)	45 to 35	35 to 30	35 to 25
Typical Free Flow Speed (mph)	40 mph	33 mph	27 mph
LEVEL OF SERVICE	AVERAGE TRAVEL SPEED (MPH)		
A	≥35	≥30	≥25
B	≥28	≥24	≥19
C	≥22	≥18	≥13
D	≥17	≥14	≥ 9
E	≥13	≥10	≥ 7
F	<13	<10	< 7

One computes average travel speed by taking the distance between Points A and B and dividing by the travel time between the same two points. Travel time includes the average delay at each of the signalized intersections and the running time between intersections. The basic relationship between average travel speed and intersection spacing is as follows: short spacings between intersections result in running time composing a lesser percentage of the travel time, and as a consequence, lower average speeds and levels of service. Longer spacings between intersections result in running time being a higher percentage of travel time, and as a consequence, higher average speeds and level of service. When computing average travel speed, however, one should realize that if **one** or more of the intersections on the arterial is oversaturated, the arterial will operate at Level of Service "F,"even if the calculated average travel speed indicates otherwise.

Critical Volume to Capacity Ratio (v/c). A measure of effectiveness for assessing operations along an arterial street is the critical volume to capacity ratio for the sequence of signalized intersections along the arterial. According to the *Highway Capacity Manual* (9), the volume to capacity ratio equals the actual or projected rate of flow on an approach or designated group of lanes during a peak 15 minute interval divided by the capacity of the approach or designated lane group. Equation 2-8 can be used to compute the volume to capacity ratio (X_i) for a specific approach as follows:

$$X_i = V_i/c_i = V_i /[(g_i/C) * S_i] \qquad [2\text{-}8]$$

where:
- X_i = volume to capacity ratio of lane group or approach i;
- V_i = volume of approach i or lane group (veh/hr);
- c_i = capacity of lane group or approach;
- g_i = effective green time for lane group or approach i (seconds);
- C = cycle length (seconds); and
- S_i = saturation flow rate for lane group or approach i (vphg).

It is important to note that the maximum rate of flow (for the subject approach) that may pass through the intersection under prevailing traffic, roadway, and signalization conditions defines the intersection's "capacity." A volume to capacity ratio of less than 1.0 indicates that the approach probably operates at an acceptable level; a volume to capacity ratio near 1.0 indicates that the approach operates near its capacity, and operational problems may occur; and a volume to capacity ratio of greater than 1.0 indicates that more demand than capacity exists and if the capacity has not been underestimated, the approach does not operate at an acceptable level and operational problems will occur for as long as this condition persists.

The critical volume to capacity ratio for an arterial is considered to be the highest volume to capacity ratio found among the intersections along the arterial. One must realize, however, that arterial analysis utilizing critical volume to capacity ratios can provide misleading results, if one does not take the operational conditions resulting from the critical volume to capacity ratio into consideration. In other words, if one or more of the intersections operates at an unacceptable level, the arterial also will operate at an unacceptable level, even if the average speed indicates an acceptable level of service. **Thus, it is extremely important in the analysis of arterial streets to check both average travel speed and volume to capacity ratios for arterial movements at each of the intersections.**

Total System Delay. The sum of the delay for each individual movement at each of the intersections along an arterial is considered to be the total delay for the arterial system. Note that because total system delay represents the delay for the total number of vehicles in the system, one may not compare it to other arterial systems with a different number of total vehicles. Analysts can estimate the delay at individual intersections along an arterial either with delay equations based on Webster's delay theory (2) or with measurements directly in the field.

Delay is a measure of effectiveness commonly used to estimate the level of service at signalized intersections. Two types of delay can be estimated: stopped delay and total delay. Stopped delay represents the amount of time a vehicle is actually stopped waiting for a green indication and/or the queue of vehicles to clear. It is more easily measured than total delay. Total delay represents an estimate of the time lost to stops and speed reductions because of acceleration, deceleration, and interference due to other vehicles. The total system delay for an arterial is typically determined using estimates for total delays.

The *Highway Capacity Manual* (9) contains the most widely used model to compute stopped delay. Two parts make up the equation: delay due to uniform arrivals and delay due to random and overflow arrivals. Delay for uniform arrivals is based on the assumption that the vehicles arrive at a constant rate and are fully discharged during the cycle. Hence, no vehicles wait for more than one cycle to pass through the intersection. The first part of the equation for stopped delay with uniform arrivals is as follows:

$$d_1 = \frac{0.38C[1 - (g/C)]^2}{[1 - (g/C)(Min(X,1.0))]} \qquad [2\text{-}9]$$

Vehicle arrival patterns, however, are not uniform. They are more likely to be random in nature. The second part of the equation for delay due to random arrivals and queue overflow (incremental delay) is as follows:

$$d_2 = 173X^2\ [(X - 1) + \sqrt{[(X - 1)^2 + mX/c]}\ ] \qquad [2\text{-}10]$$

where:	d_1	=	uniform delay (sec/veh);
	d_2	=	incremental delay (sec/veh);
	DF	=	delay adjustment factor for either quality of progression or control type.
	C	=	cycle length (seconds);
	g	=	green time per phase (seconds);
	X	=	volume to capacity ratio for that phase;
	Min (X,1)	=	the lesser value of either X (v/c ratio for lane group) or 1.0;
	m	=	a calibration term representing the effect of arrival type and degree of platooning; and
	c	=	capacity of lane group, (vehicles/hour).

The intersection stopped delay is as follows:

$$d = d_1 * DF + d_2 \qquad [2\text{-}11]$$

Total delay is the correct delay to use in the arterial evaluation because both stopped delay and delay due to decelerating and accelerating influence average travel time. Based on research conducted for FHWA in the late 1970s (10), total delay can be related to stopped delay as follows:

$$D = 1.3 * d \qquad [2\text{-}12]$$

where: D = total delay, (seconds/vehicle); and
d = stopped delay, in (seconds/vehicle).

Despite the wide acceptance of the equations in the HCM, other methods for calculating delay exist. PASSER II-90 and TRANSYT-7F are software packages commonly used for the analysis of arterial streets. These programs are discussed in detail elsewhere in this report; however, it is appropriate to mention that the equations used by these programs estimate delay differently than does the HCM. These differences are primarily the result of progression and oversaturation effects, and the programs generally prove more accurate for those conditions than the HCM equations.

Queue Length. Queue length represents another basic measure of performance and is of particular importance when a limited queue storage space exists. A heavy left-turn demand or a short left-turn lane can cause queues of left-turn vehicles to back into the through lanes and block them. Similarly, long queues in the through lanes can block the entrance to the left-turn lanes and, in some cases, can block upstream intersections. The presence of queues at the intersection impedes the smooth flow of platooned traffic; causes more stops, delays, and driver frustration; and, in turn, could lead to safety problems.

According to Akcelik (11), the average number of vehicles in the queue at the start of the green period can be calculated as follows:

$$N = qr + N_o \qquad [2\text{-}13]$$

where:

- N = average number of vehicles in queue; (vehicles)
- q = arrival flow rate in vehicles per second; (vehicles/second)
- r = effective red time in seconds; (seconds) and
- N_o = average overflow queue in vehicles and given by:

$$N_o = \frac{QT_f}{4}\left(z + \sqrt{z^2 + \frac{12(x-x_o)}{QT_f}}\right) \qquad [2\text{-}14]$$

where:

- Q = capacity in vehicles per hour;
- T_f = flow period, (hours);
- z = (x - 1);
- x = degree of saturation (q/Q); and
- x_o = (0.67 + sg/600), where s = saturation flow in vehicles per second, and g = effective green time for the lane group, (seconds).

The above-mentioned equation for queue length is based on the theoretical model which assumes that vehicles join the queue when they reach the stop line. Since vehicles actually join the queues before reaching the stop line, the equation underestimates the maximum queue length. Maximum queue length can be calculated as follows:

$$N_m = \frac{qr}{1 - y} + N_o \qquad [2\text{-}15]$$

where:

- N_m = maximum length of the queue; and
- q = arrival flow rate in vehicles per second; (vehicles/second)
- r = effective red time in seconds; (seconds) and
- y = flow ratio (volume/saturation flow rate);
- N_o = average overflow queue in vehicles.

Stops. The average number of stops represents another basic measure of performance from which other (secondary) measures of performance (like fuel consumption) can be obtained. Note that every vehicle coming to a complete stop at an intersection experiences a small delay. According to Akcelik (11), the average number of stops per vehicle is called the stop rate and can be calculated as follows:

$$h = 0.9\left(\frac{1-u}{1-y} + \frac{N_o}{qC}\right) \quad [2\text{-}16]$$

where:

- h = average number of complete stops per vehicle (stop rate);
- u = green time ratio (g/c);
- y = flow ratio (q/s);
- q = flow in vehicles per second;
- C = cycle time in seconds; and
- N_o = average overflow queue in vehicles.

One calculates the number of stops per movement by multiplying the stop rate (h) by the demand volume in vehicles per hour.

Fuel Consumption. Faced with fuel shortage and increased fuel prices, traffic signal analysts have become more interested in fuel consumption estimates. Fuel consumption in an arterial system can be divided into three components: fuel consumed travelling from Point A to Point B, fuel consumed while stopped at an intersection, and fuel consumed while decelerating to a stop and accelerating back to a desired speed. Analysts use the following model to calculate fuel consumption in both PASSER II-90 and TRANSYT-7F.

$$\begin{aligned} F = \; & (A_{11} + A_{12}*V + A_{13}*V^2) * TT \\ + \; & (A_{21} + A_{22}*V + A_{23}*V^2) * D \\ + \; & (A_{31} + A_{32}*V + A_{33}*V^2) * S \end{aligned}$$

where:

- F = estimated total system fuel consumption, (gallons/hour);
- TT = total travel, (veh-mile/hour);
- D = total delay, (veh-hr/hour);
- S = total stops, (stops/hour);
- V = cruise speed, (miles/hour); and
- A_{ij} = regression model beta coefficients, and is given by:

$$A_{ij} = \begin{vmatrix} 0.75283 & -1.5892\text{E-}3 & 1.50655\text{E-}5 \\ 0.73239 & 0.0 & 0.0 \\ 0.0 & 0.0 & 6.14112\text{E-}6 \end{vmatrix}$$

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3.0 DATA REQUIREMENTS

A major component of good signal timing plans is adequate data for analysis and optimization purposes. Poor or incomplete data results in less than desirable timing plans. One can categorize the type of data required for arterial street systems into two groups: intersection data and arterial system data. Intersection data involves data collection at each individual intersection within the system, while arterial system data corresponds to the overall characteristics of the arterial street. Knowing what data is needed before going to the field saves the traffic signal analyst time and extra trips to the project site.

The first question one should ask is how many timing plans will be needed? The number of timing plans necessary depends on the fluctuation of traffic demand throughout the day and the type of control equipment available. The analyst should collect data during the periods of interest. For example, one-way progression may be desirable in the inbound direction for the a.m. peak and in the outbound direction for the p.m. peak. Two-way progression may be desirable for the off-peak or a.m. and p.m. peaks as well. Data for developing the a.m. peak timing plan should be collected during the a.m. peak period, and data for developing an off-peak timing plan should be collected during the off-peak time period, etc.

The following sections discuss guidelines and suggestions for complete and accurate data collection needed for retiming signalized arterial streets. Analysts use these data in the development of timing plans for both pretimed and traffic actuated environments. Recommended use of the data are described in Section 4.0, "Evaluation," Section 5.0, "Optimization," and Section 6.0, "Implementation."

Four types of data need to be collected:

1. Traffic Data;
2. Signal Data;
3. Geometric Data; and
4. Travel Time Data.

The type of data needed for analyzing an arterial street varies somewhat for each arterial. A worksheet for recording individual intersection data, such as the one specified in the *1985 Highway Capacity Manual* (9) and illustrated in Figure 3-1, is helpful as a starting point.

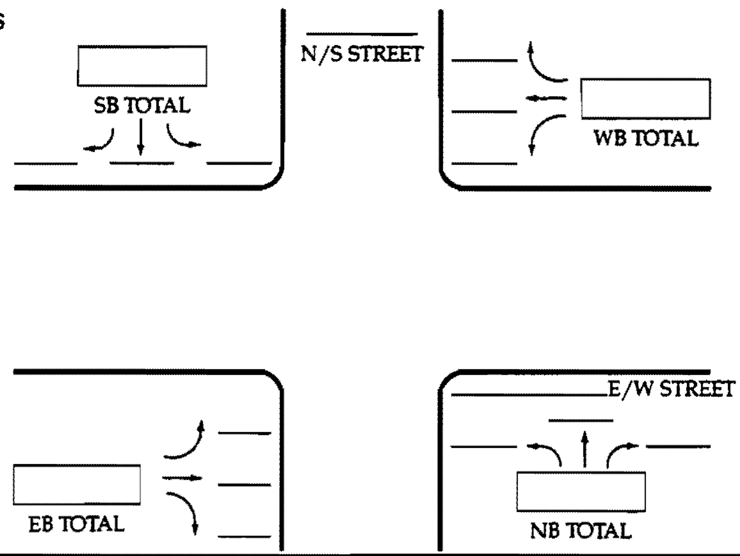
INPUT WORKSHEET

Intersection:______________________________ Date:____________

Analyst:______________ Time Period Analyzed:__________ Area Type: ☐ CBD ☐ Other

Project No.:____________________ City/State:____________________

VOLUME AND GEOMETRICS



IDENTIFY IN DIAGRAM:

1. Volumes
2. Lanes, lane widths
3. Movements by lane
4. Parking (PKG) locations
5. Bay storage lengths
6. Islands (physical or painted)
7. Bus stops

TRAFFIC AND ROADWAY CONDITIONS

Approach	Grade (%)	% HV	Adj. Pkg. Lane		Buses (N_B)	PHF	Conf. Peds. (peds./hr)	Pedestrian Button		Arr. Type
			Y or N	N_m				Y or N	Min. Timing	
EB										
WB										
NB										
SB										

Grade: + up, − down
HV: veh. with more than 4 wheels
N_m: pkg. maneuvers/hr
N_B: buses stopping/hr
PHF: peak-hour factor
Conf. Peds: Conflicting peds./hr
Min. Timing: min. green for pedestrian crossing
Arr. Type: Type 1-5

PHASING

DIAGRAM								
Timing	G = Y + R =	G = Y + R =	G = Y + R =	G = Y + R =	G = Y + R =	G = Y + R =	G = Y + R =	G = Y + R =
Pretimed or Actuated								

Protected turns | Permitted turns | -------Pedestrian | Cycle Length______Sec

Figure 3-1. HCM Worksheet to Summarize Intersection Data

3.1 Traffic Data

Traffic data identifies both the demand and capacity of the intersections as well as the factors affecting the smooth flow of traffic along the arterial. The quantification of demand requires observation of the 24-hour traffic volumes at the intersections, the traffic volumes during the peak periods, and the traffic volumes for specific turning movements during the peak periods. One also should record the midblock traffic generators and their influence on the arterial traffic. Analysts calculate the capacity of an intersection based on the saturation flow rate and available green time for each movement. The number of heavy vehicles using the intersection, bus stops, parking near the intersection, and the number of pedestrians that cross at the intersection affect the saturation flow rate. The following text elaborates on the collection of traffic data.

Traffic Volumes. The analyst should obtain traffic volumes for each intersection in the arterial system for the a.m., p.m., and off-peak time periods. The first step in this process, a 24-hour count, should be made at each intersection to determine the peak periods (or peak 15 minutes) and the fluctuation in traffic demand. A 24-hour count can be taken by placing tube counters on all approaches at the intersection or by dumping detector counts from the controller. Figure 3-2 shows an example of a 24-hour count printout and the determination of the peak hours at the intersection.

Turning Movements. After determining the peak period, manual counts are necessary to record the volumes for individual movements or lane groups during the peak period or period of interest. Twelve possible movements need counting at each signalized intersection, as shown in Figure 3-3. Generally, one should make turning movement counts in 15-minute intervals during the two hour a.m. or p.m. peak periods, and for one hour during the off-peak period.

The highest four consecutive 15-minute volumes are added together to determine the highest peak or off-peak hour flow rate. It may be helpful to record intersection data on a worksheet, such as the one in the *Manual of Traffic Engineering Studies* (12), shown in Figure 3-4. A sketch illustrating the arterial and the orientation of its intersections and their geometric basic features will also prove helpful for recording system data (See Figure 3-5).

During congested periods, it is important that the volume counted be the demand rather than the discharge volume; i.e., the measured discharge volume will be less than the true demand volume if the queue fails to clear during the green indication. If this situation occurs, the actual volume counted should be those vehicles that arrive at the back of the queue rather than those vehicles that depart when the signal is green. One should note, however, that this procedure is for counting only and not a recommended signal timing strategy; i.e., trying to clear the queue each and every cycle results in extremely long cycle lengths during congested conditions.

TRAFFIC COUNT SHEET

LOCATION: WALKER DR. East of DANTROSE DATE: SEPTEMBER 26-27, 1984

DIRECTION OF TRAVEL: WEST-BOUND DAY: WEDNESDAY-THURSDAY

TIME	COUNT	HOUR COUNT	TIME	COUNT	HOUR COUNT	TIME	COUNT	HOUR COUNT
24:00	15	41	8:00	215	604	16:00	145	643
:15	14		:15	129		:15	142	
:30	7		:30	126		:30	165	
:45	5		:45	134		:45	191	
1:00	6	25	9:00	105	483	17:00	200	715
:15	7		:15	104		:15	186	
:30	8		:30	141		:30	178	
:45	4		:45	133		:45	151	
2:00	7	15	10:00	117	482	18:00	115	441
:15	3		:15	124		:15	116	
:30	4		:30	108		:30	110	
:45	1		:45	133		:45	100	
3:00	4	10	11:00	122	559	19:00	106	380
:15	2		:15	136		:15	107	
:30	3		:30	132		:30	95	
:45	1		:45	169		:45	72	
4:00	0	17	12:00	154	639	20:00	72	233
:15	7		:15	128		:15	57	
:30	5		:30	139		:30	57	
:45	5		:45	218		:45	47	
5:00	2	26	13:00	150	599	21:00	54	157
:15	7		:15	177		:15	26	
:30	7		:30	132		:30	43	
:45	10		:45	140		:45	34	
6:00	17	120	14:00	128	536	22:00	34	96
:15	27		:15	136		:15	21	
:30	30		:30	138		:30	22	
:45	46		:45	134		:45	19	
7:00	83	670	15:00	155	630	23:00	17	60
:15	128		:15	117		:15	14	
:30	206		:30	184		:30	13	
:45	253		:45	174		:45	16	

A.M. PEAK: (07:30- 08:30)

206	803
253	
215	
129	

P.M. PEAK: (16:45 -17:45)

191	755
200	
186	
178	

24-HOUR TOTAL: (12:00 WED-12:00 THUR)

8181

Figure 3-2. Example of 24-hour Count Data and Peak Periods

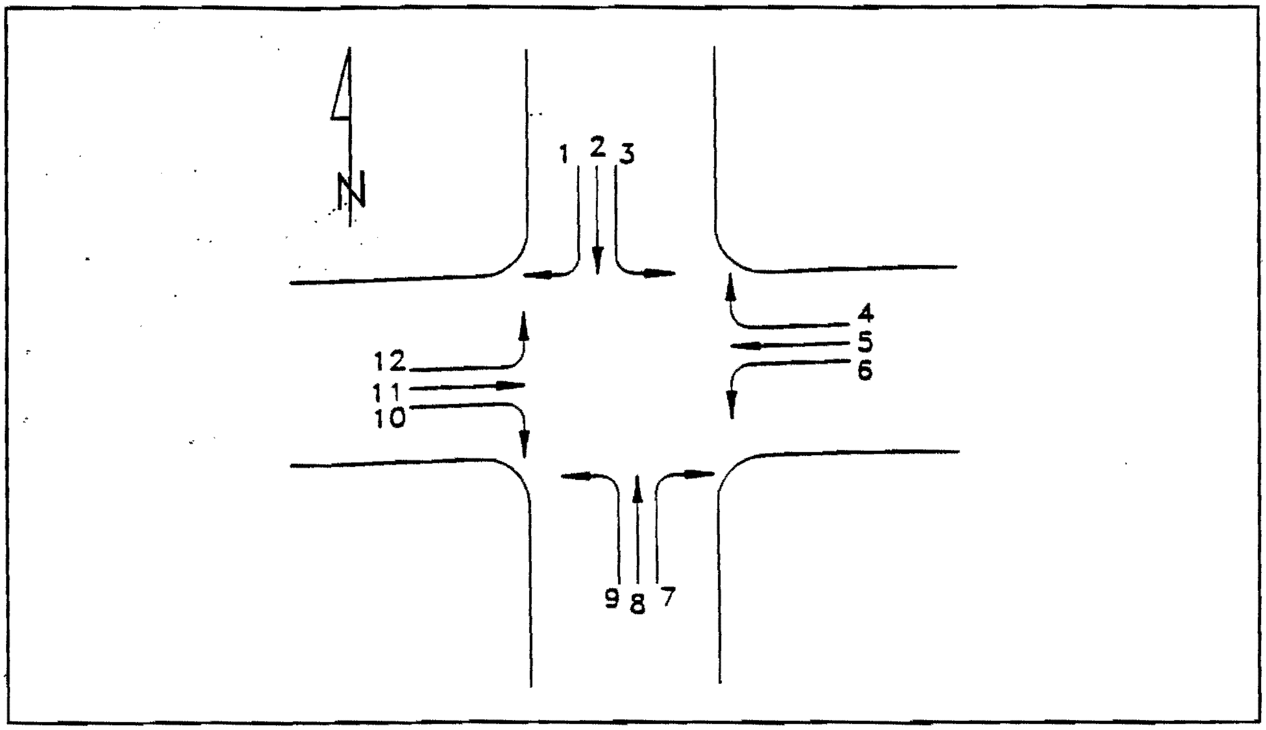


Figure 3-3. Turning Movements to be Counted at a Typical Intersection

TABULAR SUMMARY OF VEHICLE COUNTS

Observer ________ Date ________ Day ________ City ________

INTERSECTION OF ________ AND ________

R = Right turn
S = Straight
L = Left turn

TIME BEGINS	from NORTH				from SOUTH				TOTAL North South	from EAST				from WEST				TOTAL East West	TOTAL ALL
	R	S	L	Total	R	S	L	Total		R	S	L	Total	R	S	L	Total		

Figure 3-4. Worksheet to Record Intersection Data

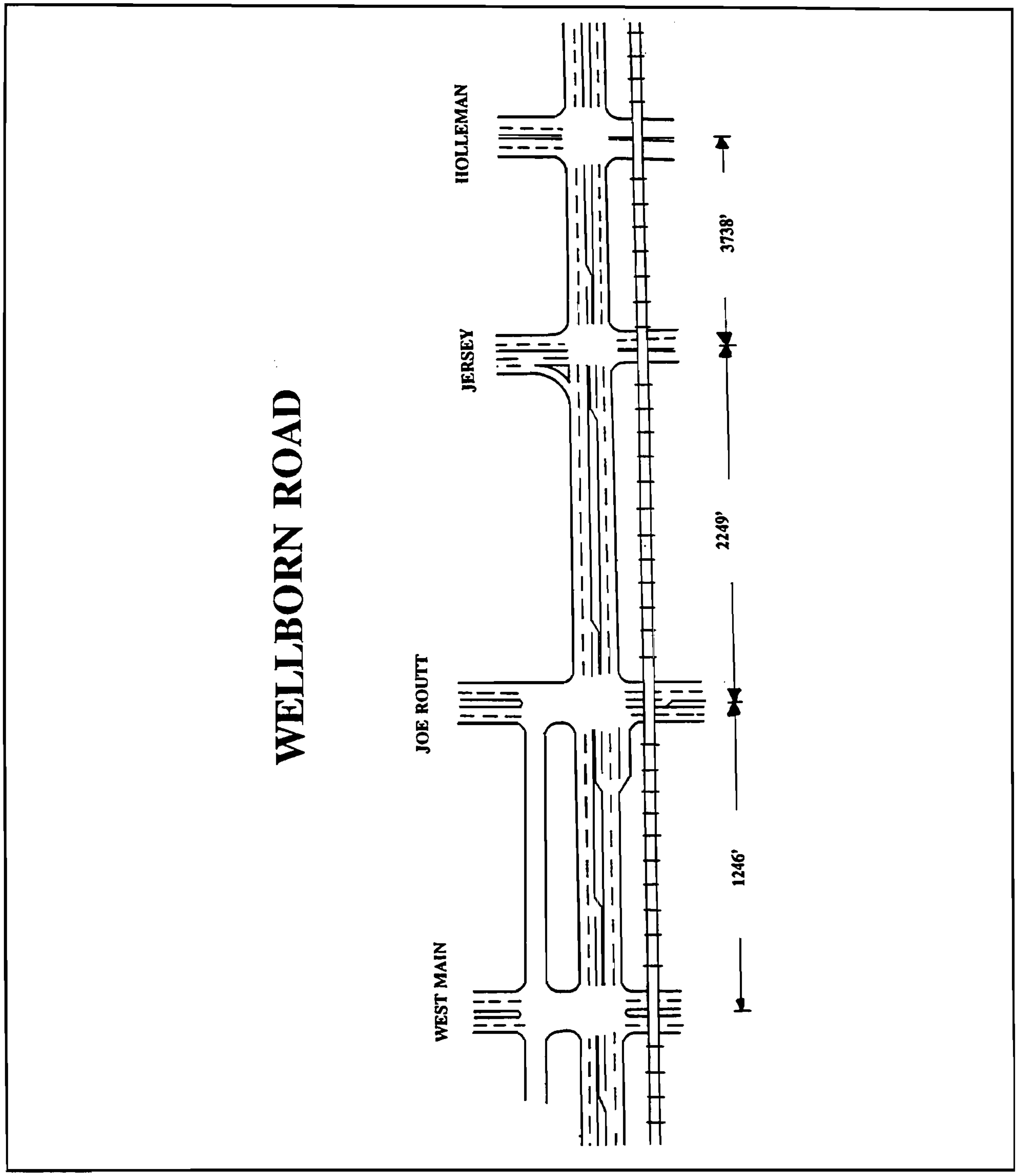


Figure 3-5. Typical Arterial Street System

It should be emphasized that saturation flow rates are extremely important when determining the capacity and required splits for specific movements. For example, if one overestimates a particular movement's saturation flow rate, less green time than needed will be allocated to that movement. On the other hand, if one underestimates a particular movement's saturation flow rate, more green time than needed will be allocated to that movement. Neither condition is efficient or desirable.

Because saturation flow rate is such a critical factor, it should be measured in the field if possible. Figure 3-6 shows a worksheet for determining the saturation flow rate for an approach using field observations. If field measurements are not available, the analyst can estimate saturation flow rate using the procedure outlined in the *1985 Highway Capacity Manual* (9).

3.2 Signal Data

Most information classified as signal data (cycle lengths; green, yellow, and red intervals; phasing; and offsets) may be taken directly from the controller for pretimed control plans. For actuated control plans, the fixed yellow and red intervals remain constant and one may obtain yield, hold, and force-off settings from the actuated controller. Average green intervals may be obtained from field measurements. The following text elaborates on the necessary signal data.

Cycle Length. The cycle length for the period of interest, a.m., p.m., or off-peak, should be recorded. For pretimed control, the cycle length of each intersection will remain constant. Actuated control systems also must operate at the same cycle length or some multiple of the system cycle length, normally called the background cycle length. The analyst may obtain the system cycle length from existing timing plans, the controllers, or by field measurement with a stopwatch.

Green Splits. The green splits for each intersection should be recorded. The green split, the green, yellow, and red clearance for each phase, will remain constant for pretimed control and can be obtained from controller settings, existing timing plans, or by field measurements. For actuated control, the green interval will be a variable length interval, and should be determined by recording 10 to 30 measurements of the green interval in the field and calculating an average green interval length. The yellow and red intervals will remain constant for both pretimed and actuated control. The analyst may obtain this information from timing plans or by field measurements with a stopwatch.

FIELD SHEET – SATURATION FLOW STUDY

Location:________________________________

Date:____/____/____ Time:____________ City:____________

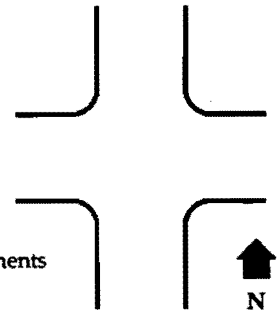
______Bound Traffic; Approaching From the________________

Observers:________________ Weather:________________

Movements Allowed

- ☐ Thru
- ☐ Right Turn
- ☐ Left Turn

Identify all Lane Movements
& The Lane Studied



Veh. in Queue	Cycle 1			Cycle 2			Cycle 3			Cycle 4			Cycle 5			Cycle 6		
	Time	HV	T	Time	HV	T	Time	HV	T	Time	HV	T	Time	HV	T	Time	HV	T
1																		
2																		
3																		
4																		
5																		
6																		
7																		
8																		
9																		
10																		
11																		
12																		
13																		
14																		
15																		
16																		
17																		
18																		
19																		
20																		
End of Saturation																		
End of Green																		
No. Veh. > 20																		
No. Veh. on Yellow																		

HV = Heavy Vehicles (Vehicles with more than 4 tires)
T = Turning Vehicles (L = Left, R = Right)
Pedestrians and buses which block vehicles should be noted with the time that they block traffic, i.e.,
P12 = pedestrians blocked traffic for 12 sec
B15 = bus blocked traffic for 15 sec

Grade__________ Area Type__________

Figure 3-6. Worksheet for Calculating Saturation Flow Rates

Right Turn on Red (RTOR). To more accurately describe the existing conditions, the analyst should record the number of vehicles making right turns on the red interval. This number will be subtracted from the total right-turn volume when modeling (analyzing) the existing conditions at any intersection along the arterial.

Midblock Volumes. Heavy traffic generators may exist between intersections along the arterial street. These generators may include major shopping centers, large parking lots, etc. One should use engineering judgment to determine the significance of the volumes generated. Most sources of large traffic generation have signalized access points; however, this generalization may not be so in all cases. Significant midblock traffic affects the quality of progression on the arterial street.

Peak Hour Factor (PHF). After making turning movement counts, adjustments may be necessary to account for the peak period. According to the HCM, peak rates of flow relate to hourly volumes through the use of peak hour factors. The peak hour factor is defined as the ratio of total hourly volume to the maximum 15 minute rate of flow within the hour. If one uses 15 minute counts, then:

$$PHF = \frac{V}{(V_{15} * 4)} \qquad [3\text{-}1]$$

where: PHF = peak hour factor;
V = highest hourly volume, in veh/hr; and
V_{15} = highest 15 minute count within that hour, in veh/15 min.

Demand volumes are generally stated in terms of vehicles per hour for a peak hour. For signal timing analysis, one normally adjusts peak hour volumes to flow rates in vehicles per hour for a 15-minute period. For example, analysts conducted a 24-hour count and determined the a.m. peak hour to occur between 7:00 a.m. and 8:00 a.m. The hourly volume was determined to be 900 vehicles per hour. The analysts also determined the peak 15-minute flow rate within that hour to equal 300 vehicles in 15 minutes or 1200 vehicles per hour.

$$PHF = \frac{900}{(300 * 4)} = 0.75 \qquad [3\text{-}2]$$

Thus, the peak hour factor for the a.m. peak equals 0.75 in this example. For timing purposes, one can calculate the peak hour flow rate either by dividing the hourly volume by the peak hour factor, or by multiplying the peak 15-minute flow rate by four. In either case, the calculated peak flow rate equals 1200 vehicles per hour. One should note that, if the peak 15-minute flow rate was multiplied by four to arrive a peak hour flow rate, the correct peak hour factor equals 1.0; i.e., the adjustment for peak flows within the hour have already been accounted for.

Saturation Flow Rate. The saturation flow rate equals the maximum flow rate at which vehicles can pass through the intersection. One expresses this rate in vehicles per hour of green per lane during an hour with continuous demand and subject to prevailing roadway conditions. For example, adjustment factors for roadway and traffic conditions, such as lane width and truck percentages, are used to reduce the ideal saturation flow rate to an adjusted rate appropriate for the location. Analysts use the following traffic data items to adjust the ideal saturation flow rate:

Percent heavy vehicles - The number of heavy vehicles operating within an intersection should be counted. A heavy vehicle is characterized as having at least 6 wheels in contact with the roadway. Heavy vehicles may be classified into three types: trucks, recreational vehicles, and buses. Heavy vehicles take up more lane space and operate differently than passenger vehicles, which contributes to a decrease in the saturation flow rate and capacity, for example, heavy vehicles accelerate from a stop at a slower rate.

Parking - Parking in the vicinity of an intersection (within 200 feet of the stop line) also will affect the flow in adjacent lanes either by frictional effect or occasional blockage of a lane due to a parking maneuver.

Bus stops - If buses make scheduled stops at an established bus stop near an intersection (within 200 feet), restriction of flow and capacity may result in lanes adjacent to the bus stop. The time of day and frequency of bus stops should be recorded. Most bus schedules are posted at the bus stop, and one may obtain further information on bus frequency from the bus company.

Pedestrians - The number and type of pedestrians crossing each intersection should be noted. Elderly pedestrians and children require more time to cross the street. Analysts need this information for the calculating the minimum green times, whether or not the intersections have pedestrian signals. Right-turn conflicts with pedestrians also should be noted; if the right-turn conflict is heavy, the capacity available for right-turn movements may require reduction. One can record pedestrian volumes as the actual number counted or as a general range (less than 50, 50 to 200, or greater than 200). Either option is acceptable; however, it is important that the data be based on field observations.

Phasing. The existing phasing, including the type and sequence of phasing, should be recorded for the intersection. As discussed in Section 2.2, analysts determine the type of phasing by the left-turn treatment and describe the sequence by the order that the left-turn phases occur. Types of phasing include permitted, protected, and protected/permitted.

Permitted -	Left-turn movements must yield to opposing traffic. They may proceed during green ball indication after yielding to opposing traffic.
Protected -	Left-turn movements proceed separately from opposing traffic. They are protected with a green arrow or a split phase. Left-turning vehicles are not allowed to proceed otherwise.
Protected/Permitted -	Left-turn movements are protected during part of the cycle and permitted in another part of the cycle. They may proceed during the protected left-turn phase or on the green ball indication after yielding to opposing traffic.

Possible phase sequences at an intersection include leading lefts, lagging lefts, and lag/lead or lead/lag.

Leading Left -	Both left-turns proceed before the through movements.
Lagging Left -	Both left-turns proceed after the through movements.
Lag-lead/lead-lag -	One left-turn movement and its adjacent through movement proceed before or after the opposing left-turn and its adjacent through movement.

Offsets. In pretimed control, signals are referenced to a master intersection by a parameter called the offset. Offsets are usually referenced to the start or end of main street green; however, they may be referenced to the start or end of the phase for the coordinated movement. Analysts may obtain existing offsets from timing plans or controller settings. Actuated controllers use force-off, yield, and hold commands to provide progression. One may also obtain these settings from controller settings.

Type of Controller. Either pretimed or actuated controllers may control arterial systems. Section 2.3 discussed the characteristics and capabilities of these controllers, but in general, one should note the following attributes for each type of controller.

Pretimed - Is the controller electromechanical or digital? How many dials does it have?

Actuated - Is the controller a single ring or dual ring? How many timing plans, cycle lengths, and split patterns will it accommodate?

Master Control Unit. A master controller coordinates the individual intersections in the arterial system. Local controllers may be interconnected with cable, or a time-base coordinator may provide coordination. Some local coordinators have the time clocks or master systems built into the cabinet, or the master controller may be a separate controller to which all other intersections are referenced. One should record the existing arrangement and equipment.

3.3 Geometric Data

Analysts may determine geometric data from site plans or through field inspections. Geometric conditions can affect traffic operational data, such as the saturation flow rate. Additionally, signal data, particularly with regard to phasing and left-turn treatments, is dictated by the geometric conditions that exist at the intersections along the arterial.

Number of Lanes. The number of lanes per approach for each intersection should be recorded. Note that the analyst should count number of lanes at the stop bar, not upstream or downstream of the intersection. The type of movements allowed from each lane also should be recorded, including exclusive turning lanes and shared lanes. Further, one should note the following information for each type of lane and/or movement:

Left-turn lanes - the number of lanes, whether left turns have an exclusive lane, the storage length, whether storage is adequate for the expected queue.

Through lanes - the number of lanes, whether the through lanes accommodate left or right turns.

Right-turn lanes - the number of lanes, whether right turns have an exclusive lane.

Lane Widths. One should measure the widths for each lane on the approach or obtain them from existing plan sheets. Lane width will affect the saturation flow rate. Lanes less than 12 feet in width reduce the saturation flow rate and, thus, the available capacity for that movement.

Percent Grade. The percent grade at each approach should be recorded. Existing plan sheets or measurement in the field will provide this information. Percent grade will also affect the saturation flow and possibly cause lost time due to longer start-up times on an uphill grade.

Location. The location of the intersections with respect to the surrounding area should be noted. Is the intersection in a central business district (CBD)? An example of a CBD would be a downtown area where arterial streets cross each other to form a grid system or network. Each arterial is of equal importance with regards to progression. Businesses and shops are prevalent, and there is heavy pedestrian traffic, parking maneuvers, and turning movements.

Intersection Spacing. One needs to measure the distance from intersection to intersection in the arterial system. The distance is usually measured from stop line to stop line by field measurements or plan sheets. Distances between intersections is usually the same in both directions; however, for skewed or offset intersections, distances between intersections may vary in the different directions.

3.4 Travel Time Data

Analysts can use the test car method to determine the average speed for an arterial street. The first steps for conducting travel time studies include making an inventory of the arterial's geometry, identifying the segments, determining segment lengths, identifying the access control in each segment, determining the existing signal timing, and identifying the peak 15 minute flow periods and an off-peak period. One should then determine the appropriate free flow speed along the arterial. The free flow speed is determined by making runs in a test car equipped with a calibrated speedometer during low volume periods and noting the speed at midblock locations. Spot speed studies at midblock locations can supplement these readings. From the information obtained, the arterial classification can be determined.

The next step is to conduct travel-time runs. One should drive the test car as if it were a through vehicle. The analyst should note the location of all desired check points and their distances from the starting point. A stop watch or timer is started at the first intersection, either at the instant the test vehicle comes to a stop, or at the midpoint of the intersection, if the vehicle does not stop at the intersection. One should note the cumulative travel time, stopped delay time, and the reason for the delay at each signalized intersections and other check points, like stop signs. The information obtained should be filled in a tabular form, as indicated in Figure 3-7.

Each study period consists of six to twelve travel time runs. These runs begin at different times with respect to the cycle to avoid being a "first in the platoon vehicle" for all the trips. The midblock speedometer readings are also noted and compared with the free flow speeds measured earlier. The analyst should then calculate the average travel time and travel speed for each segment along the arterial, and the average travel time and travel speed for the entire arterial.

TRAVEL TIME FIELD WORKSHEET

Arterial______________________________ Date______________

Driver______________ Recorder______________ Direction______________

LOCATION	DIST (mi)	Run No. __ Time		Run No. __ Time		Run No. __ Time	
		STOP TIME (sec)	CUM TT (sec)	STOP TIME (sec)	CUM TT (sec)	STOP TIME (sec)	CUM TT (sec)

S—Signal (lower box)
LT—Left Turn (upper box)
P—Pedestrian (upper box)
PK—Parking (upper box)
4W—4-Way Stop (upper box)

Figure 3-7. Travel Time Field Worksheet

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4.0 EVALUATION

After collecting the data, the next step toward retiming arterial streets is to evaluate the existing conditions. Evaluation of an existing traffic control strategy requires field observation as well as analysis of existing conditions. A recommended methodology for assessing the operational efficiency of a traffic signal control strategy for an arterial street is summarized below.

Field Evaluation

1. At the critical intersections, check that the green intervals are long enough to clear the stopped queues during most time periods. Although this objective may not be a desirable strategy with actuated control and oversaturated conditions, cycle failures over an extended period of time indicate signal timing or geometric problems. Such problems result in long delays and queue lengths, and excess fuel consumption.

2. At the critical intersections, check that the green intervals are short enough that no long periods of time exist when vehicles are not moving through the intersection. Longer than necessary green intervals result in wasted time, unnecessary delay, and longer queue lengths for the other movements. Note that longer than necessary green intervals will occur at all non-critical intersections because of the need for a common cycle length for coordination.

3. Check that the left-turn queue does not exceed the left-turn storage. If it does, left-turning vehicles may block the through lane and reduce its saturation flow-rate; i.e., the available through capacity cannot be fully utilized. The opposite condition, with long through queues blocking access to a left-turn lane, has a similar effect on left-turn capacity. Neither condition is desirable.

4. Check that the platoon arrives during the green interval so that through vehicles do not stop at the intersection. Unnecessary and sometimes excessive delay occurs if the platoon arrives during the red interval.

Computer Analysis

1. Check that individual movements are not delayed disproportionately to one another. If this condition exists, green splits may need adjustments and/or geometric modifications may be required.

2. Check that volume to capacity ratios for individual movements do not exceed 1.2. If so, the input data (usually capacity estimates) is probably in error and one should correct it. If not, the green splits and/or cycle length may be too

short and should be lengthened. If through movements are oversaturated, a capacity bottleneck exists, and arterial progression through the intersection(s) is not possible.

3. Check that the estimated queue lengths do not exceed the available storage. If so, the intersection cannot operate at its full potential for moving traffic. Signal timing or geometric modifications may increase the intersection's operational efficiency.

4. Check that the progression bands are large enough to move a reasonable platoon of vehicles. This check is met if the efficiency and attainability are high. If the progression bands are small (i.e., if the efficiency and attainability are small), then the offsets and phasing sequence should be changed.

4.1 Evaluation Software

One may perform evaluation or simulation using various computer simulation programs, such as the Highway Capacity Software (13), PASSER II-90 (14), TRANSYT-7F (15), the Arterial Analysis Package (16), and TRAF-NETSIM (17). Analysts can use the measures of effectiveness calculated by these programs to locate problems along the arterial and pinpoint areas where improvements are needed. The following sections briefly describe each of the programs.

Highway Capacity Software (HCS). Courage and Wallace at the University of Florida developed the HCS software for the Federal Highway Administration . The program calculates saturation flow rates, average stopped delay, average travel speed, level of service, and other measures of effectiveness based on the *Highway Capacity Manual* (HCM) (9) methodologies, the widely accepted standard for analysis of signalized intersections and arterial streets. The HCM program is straightforward and easy to use; however, one can use the program for evaluation only, and can only evaluate one intersection or one direction on the arterial at a time. For further information, consult the *Highway Capacity Software User's Manual* (13).

PASSER II-90. The Texas Transportation Institute at Texas A&M University developed the **P**rogression **A**nalysis and **S**ignal **S**ystem **E**valuation **R**outine for the Texas Department of Transportation. The program analyzes and optimizes isolated intersections and coordinated arterial street systems. Features include provisions for actuated and pretimed control, an engineer's assistant key for calculating saturation flow rates using HCM methods, and the capability of modeling permitted left turns. For evaluation purposes, PASSER II estimates the measures of effectiveness for movements corresponding to NEMA phases at individual intersections as well as overall measures of effectiveness for the entire arterial. The measures of effectiveness used by the program include v/c ratios, delay, queues, stops, and fuel consumption. Additionally, PASSER II evaluates the progression bandwidth efficiency and attainability for the existing or optimum signal timing conditions.

For further information on the program, refer to *Arterial Signal Timing Optimization Using PASSER II-90* (14).

TRANSYT-7F. Dennis Robertson of the Transport and Road Research Laboratory in England developed the **Traffic** Network **Study Tool** (15). Version 7 was modified to reflect North American nomenclature by the University of Florida for the Federal Highway Administration. One can use the program for the analysis and optimization of signal timing on coordinated arterials and grid networks. Features include provisions for actuated and pretimed control, the capability of modeling permitted left turn movements, and provisions for including stopped controlled intersections along the arterial street. TRANSYT estimates measures of effectiveness for each of the movements at individual intersections, as well as overall measures of effectiveness for the arterial. The measures of effectiveness used by the program include delay, queues, stops, fuel consumption, total travel, total travel time, average travel speed, and total operating cost. Additionally, TRANSYT graphically illustrates the flow profiles of the through and left-turn movements along the arterial.

Arterial Analysis Package (AAP). Courage and Wallace of the University of Florida developed the Arterial Analysis Package (16) for the Federal Highway Administration. The AAP provides a shell program to integrate the coding, evaluation, and optimization of an arterial using PASSER II, TRANSYT-7F, or a combination of the two programs. After developing the initial coded data set, PASSER can be used to optimize cycle lengths, phase sequences, offsets, and splits in order to maximize the bandwidth along an arterial. One can then use TRANSYT-7F to fine tune the offsets and phase splits determined by PASSER II in order to minimize the overall stops and delay.

TRAF NETSIM Model. Federal Highway Administration developed the TRAF NETSIM microscopic traffic network simulation model. This model can simulate traffic control systems in great detail; however, one cannot use it to optimize signal timing. The TRAF NETSIM model handles both isolated intersections and coordinated networks. The model simulates uncontrolled, stop/yield controlled, pretimed and semi-actuated systems. Fully actuated signals are simulated in isolated mode. The output includes detailed statistics on delay, stops, queues, emissions, and other variables. For further information, refer to the *TRAF User Reference Guide* (17).

These guidelines address PASSER II and TRANSYT (and their use through the AAP) due to their ability to both simulate (evaluate) and optimize arterial timing plans. PASSER II and TRANSYT can be used separately or in coordination for optimizing arterial signal retiming plans. Both PASSER II and TRANSYT may be run on an IBM PC compatible micro computer. For further information, one should refer further to the software user's manuals for both programs, as noted previously. Table 4-1 provides a comparison of the available features of both programs for traffic signal retiming projects.

Table 4-1. Features of PASSER II-90 and TRANSYT-7F

FEATURES	PASSER II	TRANSYT
Simulation	x	x
Optimization	x	x
Protected + Permitted lefts	x	x
Optimal phase sequence	x	-
Optimal splits	x	x
Analyze range of cycle lengths	x	x
Output		
Traffic Performance		
delay per movement	x	x
delay per intersection	x	x
total system delay	x	x
number of stops	x	x
degree of saturation	x	x
level of service	x	-
queue clearance	x	x
travel time	x	x
Signal Settings		
cycle length	x	x
phasing sequence	x	x
splits	x	x
offsets	x	x
interval lengths	-	x
Graphical Output		
flow profiles	-	x
time space diagram	x	x
bandwidth	x	-

4.2 Input Requirements

This section of the guidelines discusses the coding and simulation procedures for PASSER II-90 and TRANSYT-7F. Table 4-2 presents some of the common input requirements utilized by PASSER II and TRANSYT for coding existing conditions on an arterial system. A data set containing the existing operational conditions for the arterial system must be initially coded through one of the programs or the AAP. After developing the initial data set, one utilizes the selected program to simulate the existing conditions on the arterial segment. A simulation run models the arterial conditions coded in the data set and generates a performance evaluation of the conditions with respect to the modelling parameters of each program. The following sections outline the basic requirements for coding existing conditions for simulation with PASSER II and TRANSYT.

PASSER II-90 - One codes arterial data through PASSER II on coding screens accessible from various menu screens. Arterial identification data is coded on the *Arterial Data Screen* illustrated in Figure 4-1. One can reach this screen in two ways. If a new data set is being created, the user can access the screen for initial coding from the *Input Menu*. If an existing data set is currently loaded, the user can access the screen for editing from the *Edit Menu*. The *Arterial Data Screen* allows the user to code the name of the arterial segment, the orientation of the segment and primary movement (NEMA movement #2), and the number of intersections within the segment of interest. One should note that the orientation of the segment and NEMA movement 2 lies in the direction that intersection data will be entered (i.e., the direction travelled from the first intersection to the second intersection, the forward direction on the arterial). A system-wide parameter, the cycle length, is also coded on this screen and for simulation purposes the "lower" and "upper" cycles should each equal the cycle for the arterial system.

Most of the system-wide parameters are coded on the *Embedded Data Input Screen* and the *Phaser Data Input Screen*, respectively illustrated in Figures 4-2 and 4-3. The user accesses both of the screens from the *Input Data Menu*. The *Embedded Data Input Screen* allows the user to designate the type of signal control, the ideal saturation flow rate, and the system-wide defaults for the arterial. Additionally, this screen allows the user to adjust the operational level of service criteria and select appropriate permitted left-turn models. The *Phaser Data Input Screen* allows the user to designate intersection and phasing references for offset coordination along the arterial segment. The offset reference point on this screen must match the offset reference point in the field; otherwise, the simulation results will not reflect the actual field conditions. A common data entry error is the assumption that the software reference points and the hardware reference points are always the same.

Table 4-2. Common Coding Requirements for PASSER II and TRANSYT

ARTERIAL IDENTIFICATION	Name of Arterial Segment Orientation of Segment (NS or EW) Number of Intersections Distance Between Intersections
SYSTEM-WIDE PARAMETERS	Ideal Saturation Flow Rate Operational Defaults System Cycle Length System Offset References Signal Control (pretimed or actuated)
TRAFFIC/PHASING DATA	Speeds Volumes Number of Lanes Saturation Flow Adjustment Factors Phasing Sequences and Duration Additional Timing Intervals - Ped Walk - All Red

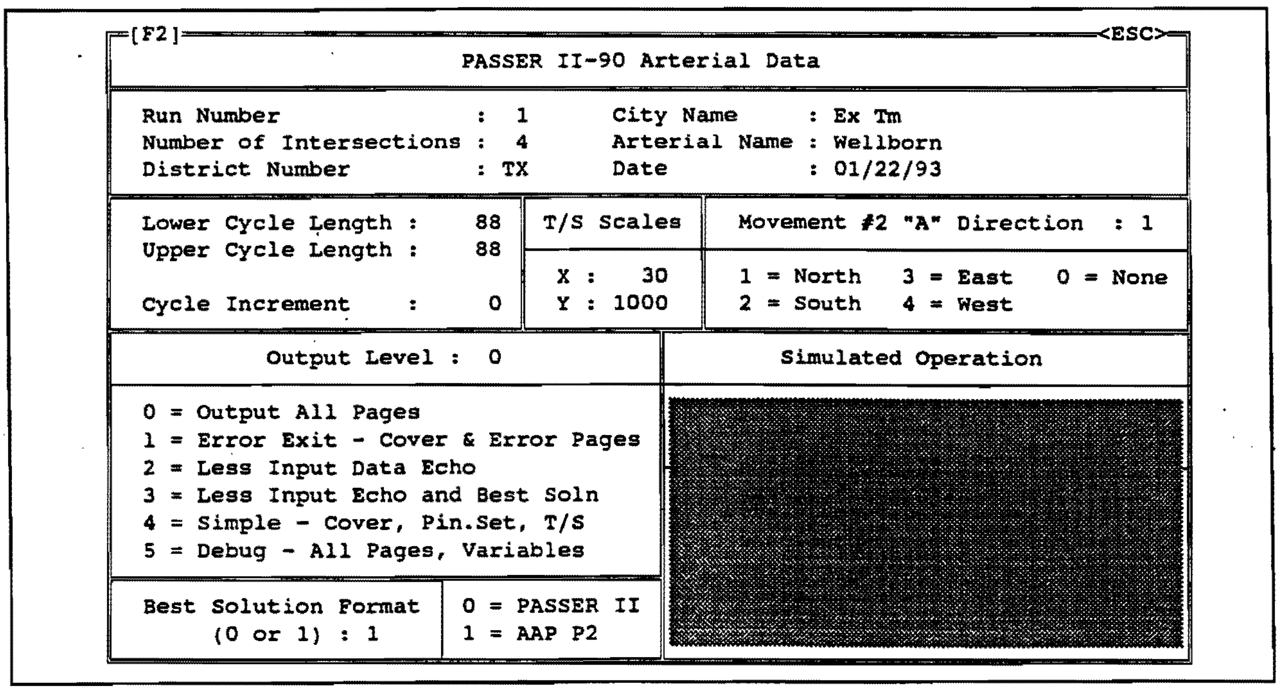


Figure 4-1. PASSER II Arterial Data Screen

```
                 PASSER II-90 EMBEDDED DATA INPUT SCREEN

 Pretimed or Actuated (P or A) = P           Sneakers,  S = 2.0
 Ideal Saturation Flow = 1800 pcphgpl        Phase Lost Time, L = 4.0
 Analysis Period, T =  15 minutes.           Left Turn P+P (A or R) = A

         LOS Delay Criteria : Total Delay,   Multiplier M = 1.3
 A :  5 * M =     6.5      C : 25 * M =    32.5      E : 60 * M =    78
 B : 15 * M =    19.5      D : 40 * M =    52        F > 60 * M =    78

 Model Form : Negative Exponential       > Texas A & M      Analytical Model <
                                           Australian       Analytical Model
                                           Univ. of Texas   Simulation Model
                                           Your Own Model   Same Model Form

 VO - Opp Sat Flow     (vph)   1750
 T  - LT Critical Gap (sec)       4.5
 H  - LT Headway       (sec)      2.5

 SL = Exponential Function of (VO, T, H)

                "P" for Pretimed or "A" for Actuated
```

Figure 4-2. PASSER II Embedded Data Input Screen

```
                       PASSER II-90 PHASER INPUT DATA

 Wellborn      Ex Tm
Mast Int =  1, Sys Int =  1, Sys Offset =   0.0, Movmnt = 0, Ref Pnt = BEGIN


Mast Int =  0, Sys Int =  0, Sys Offset =   0.0, Movmnt = 0, Ref Pnt =

Two Signal Phase Interval Reports will be generated from this input data.
These reports provide two signal timing plans from optimized PASSER II-90
settings.  The first report "DEFAULT (1)" uses the arterial barrier as the
default.  The second report "DEFAULT (2)" uses Phase 2 to reference the
offsets.  The cursor key may be used to change settings as noted below.

Comment Line : Remark line printed in output       [0-75 Characters]
Master Int   : Arterial Master Intersection        [Integer from 1 to 4]
Sys Int      : Arterial System Intersection        [Integer from 1 to 4]
Sys Offset   : System Reference Offset             [Real from 0.0 to 88]
Movmnt       : Arterial Reference Phase            [Integer 0, 2, 6]
Ref Pnt      : Phase Reference Point               [BEGIN or END of phase]
```

Figure 4-3. PASSER II Phaser Data Input Screen

The traffic phasing and progression data is coded on four separate screens: the *NEMA Vehicle Movement Screen*, the *Phasing Pattern Entry Screen*, the *Signal Offset Screen*, and the *Arterial Link Geometry Screen*. Figures 4-4 through 4-7 illustrate each of these four screens. The *NEMA Vehicle Movement Screen* allows the user to code traffic volumes, adjust saturation flow rates, and specify the type and duration of individual phases. The *Phasing Pattern Entry Screen* allows the user to designate the phasing sequence for each intersection on the arterial, while one enters the existing offsets for each intersection on the *Signal Offset Screen*. Finally, one uses the *Arterial Link Geometry Screen* to code the average travel speeds and distances between each set of intersections, as well as the queue clearance time for the intersection approaches.

After coding and visually inspecting the arterial information for accuracy, one selects the "Run" option on the PASSER II *Main Menu* to perform an operational simulation of the existing conditions. Upon selecting the "Run" option, PASSER II saves the coded information as an input data file, performs an evaluation routine, and generates an output file of the simulation results.

TRANSYT-7F. One codes arterial data for TRANSYT-7F through coding screens and windows accessible from TRANSYT's main menu, shown in Figure 4-8. The correct menu choice to create or edit an arterial data set is the TRANSYT *Data Input Manager* (DIM). After making this selection, a blank screen appears in the create mode and a screen containing data appears if an existing data set was loaded. Figure 4-9 shows an example of an existing data set; however, one should note that the figure reflects only the first 21 lines of data. The remainder of the data set is accessed by moving the cursor down to the bottom of the screen.

Note that several lines of data, with each line containing 16 five column fields, make up a TRANSYT data set. To view column headings or enter data, move the cursor to the line of interest and press the [Esc] key. This key will cause a window with column headings and current data to appear on the right side of the screen. Data within the window can be edited, and the data file will be updated when exiting the window. Figure 4-10 shows a data entry window for Card Type 1 (second line of data). Note that cycle length and analysis period length are entered on this data card.

Card Types 2, 7, and 10 contain the system level defaults and the parameters for the type of analysis that is being requested, similar to PASSER's *Arterial Identification Data* and *Imbedded Data Input Screen*. Cards Types 15 through 28 contain intersection information, such as phase lengths and sequences, traffic volumes, and link speed and distance data. This type of information will be repeated for each intersection in the arterial system. Figures 4-11, 4-12, and 4-13 illustrate *Interval Timing*, *Signal Phasing* and *Link Data*. One can see that TRANSYT requires more detailed data and a more complex data entry scheme than PASSER. As a result several input preprocessors have been written for TRANSYT, one of which is discussed in the next section.

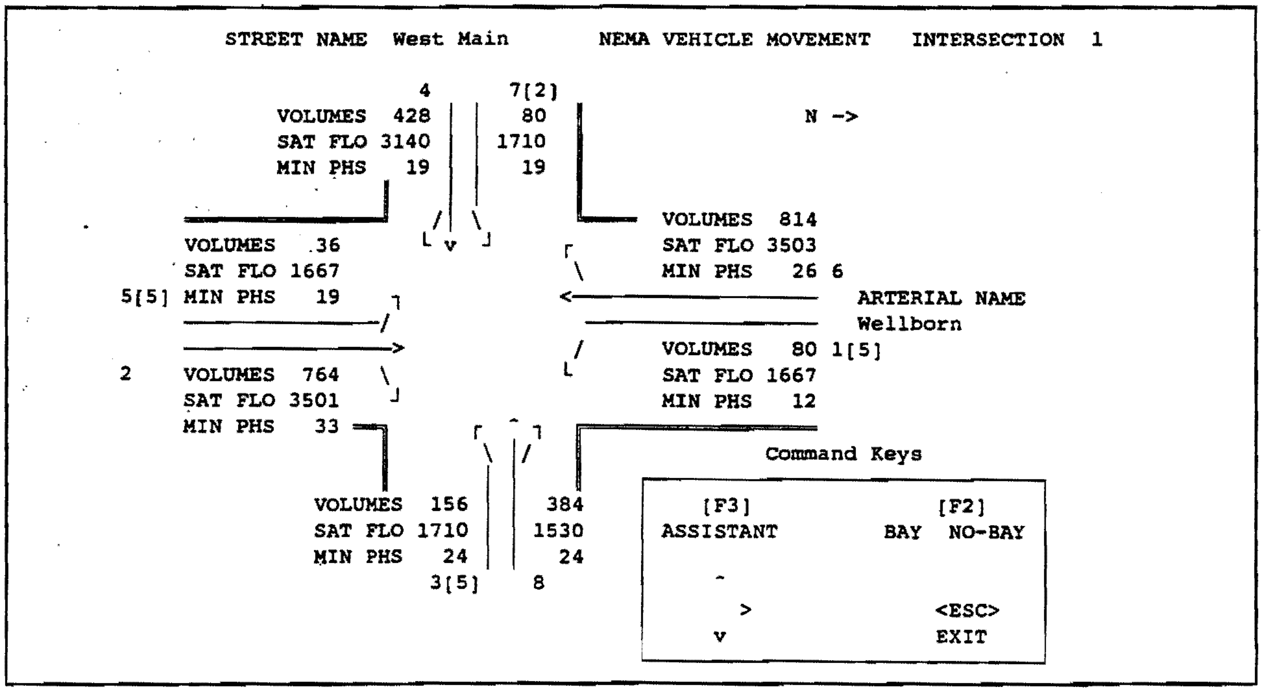


Figure 4-4. PASSER II NEMA Vehicle Movement Screen

```
-[F2]--[F3]-------------------------------------------------<ESC>-
                        Phasing Patterns Entry

  Arterial Name : Wellborn                  Intersection Number : 1
  Cross Street  : West Main
                                            Arterial      Cross Street

  Dual Lefts Leading with overlap               -              -
  Dual Lefts Leading without overlap            -              -
  Throughs First with overlap                   -              -
  Throughs First without overlap                -              -
  Left Turn # 1 Leading with overlap            Y              -
  Left Turn # 1 Leading without overlap         -              -
  Left Turn # 5 Leading with overlap            -              -
  Left Turn # 5 Leading without overlap         -              Y
  Special Phasing Selection                     -              -

Select which Phasing Patterns are needed.  <CR> to select, and <ESC> to exit.
     "Y" = phasing selected, "-" = not selected, "≡" = not possible.
   Note that "with overlap" and "without overlap" are mutually exclusive.
```

Figure 4-5. PASSER II Phasing Pattern Entry Screen

```
              Input Signal Offsets to Simulate Existing Timing.
                  Offset to Beginning of Main Street Green.
 Intersection      ( Presently  Simulation. )        Offset (sec)
 1. West Main                                           49.00
 2. Joe Routt                                           65.00
 3. George Bush                                         14.00
 4. Holleman                                            67.00
```

Figure 4-6. PASSER II Signal Offset Screen

```
[F2]                                                         <ESC>
 Wellborn                 Arterial Link Geometry        4 Intersections
```

"A" Link	Queue Clear.	Speed (MPH)	Distance (FT)	Distance (FT)	Speed (MPH)	Queue Clear.	"B" Link
1- 2	0	45	1246	1246	45	0	2- 1
2- 3	0	45	2249	2249	45	0	3- 2
3- 4	0	45	3738	3738	45	0	4- 3

From : West Main   To : Joe Routt

Figure 4-7. PASSER II Arterial Link Geometry Screen

```
McT7F - TRANSYT-7F MAIN MENU

T ---> TRANSYT-7F Program
R ---> Read Input/Output Files
A ---> Alter Data Files (T7FDIM)
N ---> New File (T7FGEN)
S ---> Send Output File to Printer
Y ---> Your Special Program
T ---> TRANSYT-7F Program
+ ---> EZ-TRANSYT PLUS
7 ---> 7F PPD Program
F ---> File Management

Copyright 1988, University of Florida

Enter your Choice [Quit, eXit  or Esc]
```

Figure 4-8. TRANSYTMain Menu for a Single Arterial

```
TRANSYT-7F DATA INPUT MANAGER                                         Version 4.2
   1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16
-Wellborn          Ex Tm                CASE NUMBER    1.                       -
[ -1   88   88    5    0    0    3    3    1    1    0   15    0    0    0    0]
[  2    1    2    3    4    0    0    0    0    0    0    0    0    0    0    0]
[  7  105  106    0    0    0  205  206    0    0    0  207  208    0    0    0]
[  7  305  306    0    0    0  405  406    0    0    0  407  408    0    0    0]
[ 10    1    0    0    0    0    0    0    0    1   95   25  100  100  125  120]
-INTERSECTION: West Main                                                        -
[ 15    1   49    1    8    4   13    1   15    4   15    4   20    4    0    0]
[ 21    1    1    1    2    0   10  103  104    0    0    0    0    0    0    0]
[ 22    1    3    3    4    0    5  101  103    0    0    0    0    0    0    0]
[ 23    1    5    5    6    0   10  101  102    0    0    0    0    0    0    0]
[ 24    1    7    7    8    0   15  105  106    0    0    0    0    0    0    0]
[ 25    1    9    9   10    0   15  107  108  112    0    0    0    0    0    0]
[ 28  101  100 3501  764    0    0    0   45    0    0    0    0    0    0    0]
[ 28  102  100 1667   36    0    0    0   45    0    0    0    0    0    0    4]
[ 28  103 1246 3503  814    0  203  686   45  208   85   45  205   41   45    0]
[ 28  104 1246 1667   80    0  203   80   45    0    0    0    0    0    0    4]
[ 28  105  100 3140  348    0    0    0   35    0    0    0    0    0    0    0]
[ 28  106  100    0   80    0    0    0   35    0    0    0    0    0    0    0]
[ 28  107  100 1800   28    0    0    0   35    0    0    0    0    0    0    0]
     [F1] For Command Mode , [Esc] For Window Mode. [?] For Card List
 File Name:   WLBRN-01.TIN          BROWSE MODE        Card No. 1  OF 73
```

Figure 4-9. Example of an Existing Data Set

```
TRANSYT-7F DATA INPUT MANAGER                                          Version 4.2
  1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16
-Wellborn           Ex  Tm              CA
[ -1   88   88    5    0    0    3       | CARD TYPE  -1           SYSTEM CONTROLS |
[  2    1    2    3    4    0    0       |                                         |
[  7  105  106    0    0    0  205   20 | MINIMUM CYCLE..................[88    ] |
[  7  305  306    0    0    0  405   40 | MAXIMUM CYCLE..................[88    ] |
[ 10    1    0    0    0    0    0      | CYCLE INCREMENT................[5     ] |
-INTERSECTION: West Main                | SEC/STEP (CYC).................[0     ] |
[ 15    1   49    1    8    4   13      | SEC/STEP (OPT).................[0     ] |
[ 21    1    1    1    2    0   10   10 | START LOST TIME................[3     ] |
[ 22    1    3    3    4    0    5   10 | EXT. EFFECTIVE GREEN...........[3     ] |
[ 23    1    5    5    6    0   10   10 | STOP PENALTY...................[1     ] |
[ 24    1    7    7    8    0   15   10 | OUTPUT LEVEL...................[1     ] |
[ 25    1    9    9   10    0   15   10 | INITIAL TIMING (Y=1)...........[0     ] |
[ 28  101  100 3501  764    0    0      | PERIOD LENGTH..................[15    ] |
[ 28  102  100 1667   36    0    0      | SEC(0) / PERCENT(1)............[0     ] |
[ 28  103 1246 3503  814    0  203   68 | SPEED(0) / TIME(1).............[0     ] |
[ 28  104 1246 1667   80    0  203    8 | U.S.(0) / METRIC(1)............[0     ] |
[ 28  105  100 3140  348    0    0      | PUNCH (Y=1)....................[0     ] |
[ 28  106  100    0   80    0    0      |                                         |
[ 28  107  100 1800   28    0    0      |                                         |
     [PgUp] [PgDn] to change cards ... [Esc] to return to Browse Mode.
  File Name:    WLBRN-01.TIN          WINDOW MODE          Card No. 2  OF 73
```

Figure 4-10. Data Entry Window for Card Type 1

```
TRANSYT-7F DATA INPUT MANAGER                                          Version 4.2
  1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16
-Wellborn           Ex  Tm              CA
[ -1   88   88    5    0    0    3      | CARD TYPE [ 15]         INTERVAL TIMING |
[  2    1    2    3    4    0    0      |                                         |
[  7  105  106    0    0    0  205   20 | NODE NUMBER....................[1     ] |
[  7  305  306    0    0    0  405   40 | OFFSET OR YIELD PT.............[49    ] |
[ 10    1    0    0    0    0    0      | REFERENCE INTERVAL.............[1     ] |
-INTERSECTION: West Main                | INTERVAL LENGTH 1..............[8     ] |
[ 15    1   49    1    8    4   13      | .               2..............[4     ] |
[ 21    1    1    1    2    0   10   10 | . (NOTE: IF THE 3..............[13    ] |
[ 22    1    3    3    4    0    5   10 | . '1X' IS NEG-  4..............[1     ] |
[ 23    1    5    5    6    0   10   10 | . ATIVE (-1X)   5..............[15    ] |
[ 24    1    7    7    8    0   15   10 | . THE SPLITS    6..............[4     ] |
[ 25    1    9    9   10    0   15   10 | . WILL NOT BE   7..............[15    ] |
[ 28  101  100 3501  764    0    0      | . OPTIMIZED.)   8..............[4     ] |
[ 28  102  100 1667   36    0    0      | .               9..............[20    ] |
[ 28  103 1246 3503  814    0  203   68 | .              10..............[4     ] |
[ 28  104 1246 1667   80    0  203    8 | .              11..............[0     ] |
[ 28  105  100 3140  348    0    0      | DOUBLE CYCLE? (Y=1)............[0     ] |
[ 28  106  100    0   80    0    0      |                                         |
[ 28  107  100 1800   28    0    0      |                                         |
     [PgUp] [PgDn] to change cards ... [Esc] to return to Browse Mode.
  File Name:    WLBRN-01.TIN          WINDOW MODE          Card No. 8  OF 73
```

Figure 4-11. TRANSYT Coding Screen for Interval Timing

```
TRANSYT-7F DATA INPUT MANAGER                                     Version 4.2
  1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16
-Wellborn         Ex  Tm               CA
[ -1   88   88    5    0    0    3      CARD TYPE [ 21]         SIGNAL PHASING
[  2    1    2    3    4    0    0
[  7  105  106    0    0    0  205  20  NODE NUMBER....................[1     ]
[  7  305  306    0    0    0  405  40  START INTERVAL.................[1     ]
[ 10    1    0    0    0    0    0      VARIABLE INTERVAL..............[1     ]
-INTERSECTION: West Main                YELLOW INTERVAL................[2     ]
[ 15    1   49    1    8    4   13      ALL-RED INTERVAL...............[0     ]
[ 21    1    1    1    2    0   10  10  MINIMUM PHASE LENGTH...........[10    ]
[ 22    1    3    3    4    0    5  10  LINKS SERVICED: 1..............[103   ]
[ 23    1    5    5    6    0   10  10  .               2..............[104   ]
[ 24    1    7    7    8    0   15  10  .  (NEGATIVE    3..............[0     ]
[ 25    1    9    9   10    0   15  10  .   NUMBERS     4..............[0     ]
[ 28  101  100 3501  764    0    0      .     MEAN      5..............[0     ]
[ 28  102  100 1667   36    0    0      .  PERMITTED.)  6..............[0     ]
[ 28  103 1246 3503  814    0  203  68  .               7..............[0     ]
[ 28  104 1246 1667   80    0  203   8  .               8..............[0     ]
[ 28  105  100 3140  348    0    0      ACTUATED OR DESIRED D/S........[0     ]
[ 28  106  100    0   80    0    0
[ 28  107  100 1800   28    0    0
     [PgUp] [PgDn] to change cards ... [Esc] to return to Browse Mode.
  File Name:   WLBRN-01.TIN        WINDOW MODE        Card No. 9  OF 73
```

Figure 4-12. TRANSYT Coding Screen Signal Phasing

```
TRANSYT-7F DATA INPUT MANAGER                                     Version 4.2
  1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16
-Wellborn         Ex  Tm               CA
[ -1   88   88    5    0    0    3      CARD TYPE   28                LINK DATA
[  2    1    2    3    4    0    0
[  7  105  106    0    0    0  205  20  LINK NUMBER....................[101   ]
[  7  305  306    0    0    0  405  40  LINK LENGTH....................[100   ]
[ 10    1    0    0    0    0    0      SATURATION FLOW................[3501  ]
-INTERSECTION: West Main                TOTAL VOLUME...................[764   ]
[ 15    1   49    1    8    4   13      MIDBLOCK ENTRY.................[0     ]
[ 21    1    1    1    2    0   10  10  1ST INPUT LINK NO..............[0     ]
[ 22    1    3    3    4    0    5  10  .             VOLUME...........[0     ]
[ 23    1    5    5    6    0   10  10  .              SPEED...........[45    ]
[ 24    1    7    7    8    0   15  10  2ND INPUT LINK NO..............[0     ]
[ 25    1    9    9   10    0   15  10  .             VOLUME...........[0     ]
[ 28  101  100 3501  764    0    0      .              SPEED...........[0     ]
[ 28  102  100 1667   36    0    0      3RD INPUT LINK NO..............[0     ]
[ 28  103 1246 3503  814    0  203  68  .             VOLUME...........[0     ]
[ 28  104 1246 1667   80    0  203   8  .              SPEED...........[0     ]
[ 28  105  100 3140  348    0    0      QUEUEING CAPACITY..............[0     ]
[ 28  106  100    0   80    0    0
[ 28  107  100 1800   28    0    0
     [PgUp] [PgDn] to change cards ... [Esc] to return to Browse Mode.
  File Name:   WLBRN-01.TIN        WINDOW MODE        Card No. 14  OF 73
```

Figure 4-13. TRANSYT Coding Screen for Link Data

Arterial Analysis Package. One may code arterial data for the AAP through pull down menus and data entry screens that are accessible from the program's main menu. As mentioned previously, the AAP creates a data set readable and usable by either PASSER II-90 or TRANSYT-7F. After loading an existing data set into active memory or after selecting the *Create New Data* option, move the cursor to the *Edit* pull down menu shown in Figure 4-14. Note that the user can edit several components of an AAP data set, as well as PASSER II-90 and TRANSYT-7F data sets.

The *Artery Setup Screen* (Figure 4-15) contains the system wide defaults used by both PASSER II-90 and TRANSYT-7F. The Global Values in the bottom of the screen are defaults, but one can override them on subsequent data screens. Thus, they should initially be set to the most common values for the system. The *Artery Data Screen* (Figure 4-16) contains speed and distance information for the arterial. The user must provide *Approach Data* (Figure 4-17) for each intersection in the system. One enters information, such as volumes, saturation flow rates, and minimum phase times, on this screen.

The user enters timing and phasing information on the *Timing Plan* screen (Figure 4-18). Existing phasing sequence, phase lengths, and offsets are entered for each intersection along with the allowable phasing sequences for a PASSER II phasing optimization. One specifies the decision to use the existing timing or to develop an optimal timing plan on the *Run Instructions* screen (Figure 4-19). This screen contains the cycle length range and the type of optimization necessary. Note that as coded in this figure, nothing is optimized; instead, an evaluation of existing conditions is requested. To request optimization of phasing sequence, splits, and/or offsets, one or all of the Ns should be changed to a Y. If one requests these options, existing timing and phasing are automatically ignored, and the minimum values are used in the optimization.

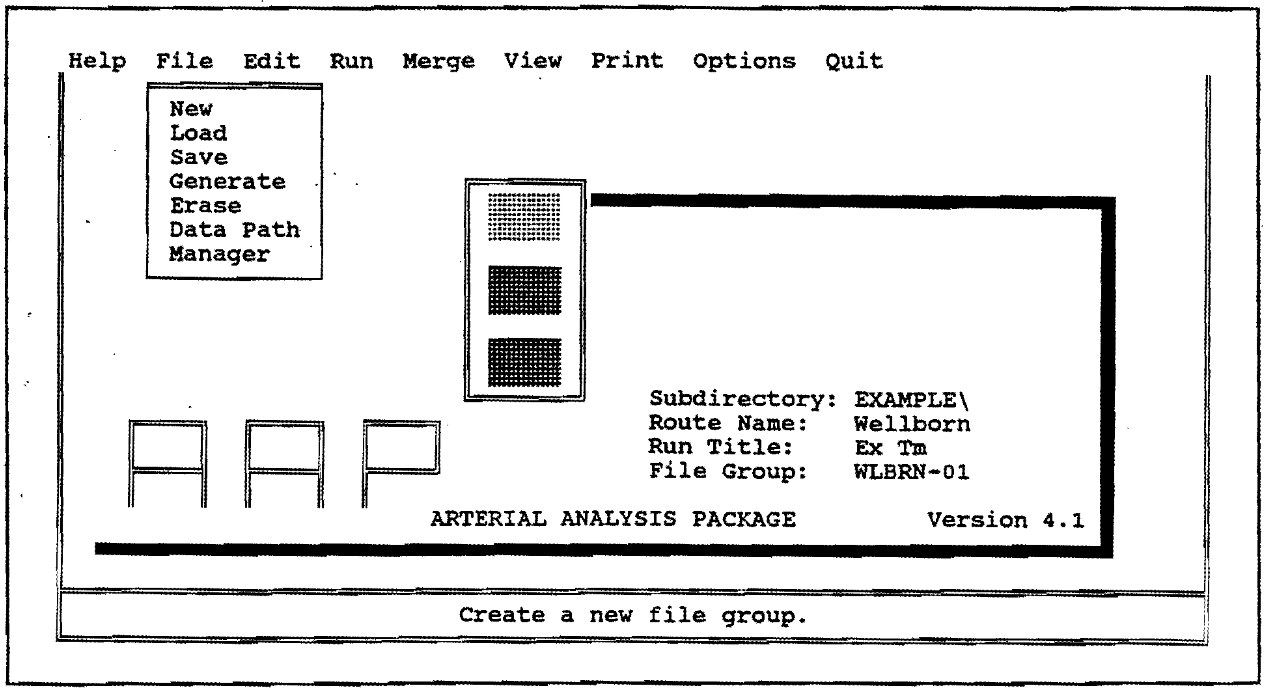


Figure 4-14. AAP Main Menu for a Single Arterial

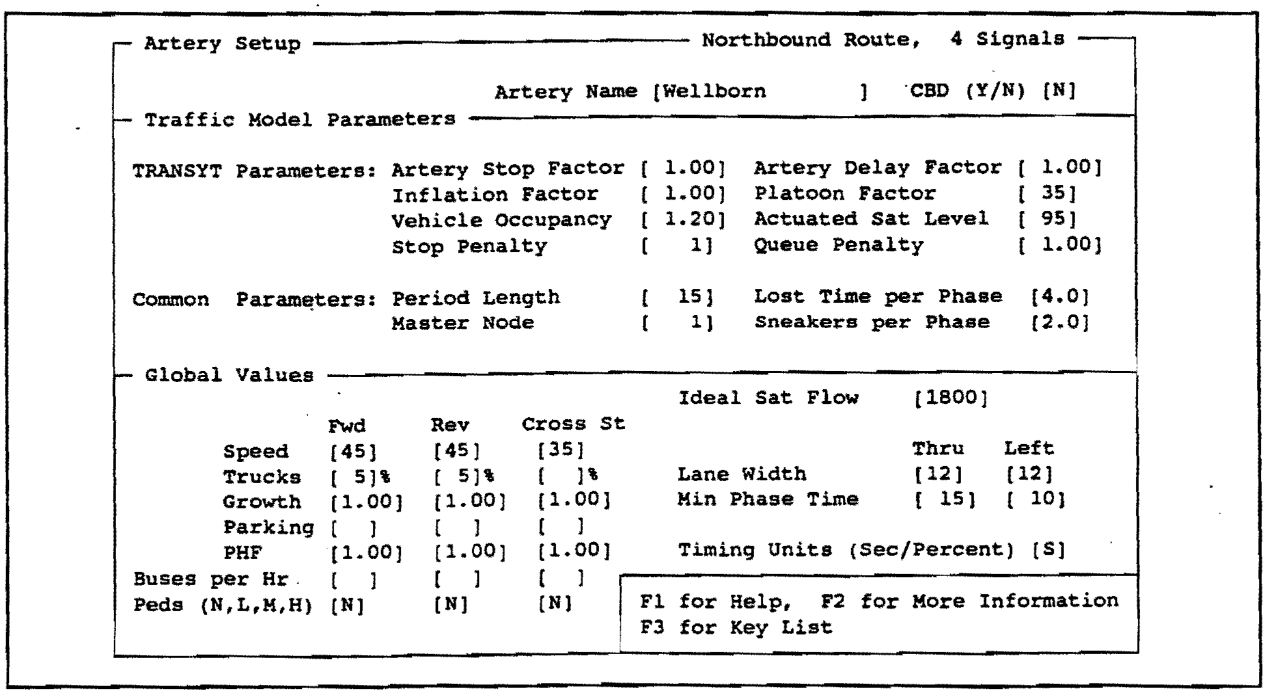


Figure 4-15. AAP Artery Setup Screen

Artery Data

Name: Wellborn

		Ref #	Mode (PFSI)	Northbound Speed Mph	Northbound Length Feet	Southbound Speed Mph	Southbound Length Feet
1	West Main	1	P	45		45	1246
2	Joe Routt	2	P	45	1246	45	2249
3	George Bush	3	P	45	2249	45	3738
4	Holleman	4	P	45	3738	45	
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

Figure 4-16. AAP Artery Data Screen

Approach Data

Reference # 1 Wellborn at West Main

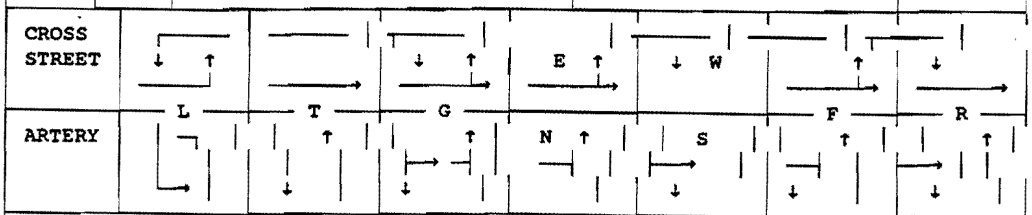
Seq # 1	Northbound			Southbound			Eastbound			Westbound		
Mode P	L	T	R	L	T	R	L	T	R	L	T	R
Movement	5	2		1	6		7	4		3	8	
Volume	36	752	12	80	804	10	80	52	296	156	28	384
# Lanes	1	2		1	2			2		1	1	1
PHF	1	1		1	1		1	1		1	1	
Free Turns	2.0			2.0			2.0			2.0		
Adj Vol	36	789	12	80	844	10	80	54	296	156	28	384
Ideal Sat	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Local Adj	1	1	1	1	1	1	1	1	1	1	1	1
Sat Flow	1667	3501		1667	3503			3140		1710	1800	1530
Storage	4			4						4		
Min Time	10	15		10	15		10	15		10	15	
Speed	45	45		45	45		35	35		35	35	
WM												

F1 for Help F2 for More Information F3 for Key List

Figure 4-17. AAP Approach Data Screen

Timing Plan

Ref #	Mode	Arterial Operation Ph	Sec	Ph	Sec	Ph	Sec	LTNS	Cross St Operation Ph	Sec	Ph	Sec	Ph	Sec	Offset Sec
1	P	S	12	T	14	N	19	2222	E	19	W	24			49
2	P	N	18	T	15	S	19	2222	E	18	W	18			65
3	P	N	13	T	11	S	27	2222	E	19	W	18			14
4	P	N	15	T	16	S	21	2222	E	18	W	18			67



F1 for Help F2 for More Information F3 for Key List

Figure 4-18. AAP Timing Plan Screen

Run Instructions Run # [1] Title [Ex Tm]

Cycle Range
Minimum [88]
Maximum [88]
Increment [5]

Optimize
[N] Sequence {P}
[N] Splits
[N] Offsets

Performance Index {T}
Disutility (S,F,C) [S]
Add Queue Penalty? [N]
Optimize (D,P,R) [D]

Output Control
[Y] Use AAP Format?

[Y] System Data Report
[Y] Intersec Data Report
[Y] Component Pgm Inputs

[Y] Route Summary
[N] Flow Profiles
[N] Time-Location Diagram
[Y] Time-Space Diagram
[Y] Timing Tables {T}

[Y] Coordinated Operation?

[N] Bandwidth Constraints {T}
[N] Arterial Link Weighting {T}
[N] Link to Link Flow Weighting {T}

[N] Speed Search {P}
[N] Queue Clearances {P}
[ ] Minimum Forward Band {P}

Use Adjusted Volumes? [N]
System Limits: From Ref # [1]
To Ref # [4]

Figure 4-19. AAP Run Instruction Screen

4.3 Output Evaluation

This section discusses the generation and interpretation of the output from simulation runs by PASSER II-90 and TRANSYT-7F. After completing a simulation run, one creates an output file of the simulation results. Because both PASSER II and TRANSYT are signal optimization programs, the output generated by each program is oriented toward developing an optimal set of signal timing parameters. This section will focus upon the components of the output critical for evaluating existing conditions. In general, output files consist of both an echo of the information coded in the initial input data file and a listing of the MOEs calculated for the existing or optimized traffic operational conditions.

PASSER II Output. The initial output section of the PASSER II simulation run consists of a report of the input conditions coded in the original data file. This input report typically refers to an input echo, and includes a cover page, an embedded data page, and input data pages for each of the intersections. If the program detects coding errors, it will list them on the error message page generated after the input data.

Pages summarizing the estimated operational traffic conditions for the arterial segment follow the input echo. The first output page is oriented toward providing a progression summary for the arterial and does not provide information when simulating existing conditions. The second output page is the intersection summary page and it presents a general description of the performance characteristics for each of the intersections along the arterial.

For simulation purposes, the two output elements of particular importance are the intersection best solution reports and the arterial MOEs report. The user can use these two components to evaluate existing conditions, by identifying specific points of congestion and evaluating the level of operational service along the arterial. A best solution report is generated for each of the intersections along the arterial. Each report includes phase times, MOEs for each movement, and the overall MOEs for each intersection. An arterial MOE report follows the series of intersection best solution reports and contains the estimated operational parameters for the entire arterial system.

The final two elements of the PASSER II output are the PIN setting reports and the time-space diagram. The program generates a separate PIN setting report for each intersection along the arterial and lists the signal controller settings for the corresponding intersection. The time-space diagram provides a graphic illustration of the timing sequence along the arterial and can be used to plot progression bands for through movements along the arterial segment. Chapter 5.0 discusses both of these output components further relative to arterial optimization.

TRANSYT Output. When entering data using TRANSYT-7F, the user may designate a portion of the plots and diagrams to be included in the output. The TRANSYT-7F user's manual (15) gives further information relative to the type of output information to be generated. In general, TRANSYT will produce an echo of the input data, intersection and system-wide performance evaluations, intersection controller settings, a time-space diagram, and flow profile diagrams after completing a simulation run. Note that the type of output produced by TRANSYT-7F is similar to that produced by PASSER II.

The table(s) of performance with initial settings provides a summary of the operational performance parameters associated with the individual movements at each intersection along the arterial. The program produces a separate table for each intersection on the arterial. For simulation and evaluation purposes, analysts can use the initial settings table(s) to identify specific bottlenecks as well as locations along the arterial where one could possibly make operational improvements. The performance measures for the entire arterial network are reported in the system wide table, which also includes the performance index calculated by TRANSYT-7F. Flow profile diagrams illustrate the position of the platoon with respect to the arterial through green phase. Ideally, most vehicles would arrive during the green phase.

Figure 4-13 and 4-14 illustrate the individual intersection best solution and performance with initial setting reports generated by PASSER II and TRANSYT-7F, respectively. Figures 4-15 and 4-16 show system wide performance measures from the two programs. Although not identical, a great deal of similarity exists in the types of information provided. One should note, however, that a comparison of the two programs' output should not be made because of slight differences in the way that some MOEs are calculated. In other words, one can compare PASSER II output to PASSER II output, TRANSYT-7F output to TRANSYT-7F output, but not PASSER II output to TRANSYT-7F output.

PASSER II and TRANSYT 7F generate time-space diagrams which provide a graphical illustration of the timing sequence at the intersections along the arterial. One can determine the bandwidth by extending a line through the green window at each intersection and then measuring its width. The Flow profile diagrams of TRANSYT-7F, illustrated in Figure 4-18, are generated for each intersection along the arterial. These diagrams graphically depict the arrival and departure pattern of vehicles during green and red. On the flow profile diagram, an "I"symbol indicates an arrival on red that queues, an "S"symbol indicates the departure of a queued vehicle, and an "O" symbol indicates an arrival and as well as a departure on green.

```
(BEST.SOLN)
             TEXAS DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION
PASSER II-90     MULTIPHASE ARTERIAL PROGRESSION - 145101      VER 1.0  DEC 90

              **** BEST SOLUTION.... NEMA PHASE DESIGNATION ****
*** INT.    1  49.0 SEC OFFSET     ART   ST PHASE SEQ IS LT 5 LEADS   (2+5)
West Main      55.7 %   OFFSET     CROSS ST PHASE SEQ IS LT 3 LEADS   (3+8)

                          ARTERIAL STREET                 CROSS STREET
CONCURRENT PHASES    2+5   2+6   1+6    TOTAL      3+8   4+8   4+7    TOTAL
PHASE TIME (SECS)   12.0  14.0  19.0     45.0     19.0    .0  24.0     43.0
PHASE TIME (%)      13.6  15.9  21.6     51.1     21.6    .0  27.3     48.9
                   -------------- MEASURES OF EFFECTIVENESS ---------------
PHASE (NEMA)         5[5]   6     1[5]   2        3[2]   4      7[2]   8
PHASE DIRECTION     SBLTPR NBTHRU NBLTPR SBTHRU   EBLTPR WBTHRU WBLTPR EBTHRU
PHASE TIME (SEC)    12.0   33.0   19.0   26.0     19.0   24.0   24.0   19.0
V/C-RATIO            .52    .69    .12    .97      .00    .81    .00    .80
LEVEL OF SERVICE    A      B      A      E               D             D
DELAY (SECS/VEH)    41.2   25.7   30.9   56.1       .0   38.7     .0   42.9
LEVEL OF SERVICE    D      C      C      E               D             D
QUEUE (VEH/LANE)     1.9    6.6     .7   13.0       .0    7.1     .0    5.8
STOPS (STOPS/HR)    74.   604.    28.   932.       0.   531.     0.   412.
TOTAL INTERSECTION DELAY        FUEL CONSUMPTION        MINIMUM DELAY CYCLE
    40.91 SECS/VEH                55.78 GAL/HR                88 SECS
```

Figure 4-20. PASSER II Best Solution Report

```
WELLBORN SIMULATION
CYCLE:   88 SECONDS,    60 STEPS

<PERFORMANCE WITH INITIAL SETTINGS>

MOVEMENT/           TOTAL  TOTAL  TOTAL   AVG.    UNIFORM    MAX. BACK    FUEL
NODE NOS.   V/C   TRAVEL   TIME  DELAY  DELAY     STOPS     OF  QUEUE   CONS.
            (%)   (V-MI) (V-HR) (V-HR) (SEC/V)  NO. (%)    NO.  CAP.    (GA)
------------------------------------------------------------------------------
  NB THRU : 74   180.40  12.96   8.99   42.3  557.( 73)   15   100    19.79
     LEFT : 14     8.50    .65    .47   46.6   24.( 68)    1    50      .94

  SB THRU :107*   15.14  37.29  36.96  163.9  756.( 93)   23>    8C   37.14
     LEFT : 69     1.49   1.26   1.23   55.2   74.( 93)    2     4     1.93

  EB THRU : 93     7.98   7.07   6.81   57.3  403.( 94)   10>    8C    7.61

  WB THRU : 90    10.59   7.59   7.25   45.9  530.( 93)   13>    8C    8.76

NODE       1:107* 224.09  66.83  61.69   82.6 2345.( 87)               76.17
```

Figure 4-21. TRANSYT-7F Intersection Performance Summary Table

```
(ART.MOE)
             TEXAS DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION
PASSER II-90    MULTIPHASE ARTERIAL PROGRESSION - 145101     VER 1.0  DEC 90

                  **** TOTAL ARTERIAL SYSTEM PERFORMANCE ****

college stat  wellborn                     DISTRICT    05/23/90    RUN NO.  1

         CYCLE LENGTH =  88 SECS      BAND A =   0 SECS   BAND B =   0 SECS
         AVERAGE PROGRESSION SPEED -  BAND A =  45 MPH    BAND B =  45 MPH

                   EFFICIENCY AND ATTAINABILITY NOT AVAILABLE

  AVERAGE INTERSECTION DELAY     TOTAL SYSTEM DELAY     TOTAL NUMBER VEHICLES
          43.5 SECS/VEH            113.0 VEH-HR/HR              9348.

  TOTAL SYSTEM FUEL CONSUMPTION    TOTAL SYSTEM STOPS    MAXIMIN CYCLE
          279.24 GAL/HR              9639. STOPS             88 SECS
```

Figure 4-22. PASSER II Arterial MOE Summary Page

```
WELLBORN SIMULATION
CYCLE:  88 SECONDS,   60 STEPS


<SYSTEM WIDE TOTALS INCLUDING ALL LINKS>

PERFORMANCE TOTAL  TOTAL TOTAL AVG.    UNIFORM    FUEL  SYSTEM TOTAL PERFOR-
MEASURES    TRAVEL TIME  DELAY DELAY    STOPS     CONS. SPEED  COST  MANCE
            V-MI   V-HR  V-HR  SEC/V   NO. (%)     GA    MI/H        INDEX
----------------------------------------------------------------------------

<TOTALS>    2644    276   214  82.6   6845( 73)    324    9.6  1089   228.1

----------------------------------------------------------------------------

NOTE: PERFORMANCE INDEX IS DEFINED AS:

      PI = DELAY + STOPS

NO. OF SIMULATIONS =   1  NO. OF LINKS =  26  ELAPSED TIME =     4.3 SEC.
```

Figure 4-23. TRANSYT-7F Table of Arterial Performance Measures

```
PASSER II-90     MULTIPHASE ARTERIAL PROGRESSION - 145101     VER 1.0  DEC 90

RUN NO   1  DISTRICT     Wellborn                   01/25/93  CYCLE =  88 SECONDS
            HORIZONTAL SCALE 1 INCH =   30 SECS   (1 inch = 10 characters)
            VERTICAL   SCALE 1 INCH = 3500 FEET   (1 inch = 6 lines)
INT   4   I
Hollema IXXX\\\\\\\          /////XXXXX\\\\\\\          /////XXXXX\\\\\\\
 67.0S    I
          I
          I
          I
INT   3   I
George    I     ////XXXX\\\\ \\\\          ////XXXX\\\\\\\\\          ////XXXX
 14.0S    I
          I
INT   2   I
Joe Rou IXXX\\\\\\          //////XXXXX\\\\\\          //////XXXXX\\\\\\
INT   1   I
West Ma I//              \\\XXXXX//////          \\\XXXXX//////
  0.0S
               /A/                                         \B\
             45 MPH                                      45 MPH
          0 SECOND BAND                               0 SECOND BAND


    === DUAL LEFTS  (1+5)                        XXX DUAL THRUS  (2+6)
    /// LT 5 LEADS  (2+5)                        \\\ LT 1 LEADS  (1+6)
```

Figure 4-24. PASSER II Time-Space Diagram

```
WELLBORN
CYCLE:  88 SECONDS,   60 STEPS

    LINK   103    MAX FLOW  3346 VEH/H     PLT. INDEX  .00

4000+
    :
    :
    :
    :                                      SSSSSSSSSSSS
    :                                      SSSSSSSSSSSS
3000+                                      SSSSSSSSSSSS
    :                                     SSSSSSSSSSSSS
    :                                     SSSSSSSSSSSSSS
    :                                     SSSSSSSSSSSSSS
    :                                     SSSSSSSSSSSSSS
    :                                     SSSSSSSSSSSSSS
2000+                                     SSSSSSSSSSSSSS
    :                                     SSSSSSSSSSSSSS
    :                                     SSSSSSSSSSSSSS
    :                                     SSSSSSSSSSSSSS
    :                                     SSSSSSSSSSSSSS
    :                                     SSSSSSSSSSSSSS
1000+                                     SSSSSSSSSSSSSS
    :IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIOOOOOOOOOOOOOOIIIIIIIIII
    :IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIOOOOOOOOOOOOOOIIIIIIIIII
```

Figure 4-25. TRANSYT-7F Flow Profile Diagram

Output Verification. After using any traffic simulation program to evaluate conditions on an arterial segment, one must validate the output to insure the accuracy of the results. The timing parameters reported by the program, such as phase splits and sequences should equal the existing parameters recorded in the field. Additionally, one should note operational measures, such as v/c ratios and queue lengths, and compare them to the v/c ratios and queue lengths predicted by PASSER II or TRANSYT. It is not always feasible to conduct a full-scale verification of the program output, but one must conduct some degree of validation. A simplified approach for verifying results could be to evaluate the total travel times along the arterial by comparing the field measurements to the program estimates.

If large discrepancies between observed and estimated values are noted, check the input data again. After making corrections, rerun the program and recheck the results. If inaccuracies persist, evaluate the system-wide default variables to assure that the assumed operational factors are reasonable. Inaccurate data cannot be used to simulate the existing conditions accurately and will result in optimization runs generating inaccurate timing plans. The user should insure the validity of the simulation run before going on to the optimization step.

4.4 PASSER II/TRANSYT-7F Comparison

This section presents a comparison of some of the common MOEs calculated with PASSER II and TRANSYT for the evaluation of a typical arterial segment. Wellborn Road, a four intersection arterial segment in College Station is used as the example arterial segment. In general, the southbound movement on Wellborn Road operates at a poor level of service. During the p.m. peak, the southbound traffic predominates, and several of the intersection's southbound movements operate near capacity. In general, the side streets, as well as the northbound movements, remain mostly undersaturated; therefore, it is likely that the capacity problems on the southbound movements may be due to inefficient allocation of the available green time.

Table 4-3 compares some of the system-wide MOEs calculated by PASSER II and TRANSYT. For both total and average delay, PASSER II's calculations are higher than those for TRANSYT II by approximately 21 percent. In a similar fashion, the total number of stops predicted by PASSER II are greater than those predicted by TRANSYT by approximately 21 percent. As previously mentioned, both programs use slightly different approaches to predict delay and stops, and one should expect some variation in these calculations. Although both PASSER II and TRANSYT use identical approaches to estimate fuel consumption, the fuel consumption calculations differ as a result of the model's incorporation of different values for delay and stops. Because the estimates for delay and stops differ, one would assume that the fuel consumption estimates would also differ.

Table 4-3. Common MOEs Calculated for the Total Arterial System

	Total Delay (veh-hrs)	Average Delay (sec/veh)	Total Stops (veh/hr)	Fuel Consumption (gal/hr)
PASSER II	122	45.6	9577	274
TRANSYT-7F	101	35.1	7884	243

For a better comparison of the MOE calculations from PASSER II and TRANSYT, one can look at the calculated MOEs with respect to specific movements. Table 4-4 compares MOEs for volume to capacity ratios, delay, and stops for each movement along the arterial. Note that PASSER II and TRANSYT produced the same or similar volume to capacity ratios as a result of having been coded identical volumes and saturation flow rates in their original data sets. The slight differences in a few of the volume to capacity ratios may be attributed to shared lane operations or round-off variation in the two programs.

For specific movements along the arterial, differences in the delay estimates from PASSER II and TRANSYT exist for the progressed through movements throughout the system. This difference results from a variation in the delay estimation procedures used by each program. PASSER II calculates delay for the progressed movements by applying a modified version of the HCM delay equation. TRANSYT-7F calculates delay for these movements by measuring delay from flow profiles throughout the system. For the exterior cross-street movements (EB and WB) and the non-progressed arterial movements (NB at Holleman and SB at West Main), PASSER II and TRANSYT-7F use essentially the same methodology for calculating delay. As a result, not a great deal of variation exists in the delay estimates for these movements.

Similar to delay, PASSER II calculated a higher number of stops than TRANSYT. Again, for the exterior and non-progressed movements, PASSER II and TRANSYT use similar approaches for predicting stops. On the progressed arterial through movements, however, the two programs use different approaches, resulting in different estimates for stops. PASSER II uses an analytical equation to calculate stops, while TRANSYT-7F derives the number of stops from its delay estimation. PASSER II will always predict more stops because it counts a vehicle stopping more than once at an intersection as multiple stops, whereas TRANSYT-7F assumes a vehicle can only stop once at an intersection. It is worth noting that the degree to which PASSER II calculated a greater amount of stops than TRANSYT-7F increased for progressed movements with higher volume to capacity ratios (those situations where multiple stops at the intersections are more likely).

Table 4-4. Common MOE's Calculated for Individual Phases

WEST MAIN	**NBT**	**NBL**	**SBT**	**SBL**	**EBT**	**EBL**	**WBT**	**WBL**
V/C Ratio								
PASSER II	.66	.13	.93	.53	.80		1.11	.40
TRANSYT	.66	.13	.82	.53	.80	.80	0.07	.40
Delay (sec/veh)								
PASSER II	26.6	31.0	40.8	41.7	42.7		131.3	29.4
TRANSYT	26.1	30.7	29.0	27.3	40.4	40.4	26.6	30.1
Stops (veh/hr)								
PASSER II	703	28	854	75	412		694	122
TRANSYT	614	29	723	75	316	73	21	126

JOE ROUTT	**NBT**	**NBL**	**SBT**	**SBL**	**EBT**	**EBL**	**WBT**	**WBL**
V/C Ratio								
PASSER II	.49	.04	1.06	.32	.35		.90	
TRANSYT	.44	.04	1.06	.32	.35	.35	.89	.89
Delay (sec/veh)								
PASSER II	31.9	31.6	79.0	32.3	33.1		54.9	
TRANSYT	13.9	61.4	62.0	24.3	33.0	33.0	47.0	47.0
Stops (veh/hr)								
PASSER II	342	8	1738	74	149		481	
TRANSYT	265	10	1193	87	104	51	281	131

GEORGE BUSH	**NBT**	**NBL**	**SBT**	**SBL**	**EBT**	**EBL**	**WBT**	**WBL**
V/C Ratio								
PASSER II	.42	.26	.84	.90	.78		.35	.62
TRANSYT	.37	.26	.84	.90	.78	.78	.35	.62
Delay (sec/veh)								
PASSER II	53.6	36.5	28.6	51.2	40.8		33.4	38.3
TRANSYT	16.7	38.6	31.4	47.2	39.3	39.3	34.4	39.4
Stops (veh/hr)								
PASSER II	229	37	994	429	424		91	152
TRANSYT	223	32	725	289	378	33	86	150

HOLLEMAN	**NBT**	**NBL**	**SBT**	**SBL**	**EBT**	**EBL**	**WBT**	**WBL**
V/C Ratio								
PASSER II	.26	.10	.81	.75	.17		.30	
TRANSYT	.24	.10	.81	.75	.17	.17	.29	.29
Delay (sec/veh)								
PASSER II	36.9	34.0	28.3	41.5	31.9		32.7	
TRANSYT	10.8	26.9	26.8	40.2	32.0	32.0	33.3	33.3
Stops (veh/hr)								
PASSER II	103	16	998	231	75		119	
TRANSYT	141	11	884	214	56	23	111	13

The trends discussed for Wellborn Road are based on the results of simulating only one data set, and one should not interpret them as representing the expected trends in PASSER II and TRANSYT for all types of data sets. It is necessary to evaluate the specific parameters associated with each system in order to make an assessment of the MOEs calculated by either program.

4.5 Arterial Level of Service and Speed Profile

Arterial level of service, as defined by the 1985 Highway Capacity Manual (9), is based on the average travel speed for the segment, section, or entire arterial under consideration. One computes the average travel speed from the running time on the arterial segments and the average intersection approach delay. These two variables can be estimated either from the field or by computer programs like the Highway Capacity Software, PASSER II or TRANSYT-7F.

One estimates segment lengths and free flow speeds from existing data, computes running times using tabular values, and estimates approach delays using HCM delay equations. Segment travel times are obtained by adding the approach delays and the running times. Figure 4-19 also shows the construction of a speed profile for the arterial. Figure 4-20 shows the necessary calculations to obtain arterial level of service. Free flow speeds were used as input data and the PASSER II-90 output for NEMA Movement 2 provided delay estimates for the southbound through movement. It should be noted that delay estimates from TRANSYT-7F or field measurements could have been used in this analysis.

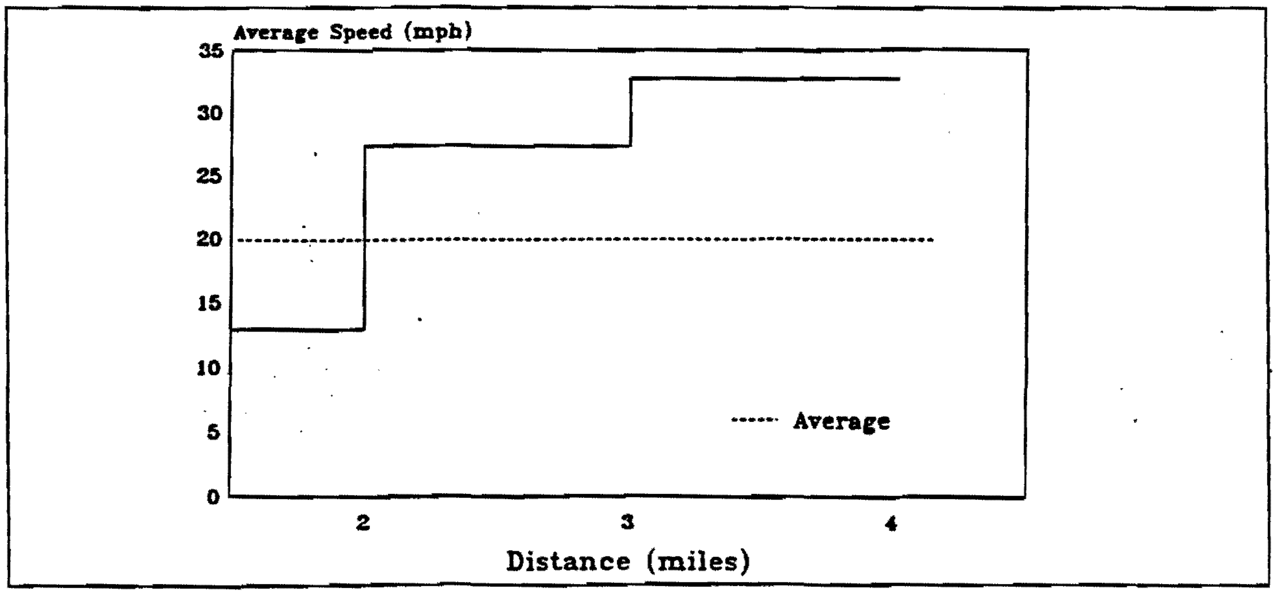


Figure 4-26. Speed Profile for the Arterial

COMPUTATION OF ARTERIAL LEVEL OF SERVICE WORKSHEET

Arterial: Wellborn Road South-bound

File or Case #: Date 1-25-93

$$\text{ART SPD} = \frac{3600\ (\text{Sum of Length})}{\text{Sum of Time}}$$

Prepared by Sunkari.Srinivasa

Seg-ment	Length (mi)	Arterial Class	Free Flow (mph)	Section	Running Time[a] (sec)	Intersec. Approach Delay[b]	Other Delay (sec)	Sum of Time by Section	Sum of Length by Section	Arterial SPD[c] (mph)	Arterial LOS by Section
1	.24	I	45		19.2	79.0		98.2	.24	8.79	F
2	.43	I	45		34.4	28.6		63	.43	24.6	C
3	.71	I	45		56.8	28.3		62.7	.71	40.76	B
4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											

Grand Sum of Time = 224.4

Grand Sum of Length = 1.38

$$\frac{3{,}600 \times 1.37}{224.4} = 22.18 \text{ MPH}$$

D

[a] Use Table 11-4 and multiply by segment length
[b] From summary on Arterial Summary of Intersection Delay Estimates Worksheet
[c] See upper right corner of this Table for the Equation

Note: Round delay estimates to one place after decimal

Figure 4-27. Computation of Arterial Level of Service

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5.0 OPTIMIZATION

After running a simulation to evaluate the existing conditions and checking the output for accuracy, the next step toward retiming an arterial street is to develop a signal timing plan that optimizes operations on the arterial. Analysts making additional computer runs seek to find cycle lengths, green splits, phase sequences, and offsets which will minimize delay, stops, and fuel consumption, increase capacity, and/or maximize bandwidth. The "best solution" depends on what the traffic signal analyst hopes to accomplish. To quantify improvements, one should make comparisons between the best solution for the optimized runs and the evaluation run for the existing conditions.

Analysts can make optimization runs with PASSER II-90, TRANSYT-7F, or, with a combination of PASSER II and TRANSYT-7F (through use of the AAP). Most of the data needed for the optimization runs has already been coded for the evaluation of existing conditions. The parameters that differ can be changed by editing the data. One edits the data base in PASSER II by accessing the EDIT screen, in TRANSYT-7F by accessing the Data Input Manager, and in the AAP by accessing the EDIT menu.

The following sections discuss procedures and guidelines for optimizing arterial street signal timing using PASSER II-90, TRANSYT-7F, and the AAP presented by Wallace and Courage (18). As mentioned above, the user will have previously entered most of the data required for optimization, checked it for accuracy and calibrating it for local conditions. This data will be edited depending on the type of optimization to be performed.

Before proceeding, it should be stressed that the volume to capacity ratios and delays estimated by the computer models should be consistent with existing conditions in the field; i.e., movements estimated to operate at oversaturated conditions should correspond to movements that fail to clear the entire queue during the green phase. If the model estimates are inconsistent with existing conditions, the resultant signal timing design will be less than optimum.

5.1 Signal Timing Design

Signal timing design ultimately depends on the quality of the traffic data and the parameters that represent the nature of traffic flow. The most significant of these inputs to traffic signal optimization models are clearly the traffic volumes and the saturation flow rates. These two classes of data are so important to the process of traffic signal timing that they deserve special attention. The following are some general guidelines in selecting data for use in evaluation of existing conditions and developing a good signal timing design.

1. One should use actual **demand** volumes, as measured in the field, for evaluation.

2. Adjusted volumes, which consider lane distribution and peak hour factors, should be used for purposes of traffic signal timing. While adjusted volumes are proper for design, problems that artificial vehicles suffer during stops, such as delay, and fuel consumption, prove inappropriate for evaluation.

3. Always use measured saturation flow rates if possible. If you must estimate them, use PASSER's assistant function, or the full *Highway Capacity Manual* (9) saturation flow adjustment method. The HCM procedure is built in both PASSER II and the AAP.

4. Use measured cruise speeds for evaluating (and calibrating) the existing conditions, but use desired progression speeds for design.

5.2 Optimization Strategies

Both PASSER II and TRANSYT-7F use their input data to decide how your signal system should operate. The decisions are expressed in terms of several control parameters, including phase sequence, cycle length, phase lengths and offsets. Several important points about the process arise for consideration in the design process. The following subsections give brief overviews of the considerations that go into determining signal design parameters.

Determining Phase Sequences. Selection of the best phase sequence (including how many phases are needed) hinges on the answers to (at least) the following questions:

1. What left-turn movements (if any) need protection?

2. Should the left-turn protection (if required) be protected only or both permitted and protected?

3. Assuming both left turns on the arterial street must be protected, what benefits arise from overlap phasing?

4. Assuming both left-turn movements from the arterial street must be protected, what benefits arise from both left turns leading or lagging versus lead-lag left-turn phasing?

The issue raised by the first question, the need for protection, arises more or less independent of the other three questions. While several factors figure into this decision, including local preference, both PASSER II and TRANSYT-7F can provide some guidance by showing the effect of protected turning intervals on delay, stops, fuel consumption and left-turn conflicts. One may also directly use the program's output to provide insight into all of the other questions.

Unless run in the isolated intersection mode, PASSER II evaluates intersection operations from the point of view of progression, so one must take care not to overlook the potential impact of residual queues blocking the through platoons. One can specify the queue clearance option to see if the estimated delay is reduced, indicating a positive trade-off of bandwidth for reduced delay and probably stops as well. Reduced delay and stops results in reduced fuel consumption and vehicle emissions.

When PASSER II considers both multiple phase sequences and overlap phasing, it generally recommends a mixture of phasing sequences. This mixture tends to give the best progression solution, and, thus, superior operation than say, the popular leading lefts phasing sequences. The question is, how willing are you to trade off improved operation for potentially confusing signal operation? Operators at many locations are concerned about motorist behavior being too unpredictable and are unwilling to allow phasing variations. Many other locations, however, will allow complete flexibility, even to the extent of allowing the sequence at individual intersections to change during different times of the day.

A consistent phasing sequence at all intersections or flexible phasing sequences at some locations is a matter of local preference. It should be noted however, that it is almost always true, that varying the phase sequences among intersections produces better progression along the arterial.

Optimizing Cycle Lengths. PASSER II bases cycle length selection on maximizing bandwidth efficiency, whereas TRANSYT-7F bases cycle length selection on minimizing some linear combination of stops and delay. The key issues about determining cycle lengths with PASSER II are:

1. When evaluating a range of cycles, PASSER II uses a less than full scale optimization process (optimization based solely on maximizing bandwidth); thus, the analyst should not make a decision based on results from a single run with a wide range of cycle lengths.

2. One should carefully coordinate the cycle length with the phase sequences. A more flexible set of phase sequences may result in a different cycle length than a more constrained phasing plan.

3. PASSER II reports the system-wide maximin cycle length, or the maximum "minimum delay" cycle length, discussed in Section 2.1. One can use this cycle length as a guide for the appropriate range of cycles to examine, generally from the maximin cycle length or in some cases 5 seconds below this value to 10 to 15 seconds above the maximin cycle length.

Optimization of Offsets. PASSER II bases its design of offsets on maximal bandwidth progression without real regard of traffic performance. It is possible that an excellent bandwidth design will in fact be negated by side street mid-block traffic forming queues that block the platoon on the arterial. There is no way to know that for sure with PASSER II; however, if the front of the through green is not in the progression band at the upstream intersection, if the left or right-turn volumes from the upstream intersection measure greater than 10 percent of the total volume, or if the downstream volume exceeds the upstream volume by more than 10 percent, stopped queues may block the platoon. TRANSYT-7F can prove very useful in this determination, particularly by inspection of its *Platoon Progression Diagrams*.

If queue blockages do in fact exist, it may be necessary to use PASSER II's queue clearance option to prevent blocking the platoon. The speed variation provides another option to try in PASSER II, which could produce better results with only minor changes in progression speeds. One should note however that PASSER II does not tell the user when the speeds have been changed from those already input; however, the speeds used in the final signal timing design are properly reflected in the optimal progression settings.

PASSER II produces its best results on longer sections, when the spacing is such that most intersections prove critical to the progression scheme and when the potential exists for significant progression bands. It also excels when most of the signals use multi-phase operation, provided that the analyst is prepared to implement a mixture of phasing schemes on the same artery. If the arterial street is quite long and the through bands are very narrow, consider splitting the system into two (or more) subsystems, where better operation may result within each of the shorter arterial subsystems.

5.3 Recommended Design Procedure

It should be clear from the earlier discussions that one should use an iterative procedure involving more than one signal timing design program in optimizing and evaluating arterial signal system performance. This process involves evaluating existing conditions, optimizing with both existing phasing and flexible phasing, and developing a final design. For purposes of this discussion, it is assumed that the analyst will pursue all steps in detail.

Initial Evaluation. As described in Section 4.0, one should perform the initial evaluation using the existing cycle length, splits, phasing sequence, and offsets. Though this step is often overlooked, two important reasons exist to perform an initial evaluation:

1. To provide a basis for evaluation of the benefits from signal retiming; and

2. To ensure that the system operation is being modeled correctly.

It should be self-evident that one should not proceed with a design using a model that does not describe the existing conditions adequately. Before proceeding further, therefore, one must decide whether the model has given credible results. A detailed evaluation would require field measurements of delay, degrees of saturation, etc. The data collection requirements for a detailed evaluation lie beyond the resources of most traffic engineering agencies. As a minimum, however, one should examine all of the approaches at each of the intersections (especially those operating near full saturation) to insure the model agrees at least qualitatively with your field observations.

For example, what if the program's output indicates an oversaturated approach, when, in fact, you know one does not exist? The analyst must check and correct the capacity inputs (the saturation flow rates, lost time, or other factors determining capacity). If one fails to correct this inaccuracy, the program will want to allocate an unreasonable amount of green time to that approach (at the expense of the other approaches), to cure a problem that never existed.

Optimizing Splits with Existing Phasing. Since timing changes prove much easier to implement than phasing changes, one should concentrate first on producing the best design with the existing phasing. This step in the process requires a PASSER II run(s) with the existing phasing. The analyst should make a PASSER II run for each cycle length under consideration for implementation. If changes in intersection phasing lie beyond the scope of one's resources, then the design produced at this early stage may well be the one to implement, at least in terms of phase sequences. Of course, if the analyst is designing a totally new system, skip this step and ignore further references to "existing phases."

Optimize Splits and Phasing. Even if the analyst has no strong intention of changing any phasing in the field, one should assess the potential improvements, if only to establish priorities for future improvement projects. In other words, if the analyst assesses the benefits of changing phasing and these benefits prove significant, one can make a strong argument for allocating future resources to these changes. This step requires one additional PASSER II run with all phasing constraints removed for each cycle length under consideration for implementation.

Final Phasing Design. When the analyst has the results of the existing and optimal phasing designs, the decision on a final design may be based on bandwidth optimization. This design should incorporate all phasing changes proposed for implementation.

This step is an appropriate point in the design process to evaluate the suitability of a bandwidth solution. The measure of interest is "attainability," previously defined as the bandwidth divided by the sum of the shortest through green time in each direction. The rationale behind this measure is that it is not possible to obtain a through band exceeding the critical green time. Theoretically, one can achieve an average attainability of approximately 50 percent by arbitrarily assigning all progression to one of the two directions (100 percent in one direction and 0 percent in the other direction). So, a bi-directional attainability less than 50 percent indicates that the compromise required to achieve an equitable bandwidth distribution of progression opportunities resulted in a generally poor design. Such a result often indicates that a solution based on stops and delay optimization by TRANSYT-7F would prove more appropriate.

An alternative solution for an arterial street where an acceptable progression solution is not attainable may be to partition the arterial into two or more subsystems, with each free to operate on its own cycle length. The rationale behind this alternative is that the improvements resulting from suboptimization may prove great enough to offset the problem of lost progression between subsystems. Each of the two sections should, of course, be optimized for phasing as well as timing and offsets.

Cycle Length and Timing Selection. Once the phasing is reasonably well settled, select the cycle length as follows (if using PASSER II outside the AAP, remember to change the minimum phase times to realistic minimum phase times rather than the actual phase times entered for evaluation):

1. Run PASSER II first with a wide cycle length range, perhaps exceeding any range one would actually consider. The analyst may use a large increment because one is not really interested in the solution at this point. An output from this initial run will be minimum delay cycle lengths for each intersection.

2. A suggested range for closer scrutiny is as follows:

    a. The minimum cycle length should equal no less than 0.85 times the maximin cycle length; and the maximum cycle length should equal no higher than 1.25 times the maximin cycle length.

    b. The analyst may need to adjust these minimum and maximum values to the nearest five seconds to accommodate the cycle length resolution offered by some systems.

    c. Although one may use this range as a general guide, the analyst should really let the quality of progression and the resulting MOEs dictate which cycle length to use.

3. Run an optimization over this range with a five or ten second (maximum) increment. Use the results of this run, and similar ones from other peak periods, to resolve any phase sequence questions.

4. After selecting the "final" phase sequences, run single-cycle optimizations for each cycle length in the range that is being considered.

5. Do a final check of sequences to insure no drastic change has occurred. If it has, repeat Steps 3 and 4.

If at any step in the process, the "best" cycle length recommended falls on the minimum or maximum values, repeat the analysis expanding the range to encompass the threshold value, unless the threshold value equals the absolute minimum cycle length.

5.4 Model Limitations

In the following sections, several special modeling applications result from limitations of the PASSER II model. The text below discusses overcoming these limitations.

Traffic Modeling. PASSER II does not use a full-fledged simulation model, nor does it consider all traffic movements on the artery; i.e., PASSER II focuses on arterial through movements. Reasonable approximations are made of the distribution of turning movements, platoon propagation, arrivals on green versus red, and queuing. The MOEs should not be used in absolute terms, rather they should be viewed in relative terms.

Phase Sequence Changes. When several or all phase sequence options are allowed in an optimization, PASSER II will recommend the "best" set of sequences. It does not, however, give an indication on the strength of the recommendation, compared with other options; i.e., it reports only the best solution. If two different phasing sequence solutions equal one another in terms of bandwidth efficiency, the program again reports only one solution, the first one tried. It is important, therefore, to closely scrutinize the recommended solution and compare it with other alternatives, particularly the existing phasing, to see how strong the suggested changes really are.

Similarly, an optimization run often recommends a change in phasing that is numerically superior, but the actual utilization of the new phasing is minimal. Examine the time-space diagram carefully to insure that any recommended phasing change really proves worthwhile. In other words, PASSER II, like any other computer program, performs calculations and makes recommendations; the responsibility for the decision to implement those recommendations lies with the traffic signal analyst.

Splits. PASSER II bases its split calculations on minimizing delay. It does not "optimize" splits as do, for example, SOAP or TRANSYT-7F. The design splits will likely be relatively good as long as the intersection is not congested, particularly if the controller is actuated. In the latter case, the operation will be locally optimized anyway, and the main concern is with sequence, cycle length, and offsets. If, on the other hand, good splits are critical to the intersection's operation, one may wish to consider enlisting the aid of another model, such as TRAF-NETSIM or the TEXAS model.

Other Timing Parameters. The major limitations of PASSER II are those related to the maximal bandwidth approach, which tries to maximize the quality of progression as perceived by the driver. The main problem is that this approach deals most directly with progression opportunities, which extend throughout the artery and ignores opportunities occurring through only a portion of the route. Further, the program gives no explicit consideration to the effect of blocking queues. One can identify the potential problems by a visual inspection of the program's output; however, they do serve to emphasize the need to examine the optimum solution for hidden bottlenecks.

Being a "single pass" optimization model, PASSER II reports only the last, best solution. It gives no indication of how good other solutions (e.g., fewer phasing changes), which may have been less costly to implement, might have been. For example, PASSER II may recommend changing a phase sequence, even though the progression bands use an insignificant amount of the recommended phasing change, as noted previously. Remember that PASSER II recommends the phasing that produces the greatest bandwidth under the specified conditions. This recommendation results from selecting the "best among equals"; i.e., the largest of very small numerical differences in bandwidth efficiencies. Thus, the analyst should make a number of PASSER II runs to evaluate the strength of recommended phase sequence changes and avoid unnecessary phasing changes.

One should consider an additional factor when scrutinizing the results. Some intersections, because of their position in the system, are not critical to the maximization of bandwidth. In other words, within a given design, the offset may be shifted a few seconds one way or the other without affecting the width of the through progression band. In such cases, a typical maximal bandwidth program must make an arbitrary choice of offset. This choice does not always produce the greatest opportunity for progression within the system, although PASSER II has an internal adjustment which attempts to "fine tune" the design to reduce this tendency.

The traffic signal analyst must review maximal bandwidth solutions carefully to insure that the program does not impose such sacrifices and recommend changes that are "numerically superior, but practically equal," solutions. Note that the objective function (bandwidth efficiency) in PASSER II is approximated in the cycle length evaluation. When optimizing using a single cycle (only) the absolute results may differ. The trends, however, generally track in both alternatives, so that the "best" cycle length (at least from the perspective of maximal bandwidth) usually equals what would be determined by separate, single cycle length runs.

5.5 Example Problem

This section presents an example problem illustrating the development of an optimum arterial street signal timing plan using both PASSER II and TRANSYT-7F through the AAP. The purpose of this example is to lead the traffic signal analyst through the steps they might normally use in a signal timing or, more often, retiming project. One also may use the example as a learning tool for new users. This relatively simple example, where results are reasonably predictable, easily accomplishes these objectives.

The example problem is a four-intersection arterial called "Wellborn." Figure 5-1 shows the basic schematic of the artery and the fundamental geometric and traffic data. The "existing" control is pretimed and coordinated with the phasing and timing, as shown in Figure 5-2. While these are fairly simple phase sequences, they are illustrated graphically so one can see how they are converted from a typical phasing diagram to the AAP "phase codes."

This example seeks to develop a new, more efficient operating system for the Wellborn arterial system. The objectives of the study are as follows:

1. To simulate the existing timing plan, which analysts would in reality use to calibrate the models and to provide a basis for evaluating the new plans to be developed.

2. To develop optimal timing plans for pretimed control. Phasing changes will be permitted only if strongly recommended by the process, since this would require wiring changes.

The example that follows concentrates on a single peak period. All control periods require the same degree of attention in reality, but to avoid redundancy, discussions of **the process** for multiple periods will not be repeated. When the other time periods need mentioning, appropriate references will be made. In an actual study, one must repeat the analysis and evaluation of differences, particularly in phasing, for each control period.

Evaluating the Existing Conditions. One may check the data by printing the Data Report, which is developed in the next step - evaluating the existing data. There are two major purposes of this step:

1. To check and verify the correctness of data; and

2. To calibrate the model parameters.

In this example, these checks will be trivial. In reality, however, this step is perhaps the most important step in the design process. The final designs can only prove as "good" as the data and parameters that control the models - saturation flow rates, lost times, platoon dispersion factors, etc. Here, only the mechanics of the process will be reviewed.

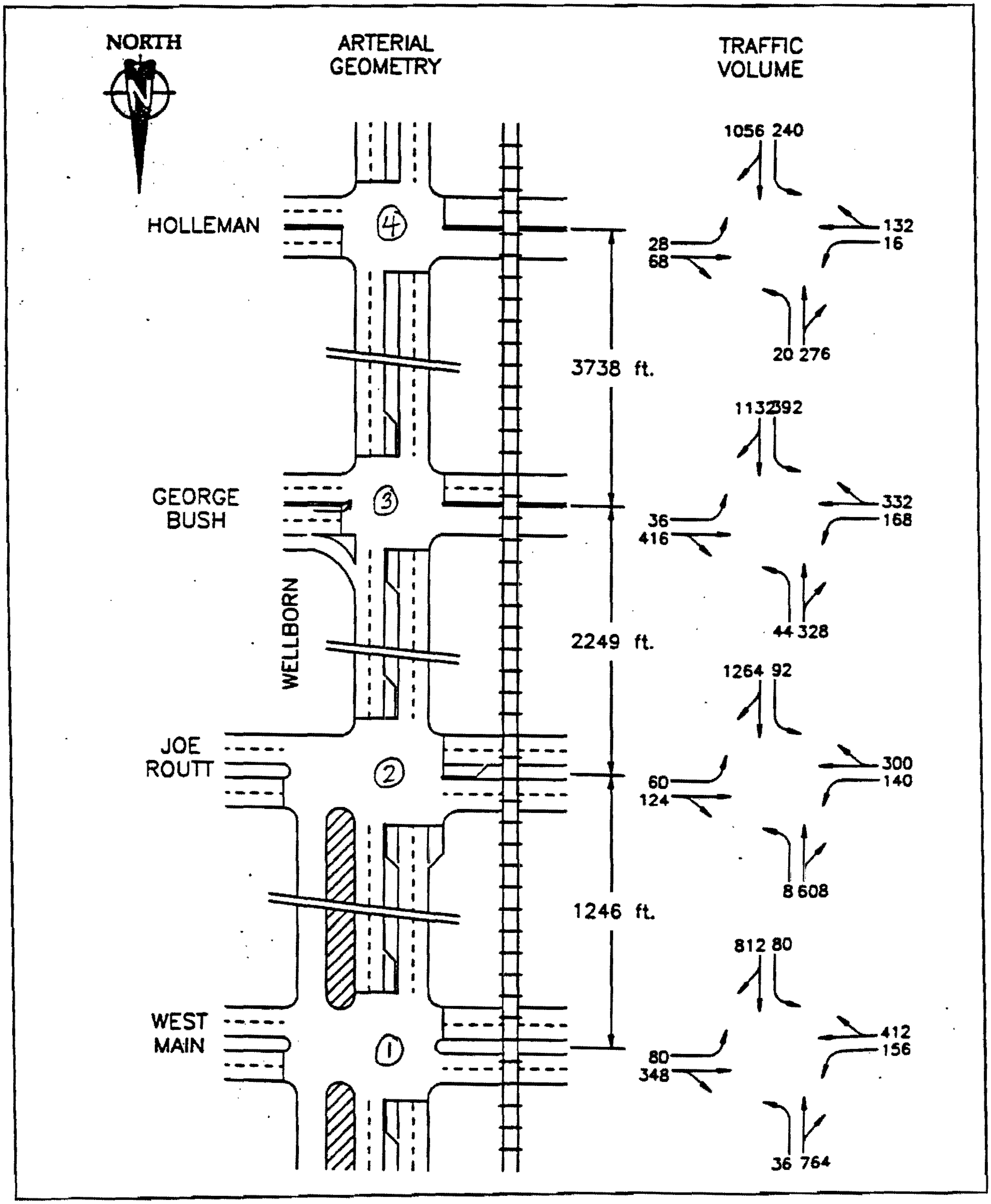

Figure 5-1. Geometric and Traffic Data for Wellborn Example

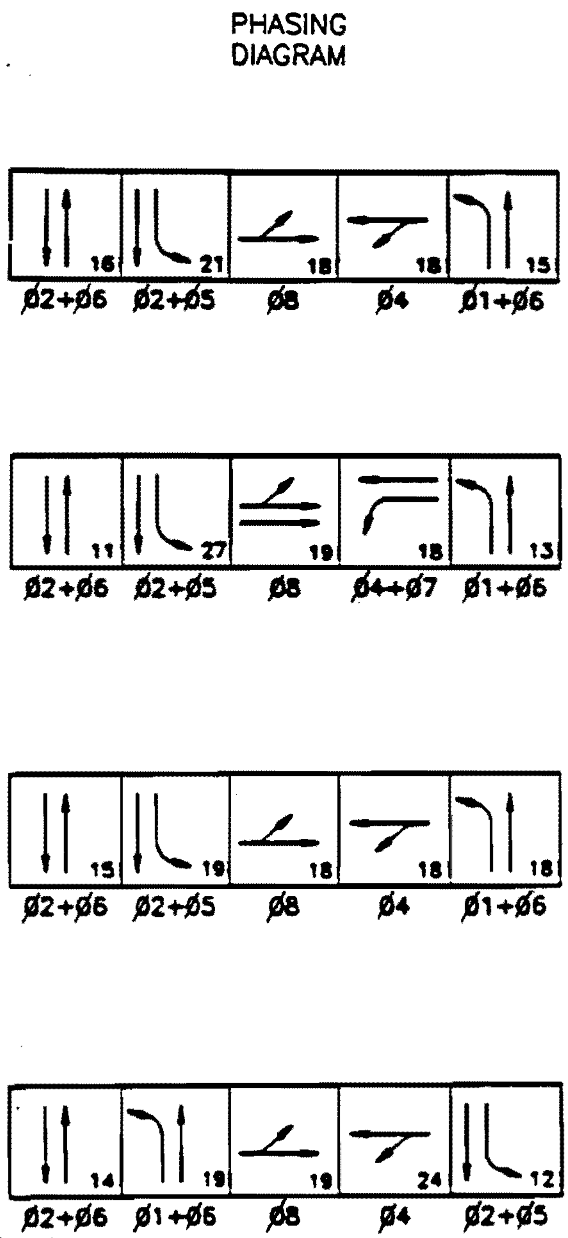

Figure 5-2. Existing Phasing and Timing on Wellborn

TRANSYT-7F provides the most thorough evaluation of an existing timing plan. To run this model in the evaluation mode, select *Edit ...Run Instructions* to set up the run. At a minimum the following steps should be accomplished:

1. The initial run number (1) is okay for this run. Enter a "Run Title," such as "T7F on Existing," for TRANSYT-7F evaluation of existing conditions.

2. Enter the actual cycle length (88 sec) in both the "Min" and "Max Cycle." One can ignore the "Incr(ement)" in an evaluation run.

3. Enter N for all three optimization choices, since this is a simulation run. At this point the TRANSYT-7F optimization objectives are not of concern, although in practice one should decide on the basic objective function and set it early so all future runs will have a compatible objective function.

4. For data review, it is particularly important to make sure the *Artery Data Report* and *Intersection Data Report* are "on"(enter **Y**) because these will be the main reports used to check data for accuracy. At this point in the process, the various diagrams could be left "off"(**N**) to keep the printing short.

5. It is important at this point, to use "unadjusted" volumes ("use Adj Volumes" = N), so the program can make a comparison with the known data.

When verifying the raw data, review the *Artery Data* screen, each *Approach Data* screen and the *Timing Data* screen to check against the original sources of data (in this case, Figures 5-1 and 5-2). After making all needed corrections, select *Run ...TRANSYT-7F* from the main menu. To help double check all coded data, print the AAP and TRANSYT-7F *Input Data Reports* and review them carefully against the raw data sources.

After checking the data for correctness, begin the process of model calibration. This step involves examining the TRANSYT-7F results to insure that degrees of saturation (volume to capacity ratios), delays, queue back ups, and platoon progression all conform with the actual arterial operation; i.e., TRANSYT-7F's output is reasonable and matches observations made in the field.

The final step of this process is to make final evaluation runs. At this point it might prove useful to run both PASSER II and TRANSYT-7F to get baseline runs for future comparisons. One should note that traffic signal analysts should never assume they are finished reviewing the base data at the conclusion of this step. Often the optimization process points out further necessary corrections to the data. Because the AAP allows promulgation of numerous data bases, always make further corrections in all files as appropriate and re-execute those runs that may be obviated. Thus, the need may arise to make final evaluation runs for both "before" and "after" as a last step in the design process.

The next several steps involve PASSER II runs. Before entering the design (or optimization) stage, however, make base runs for both PASSER II and TRANSYT-7F using adjusted volumes. Up to this point, the analyst has dealt with one data base like "Ex Tm"; i.e., it has not been necessary to use and/or save multiple data bases. Because design runs use amended revisions of the original data base, the decision whether to actually save the revised data sets will depend on how easily the changes are to reproduce and how quickly one may need to access them. In this example, most of the data base files will be saved to provide easy recognition in the run log.

Now return to the *Edit ... Run Instruction* screen and enter Y in the "Use Adj Volume" field. Change the run number and title and save the data bases (in these cases as "Ex Tm Adj Vol"). Run both component programs in the evaluation mode (that is, with all optimization choices still set to N). The run log for these runs so far is shown below. Note that, as discussed in Section 4.4, PASSER II estimates higher system-wide MOEs for existing conditions for the Wellborn arterial system.

Table 5-1. Arterial Analysis Package Run Log 1

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ARTERIAL ANALYSIS PACKAGE RUN LOG

Date	File Group	By	Run Title	Cyc Sec	Delay V-H	Stops	Fuel G/L	Cost{T} Att{P}	PI{T} Eff{P}
01-23	WLBRN-01	T	Ex Tm	88	101	7884	243	939	103.2
01-23	WLBRN-02	P	Ex Tm	88	122	9577	274	N/A	N/A
01-23	WLBRN-03	T	Ex Tm Adj Vol	88	113	8111	258	985	115.1
01-23	WLBRN-04	P	Ex Tm Adj Vol	88	140	10371	300	N/A	N/A

PASSER II Existing Phasing. Now return to the *Edit ...Run Instruction* screen and set the "Optimize Splits and Offsets" choices to Y. Select a range of cycle length of 70 to 120 seconds, and make multiple runs of PASSER II for cycle lengths in the specified range (70 to 120 seconds) in increments of 5 seconds. Naturally, change the run number and title too. The analyst should call these runs "P2 Op Ex Ph" for PASSER II optimization using existing phasing. In simple retiming projects, this analysis is an important step because phase changes prove more costly than timing changes, particularly for pretimed controllers. The run log shown below illustrate runs so far.

From a visual inspection of the run log, one can see that, as expected, all MOEs were reduced as a result of optimizing splits and offsets (PASSER II does not calculate attainability or bandwidth efficiency for simulated runs, so the analyst cannot compare those). Note that minimum delay, stops, and fuel consumption occur for cycle lengths between 80 and 110 seconds. One could evaluate these solutions with TRANSYT-7F if a real concern about phasing changes existed. This example does not show such an analysis, but the process described in a following section.

Table 5-2. Arterial Analysis Package Run Log 2

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ARTERIAL ANALYSIS PACKAGE RUN LOG

Date	File Group	By	Run Title	Cyc Sec	Delay V-H	Stops	Fuel G/L	Cost{T} Att{P}	PI{T} Eff{P}
01-23	WLBRN-05	P	P2 Op Ex Ph1	70	103	10309	273	10.7	2.9
01-23	WLBRN-06	P	P2 Op Ex Ph2	75	100	9842	266	33.7	8.8
01-23	WLBRN-07	P	P2 Op Ex Ph3	80	95	9310	256	46.0	12.1
01-23	WLBRN-08	P	P2 Op Ex Ph4	85	92	9055	251	33.0	8.5
01-23	WLBRN-09	P	P2 Op Ex Ph5	90	91	8818	248	15.9	4.1
01-23	WLBRN-10	P	P2 Op Ex Ph6	95	87	8935	246	13.2	3.4
01-23	WLBRN-11	P	P2 Op Ex Ph7	100	91	8852	248	26.8	7.0
01-23	WLBRN-12	P	P2 Op Ex Ph8	105	95	8796	251	32.1	8.5
01-23	WLBRN-13	P	P2 Op Ex Ph9	110	97	8591	250	37.0	9.8
01-23	WLBRN-14	P	P2 Op Ex Ph10	115	100	8496	251	41.8	11.2
01-23	WLBRN-15	P	P2 Op Ex Ph11	120	103	8440	253	45.2	12.2

PASSER II Optimized Phasing. The next step in the process is to optimize phasing with PASSER II. The change is trivial, change "Optimize ...Phase Seq" in the *Edit ...Run Instructions* screen to Y, along with the run number and title. The phasing optimization step also made multiple runs of PASSER II for cycle lengths in the range of 70 to 120 seconds in a 5 second increment; however, in practice a range from 85 to 100 would have been sufficient to find an optimal timing plan. One could have selected this range of cycle lengths as good cycle lengths for minimizing system delay from the results of the previous step. The run log table shown below illustrates all the runs done for optimizing splits and offsets.

As expected, the MOEs (when splits, phase sequences, and offsets were optimized) are improved from the existing conditions (*when comparing only the PASSER II runs*).

Table 5-3. Arterial Analysis Package Run Log 3

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ARTERIAL ANALYSIS PACKAGE RUN LOG

Date	File Group	By	Run Title	Cyc Sec	Delay V-H	Stops	Fuel G/L	Cost{T} Att{P}	PI{T} Eff{P}
01-23	WLBRN-16	P	Wel PFN Ph1	70	104	10377	275	82.4	22.0
01-23	WLBRN-17	P	Wel PFN Ph2	75	100	9900	267	96.2	25.1
01-23	WLBRN-18	P	Wel PFN Ph3	80	93	9397	256	83.4	21.9
01-23	WLBRN-19	P	Wel PFN Ph4	85	90	9060	250	97.0	25.0
01-23	WLBRN-20	P	Wel PFN Ph5	90	86	8833	245	89.5	23.1
01-23	WLBRN-21	P	Wel PFN Ph6	95	92	8716	247	98.4	25.5
01-23	WLBRN-22	P	Wel PFN Ph7	100	92	8887	249	100.0	26.1
01-23	WLBRN-23	P	Wel PFN Ph8	105	97	8561	249	100.0	26.4
01-23	WLBRN-24	P	Wel PFN Ph9	110	97	8475	248	100.0	26.5
01-23	WLBRN-25	P	Wel PFN Ph10	115	100	8272	248	100.0	26.7
01-23	WLBRN-26	P	Wel PFN Ph11	120	103	8228	249	100.0	26.9

After printing the results of this run, compare the time-space diagrams (TSDs) from the two PASSER II runs for existing phasing and optimized phasing (90 second cycle), along with the MOEs. Consider the phasing changes recommended by PASSER II summarized below:

	Arterial Phasing:	
Intersection	Existing	Optimum
West Main	STN	NTS
Joe Routte	NTS	STN
George Bush	NTS	LST
Holleman	NTS	LST

Note that PASSER II recommended phasing changes at all four of the intersections. At this point, one should consider two other questions:

1. What phasing will apply to the rest of the day?
2. How much of a changed (or unusual) phase sequence is actually used?

To answer the first question, the analyst should repeat the preceding analyses for all control periods. Then, compare the selected phasing for each peak on all the other peak period data sets to select the best overall phasing sequences; however, remember that, in this example, the other control periods have been ignored.

To answer the second question, examine the time-space diagram (TSD) for the PASSER II phasing optimization run, shown in Figure 5-3. In two cases of suggested phase sequence changes, significant use is made of the revised phasing, namely intersections 1 and 2. The progression bands go through the leading and lagging portions of the arterial phase. The phasing changes suggested by PASSER II would thus appear to be justified at these intersections. At the other two intersections the changes prove less significant. Again the analyst must evaluate the cost of rewiring, but for this example assume the changes are justified and the PASSER II optimized phasing should be implemented at all four intersections.

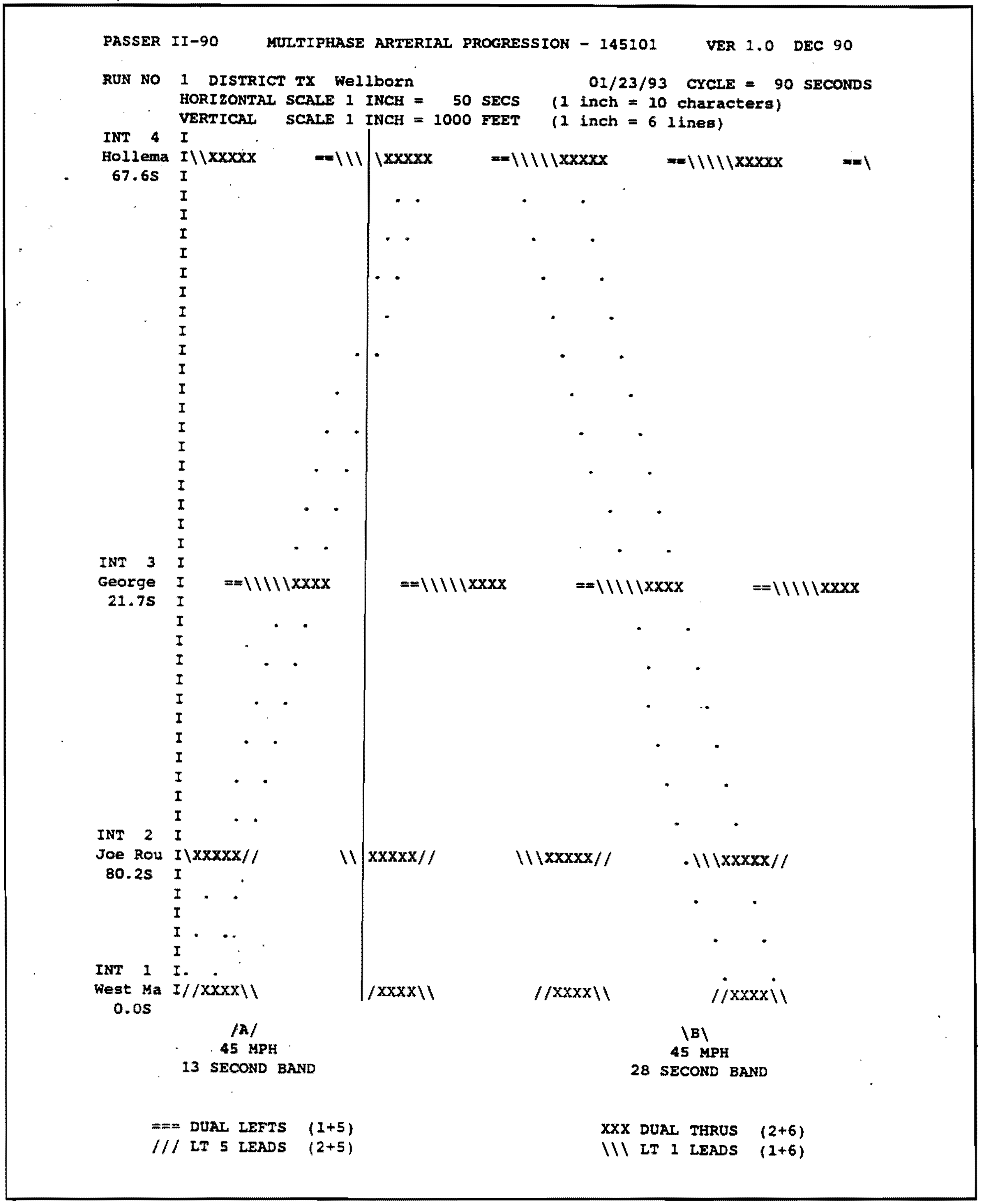

Figure 5-3. Time-Space Diagram of PASSER II's Optimal Phasing

TRANSYT-7F Optimization. The next step in the process is to use TRANSYT-7F to fine tune the offsets and splits for the cycle length and phasing sequence recommended by the PASSER II analysis for the same data (90 second cycle length).

Comparison of Alternative Design. Of course, many different runs could (and in a real world case should) be conducted. This example has simply illustrated the basic mechanics of using both PASSER II and TRANSYT-7F within the AAP. Several items that need emphasizing are:

1. Compare the basic MOEs of candidate solutions, both at the artery level, as well as the intersection level -- particularly at critical intersections.

2. Print the plot outputs to get visual evidence of likely operations:

    - Time-space diagrams (TSDs), to study utilization of leading and/or lagging phases, particularly lead-lag subsequences;

    - Flow profile diagrams (FPDs) to get a better view of probable traffic performance at the intersections; and,

    - Platoon progression diagrams (PPDs) to evaluate the overall progression and the effect of queues.

3. Whatever decision you make, fine tune the plan, both in the office and in the field.

The last point is the most important -- the analyst should make final choice of the best timing plan, not the computer programs.

In this example the most telling explanation of the differences between the PASSER II and TRANSYT-7F optimum splits and offsets can be seen by reviewing the PPD plots, shown in Figures 5-5 and 5-6, respectively. The PASSER II design has excellent time-space progression; however queue interferences exist at Intersections 2 and 3 southbound (downbound) and Intersections 2 and 3 northbound.

TRANSYT-7F's perceived progression is not as impressive, but the clearing of queues formed by cross-street traffic and dispersed arterial traffic eliminates the trouble spots at Intersection 3 southbound and northbound.

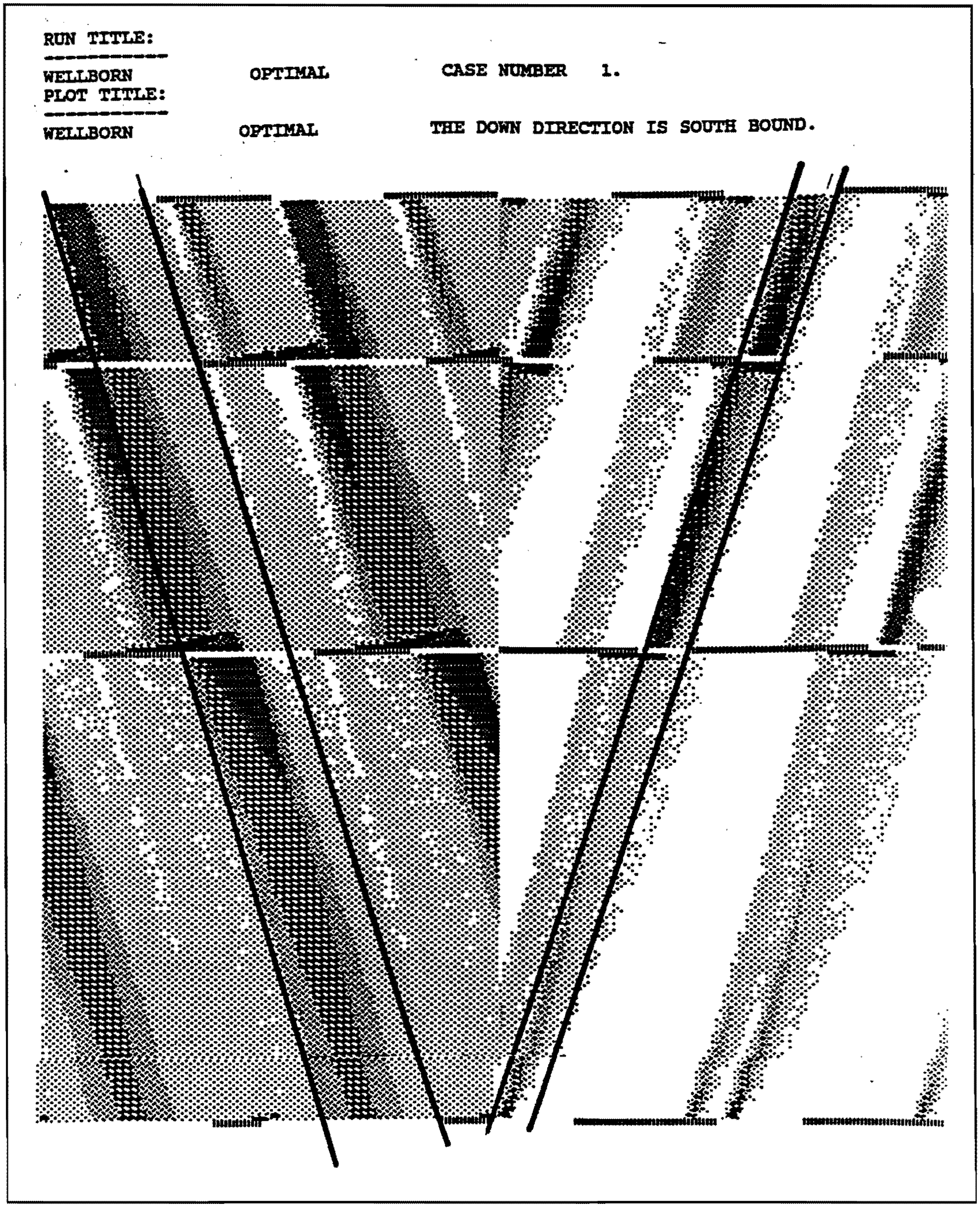

Figure 5-4. Platoon Progression Diagram of PASSER II Solution

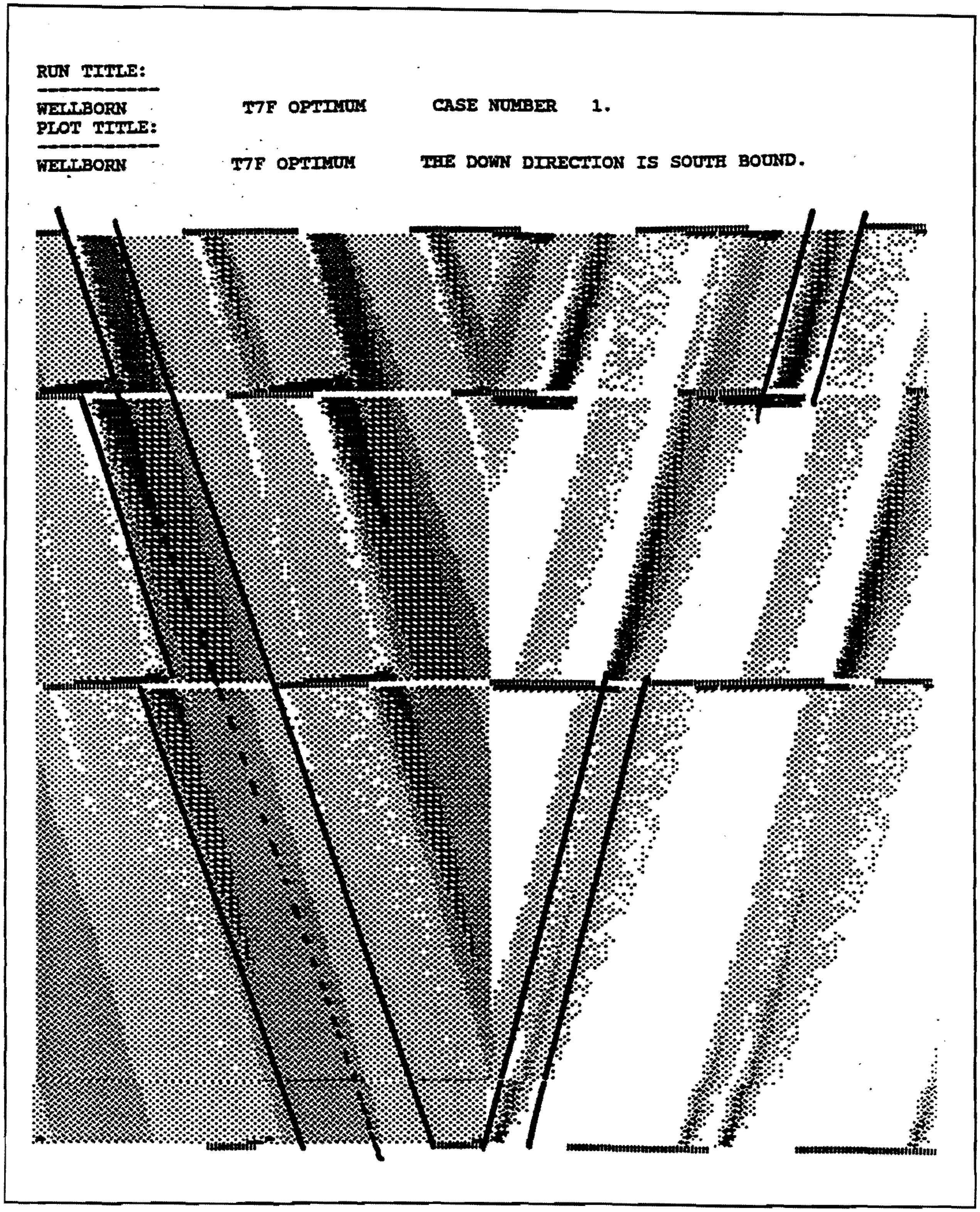

Figure 5-5. Platoon Progression Diagram of TRANSYT-7F Solution

The last step (at least in this example) is to evaluate the final timing plan for a cycle length of 90 seconds using TRANSYT-7F, but with unadjusted volumes. The final run log is shown in the table below:

Overall, the integrated use of PASSER II and TRANSYT-7F to redesign the phasing, cycle length, and timing has resulted in an 32.7 percent reduction in delay, a 7.8 percent reduction in stops and a 13.2 percent drop in fuel consumption. There was a 32.3 percent reduction in the performance index (PI), but one should only use the PI as a performance measure to compare runs; not for quantifying benefits. This example has demonstrated that the combined use of PASSER II and TRANSYT-7F can indeed result in an overall improved signal timing design for an arterial street signal system.

Table 5-4. Arterial Analysis Package Run Log 4

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ARTERIAL ANALYSIS PACKAGE RUN LOG

Date	File Group	By	Run Title	Cyc Sec	Delay V-H	Stops	Fuel G/L	Cost{T} Att{P}	PI{T} Eff{P}
01-23	WLBRN-27	T	Wel Opt Adj Vol	90	71	7991	226	915	73.3
01-23	WLBRN-28	T	Wel Opt Unadj Vol	90	68	7269	211	855	69.9

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6.0 IMPLEMENTATION

The next step in the retiming of a traffic signal involves implementing the improved timing plan. After determining a "best solution" either from PASSER II-90, TRANSYT-7F or the AAP, the analyst should transfer results to a controller worksheet for use in the field. This text does not address all entries to the controller sheet, but only those entries directly related to the computer output. Different controller data sheets for electromechanical pretimed and actuated control exist; worksheets may vary with the brand of controller, or a self-made worksheet may be used. These guidelines address the current TxDOT controller standard specifications as much as possible.

The timing design from PASSER II, TRANSYT-7F, the AAP is generally **not** the design "installed in the field." It is impossible for computer models to consider everything that must be considered in the real world. This limitation is where the fourth component, "the traffic engineer" comes in.

Regardless of the type of control -- pretimed or actuated -- the first step in timing implementation should be to fine tune the model's design. One should examine the timing plan closely to adjust offsets and splits. A few seconds one way or the other may change the throughput of an intersection by hundreds of vehicles per hour.

Once satisfied with the design "on paper," the next step is implementation of the timing plan in the field, a function of the type of control.

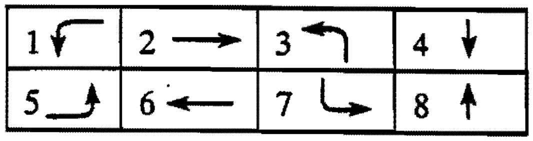
6.1 Terminology

Before discussing the implementation of the timing plans, one must first define some terms commonly used in traffic signal timing (1):

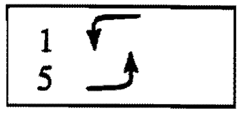
Split - The portion of the cycle length allocated to each of the various phases, expressed in seconds or as a percent of the entire cycle length.

Interval - A discrete portion of the signal cycle, during which the signal indications do not change. This time includes the green, yellow, and red clearance intervals per movement.

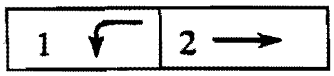
Phase - Individual movement; for example, at a typical intersection, eight movements are generally given some green time.



Concurrent phases are protected phases that are timed together:



Sequential phases are protected phases that follow one another:



6.2 Output Interpretation

The starting point is the format of the typical signal timing outputs. Each program produces a typical table summarizing the signal timing plan and contains the following information:

1. Cycle length;
2. Movements serviced on each phase;
3. Time allotted to each phase; and
4. Offset with respect to a specified phase or interval.

Different programs use different methods to describe timing plans. Figures 6-1 and 6-2 illustrate the typical signal timing design plans presented by PASSER II and TRANSYT-7F. These plans illustrate the timing plans for the Example Problem illustrated in Section 5.5. A comparison of the PASSER II and TRANSYT-7F timing plans indicates some interesting similarities and differences.

PASSER II Signal Timing Tables. The PASSER II format attempts to represent dual-ring operation, even though the program itself models a single-ring sequence. This representation is achieved by assigning a phase number to each of the movements in the NEMA compatible scheme. The assignment is based on PASSER II's internal definition, and may not reflect actual assignment in the field.

INTRSC 1 : West Main COORD PHASE : 0 OFFSET : .0 SEC : .0%
*-[MASTER AND SYSTEM INTERSECTION]

DUAL-RING PHASE #	5	6	1	2	3	4	7	8
PHASE SPLIT (SEC)	19.0	26.0	12.0	33.0	24.0	19.0	19.0	24.0
PHASE SPLIT (%)	22.%	30.%	14.%	38.%	27.%	22.%	22.%	27.%
PHASE REVERSAL	6	5	--	--	4	3	--	--
LEFT TURN	LAG	--	LEAD	--	LAG	--	LEAD	--

CONCURRENT PHASES	1+6	2+6	2+5	4+7	4+8	3+8	MAIN	CROSS
DURATION (SEC)	12.0	14.0	19.0	19.0	.0	24.0	45.0	43.0
CYCLE COUNT (SEC)	.0	12.0	26.0	45.0	64.0	64.0	.0	45.0
CYCLE COUNT (%)	0.%	14.%	30.%	51.%	73.%	73.%	0.%	51.%

Figure 6-1. PASSER II 90 Timing Design Table

INTERSECTION 1 PRETIMED - SPLITS ARE FIXED

INTERVAL NUMBER :	1	2	3	4	5	6	7	8	9	10
INTVL LENGTH(SEC):	8M	4	13	1	15	4	15	4	20	4
INTVL LENGTH (%):	9	5	15	1	17	5	17	5	21	5
PIN SETTINGS (%):	100/0	9	14	29	30	47	52	69	74	95
PHASE START (NO.):	1		2		3		4		5	
INTERVAL TYPE :	V	Y	V	Y	V	Y	V	Y	V	Y
SPLITS (SEC):	12		14		19		19		24	
SPLITS (%):	14		16		22		22		26	
LINKS MOVING :	103		101		101		105		107	
	104		103		102		106		108	
									112	

Figure 6-2. TRANSYT-7F Controller Setting Table

Two tables in Figure 6-1 present PASSER II's recommended signal timing plan design. The first table (middle of figure) shows the phase splits for each movement by number indicating the duration in seconds as well as the percent of the cycle of each phase. Based on the position of the left-turn phase with respect to the through phase, each left turn is shown as a "lead" or "lag." The second table (bottom of figure) illustrates the movements proceeding in each of the six possible single ring sequential phases. The phase duration as well as the "cycle count", which indicates the cumulative cycle time prior to the beginning of each phase is shown. Note that all phases, regardless of their existence, are shown. Any phase not present has a duration equal to 0 seconds.

TRANSYT-7F Signal Timing Tables. Unlike PASSER II, TRANSYT-7F makes no attempt to represent dual-ring operation in its timing table. A table is presented with one column for each interval in the single-ring sequence. For each interval, the interval length and the pin settings are provided. The table indicates the interval which begins each phase along with the type of interval in each phase. The interval types are as follows:

F	Fixed	The duration of the phase is not subject to change by TRANSYT-7F during the optimization process.
V	Variable	The optimizer can modify the duration of this interval. Only one variable interval is allowed per phase.
Y	Yellow	This interval represents the yellow portion of the change period.
R	Red	This interval represents the red portion of the change period.

Following the interval types, the table shows the splits for each phase. The link list is presented next. TRANSYT-7F uses a link node concept to represent a network of traffic signals. A node represents each intersection, and each movement is generally represented by a link. TRANSYT-7F User's Guide (15) suggests two such link numbering schemes. The first two digits of the four digit link number represent the intersection number. The last two digits represent the movement number. Figure 6-3 illustrates these two schemes.

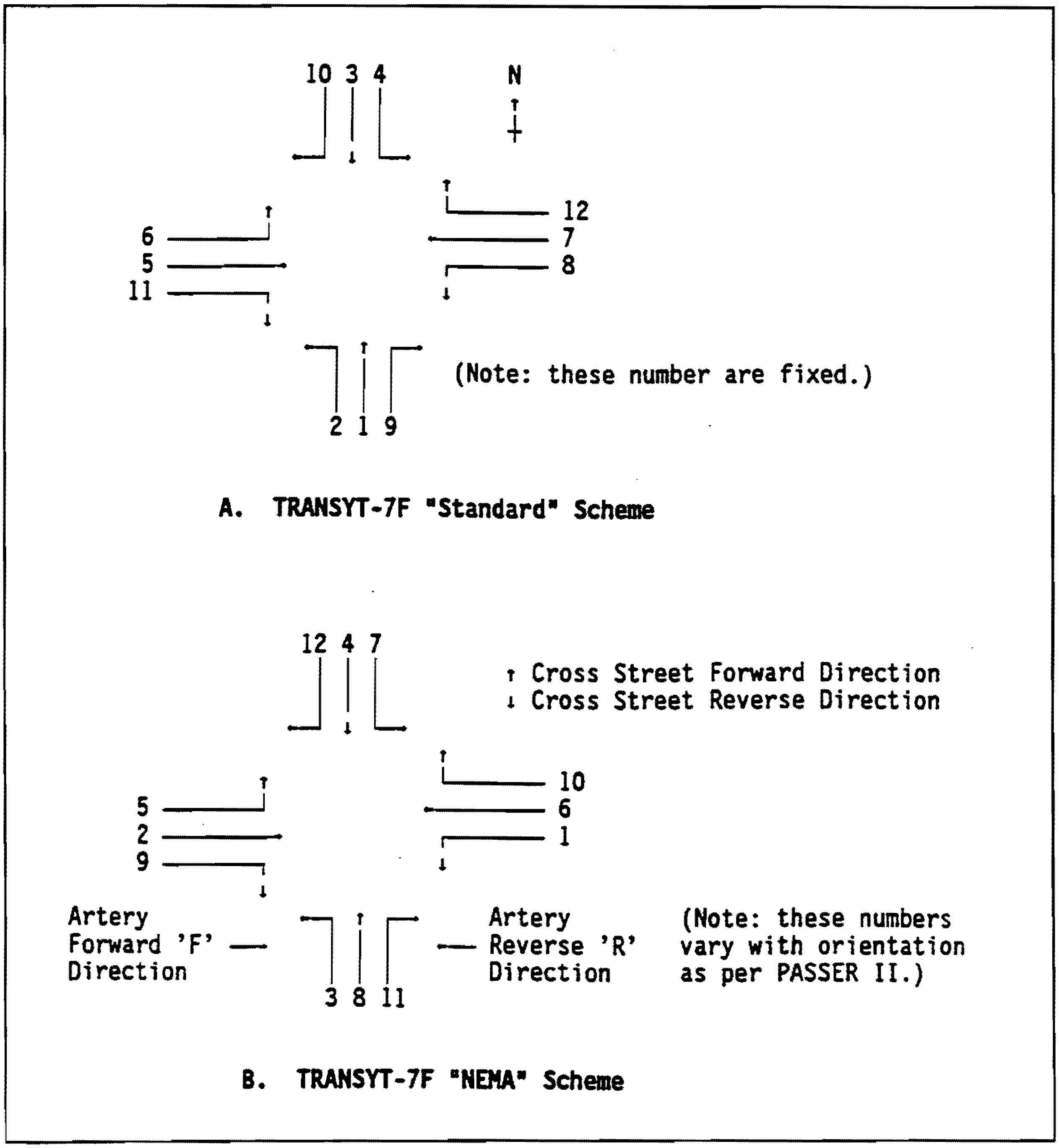


Figure 6-3. TRANSYT-7FMovement Numbering Schemes

6.3 Typical Traffic Control System Timing Inputs.

Each traffic control system has its own unique requirements for timing plan data. Thus, it is essential that the analyst thoroughly understands the specific equipment operating the control system before making any timing design changes in the field. Some categories of the type of control equipment follow.

1. Pretimed controllers, which may operate either isolated or coordinated with other pretimed controllers in the same system.

2. Large scale computerized systems, like Urban Traffic Control System (UTCS), which take direct control of the field equipment.

3. Traffic responsive systems, in which external hardware supervise standard NEMA dual-ring traffic actuated controllers to impose some aspects of a coordinated operation. Generally, analysts refer to this category as "externally coordinated systems."

4. Traffic responsive systems, in which the developers have gone a step beyond the NEMA standards and incorporated the coordination hardware and software internally within the controller. The timing plan resides in a system master controller, not in the local traffic actuated controllers themselves. Generally analysts refer to this category as "internally coordinated systems."

The following sections contain timing plan implementation guidelines suggested by Wallace and Courage (18).

6.4 Implementation in Pretimed Controllers.

When implementing timing plans for pretimed control, one can determine both the splits and pin settings from the PASSER II-90 output. The output table called *GREEN TIME* gives the splits, also referred to as green time, for concurrent and individual phases. The analyst can read the pin settings directly from the PASSER output under the title *PIN.SET* in either seconds or percent of the cycle. The *PIN.SET* equals zero for the first phase; for every subsequent phase the *PIN.SET* equals the *PIN.SET* of the previous phase plus the total time for the previous phase. The term *PIN* in the output gives the green time (splits) for each concurrent phase.

The phase times reported in PASSER II-90's output include the yellow and the red clearance for each phase. If protected left-turn phasing with overlap is used, PASSER II-90 automatically selects the heavier left-turn movement as being the first left-turn movement to be serviced. In a dual-ring traffic actuated controller, the heavier left-turn movement will always be serviced in the overlap phase. In a pretimed controller, however, the analyst must designate one of the two left-turn movements as a leading movement.

TRANSYT-7F can create an interval structure that matches the field operation exactly; however, if the AAP is used for data entry, the extra intervals need to be specified. The AAP also does not create pedestrian clearance or red clearance intervals. Furthermore, AAP assumes a yellow time of 4.0 seconds for all phases.

6.5. Implementation in Externally Coordinated Systems

Traffic actuated controllers do not recognize the concept of cycle length, phase splits, or offsets used by signal timing design programs. Without coordination, these programs would constantly adjust to fluctuations in demand and generate their own timing plans on each cycle. Thus, analysts need some means of imposing a constant cycle length with predictable time relationships, if a group of traffic actuated controllers is to function as a coordinated system. There are two external control functions commonly used to impose a background cycle and offset on an isolated traffic controller.

Hold Function - Causes the controller to hold at one point in the cycle until release, regardless of the detector demand.

Force-off Function - Causes the controller to terminate a phase, and move on to the next phase, again regardless of detector demand.

Elements of Coordination. One uses the external commands discussed earlier to modify the operation of a traffic actuated controller to impose a specific cycle length, splits and offsets. The *Traffic Control Systems Handbook* (1) offers a detailed discussion of the control concepts. The typical elements in coordination are:

Non-Actuated Phase - Generally the "main street" or arterial phase, displayed each cycle without the need for detector demand.

Subsequent Phase - Referred to as "non-actuated+1," or "non-actuated+2," etc. A four-phase operation would generally consist of the non-actuated phase plus three actuated phases.

Yield Point - The point in the cycle at which the hold function is released. If the non-actuated phase has pedestrian provisions, the yield point would normally occur at the beginning of the Flashing Don't Walk. If no pedestrian provisions exist, it would occur at the end of the green. In a typical coordinator, all times are referenced to the yield point.

Offset - The elapsed time from an arbitrary system zero reference point to the beginning of the non-actuated phase. This point is the value normally reported by PASSER II and TRANSYT-7F, although for an "actuated" controller, TRANSYT-7F refers to this time as a yield point.

Figure 6-4 illustrates the computation of the yield point for a typical timing plan. A yield point can be calculated as:

Yield point	=	Offset	+	Split	-	(FDW	+	Clearance)
	=	27	+	35	-	(15	+	5)
	=	42						

The force-off point for any of any of the actuated phases may be calculated as:

Force off	=	(phase) Begin Time +	Splits	-	Clearance
	=	(non-act + 1) 20 +	20	-	5
	=	35			

(non-act + 1) 20 + 25 - 5 = 35
(non-act + 2) 40 + 25 - 5 = 60
(non-act + 3) 65 + 20 - 5 = 80

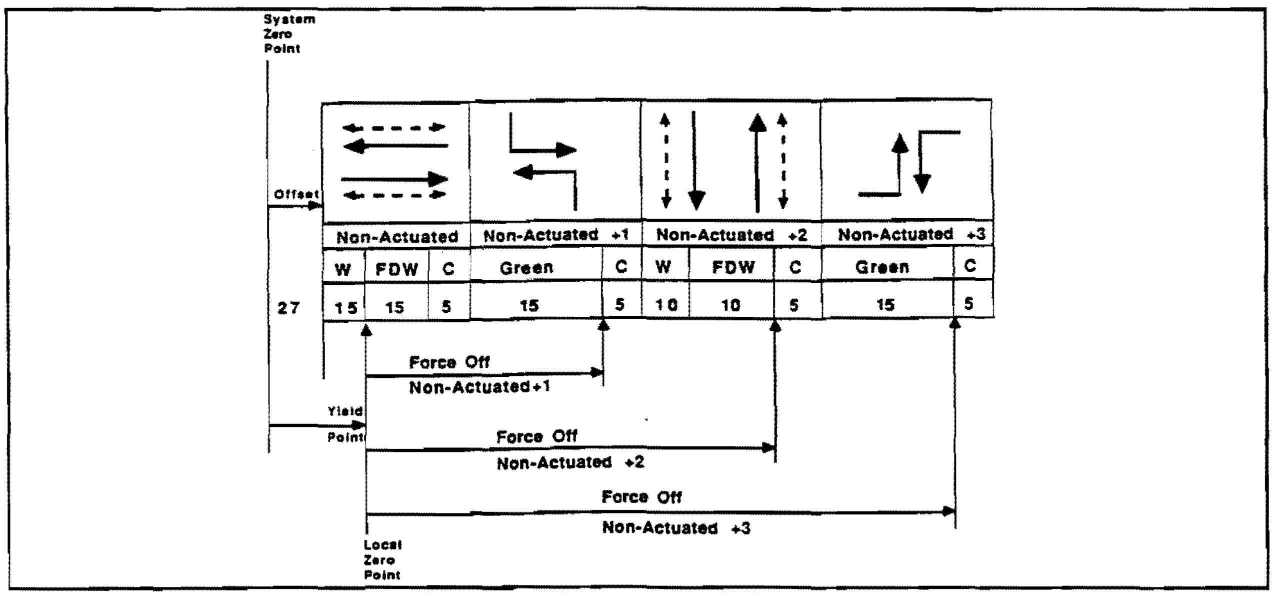


Figure 6-4. Sample Calculation of Force-offs and Yield Point

Permissive Periods. If the operation as described earlier was implemented as is, one instant (yield point) would exist when the actuated phase (cross street) could be initiated if a vehicle places a call on the detector. During peak periods, a constant demand of traffic on the cross street exists; however, during off-peak periods, if a cross street vehicle arrives just after the yield point, it will have to wait the whole cycle for service. Thus, the concept of the permissive periods gains importance. One implements the permissive periods to service the cross street traffic even after the onset of the yield point, as long as the subsequent phases are not affected. This action will reduce the delay to the cross street without compromising the arterial coordination. Figure 6-5 illustrates the calculation of the yield point, force-offs, and the permissive periods.

Note that the term "permissive period" does not relate in any way to the left-turn treatment. The use of the word "permissive" or "permitted" in connection with left-turn protection is a totally different subject.

6.6 Implementation in Internally Coordinated Systems.

Due to complications involved in external coordination, more and more traffic control systems have incorporated internal coordination features. Internal coordination systems accept cycle length, splits, and offsets and perform computations. Therefore, computerized timing designs prove much easier to implement with internally coordinated systems.

A program called AAP2NEMA provides a link between the traffic signal timing design programs of the AAP and internally coordinated arterial traffic control systems. AAP2NEMA is designed to accommodate arterial traffic control systems which use NEMA standard eight phase dual-ring controllers at each intersection. While the NEMA intersection controllers are well standardized, the coordination hardware and software vary considerably. Thus, one must carefully tailor the data transfer routines to each system.

6.7 Multiple Period Considerations

For a given control period, the development of a timing plan involves more than simply running PASSER II once. Follow the steps presented in Section 5.0 to develop a recommended timing plan for each control period. Then the analyst must resolve the differences, as explained below.

Selection of a Timing Plan for a One-Dial System. If the signal system can handle only one timing plan, one may follow the procedure discussed below to determine an acceptable timing plan; however, no one signal timing plan will prove optimum for all periods throughout the day. Thus, the selection of the "best" signal timing plan necessarily requires engineering judgment.

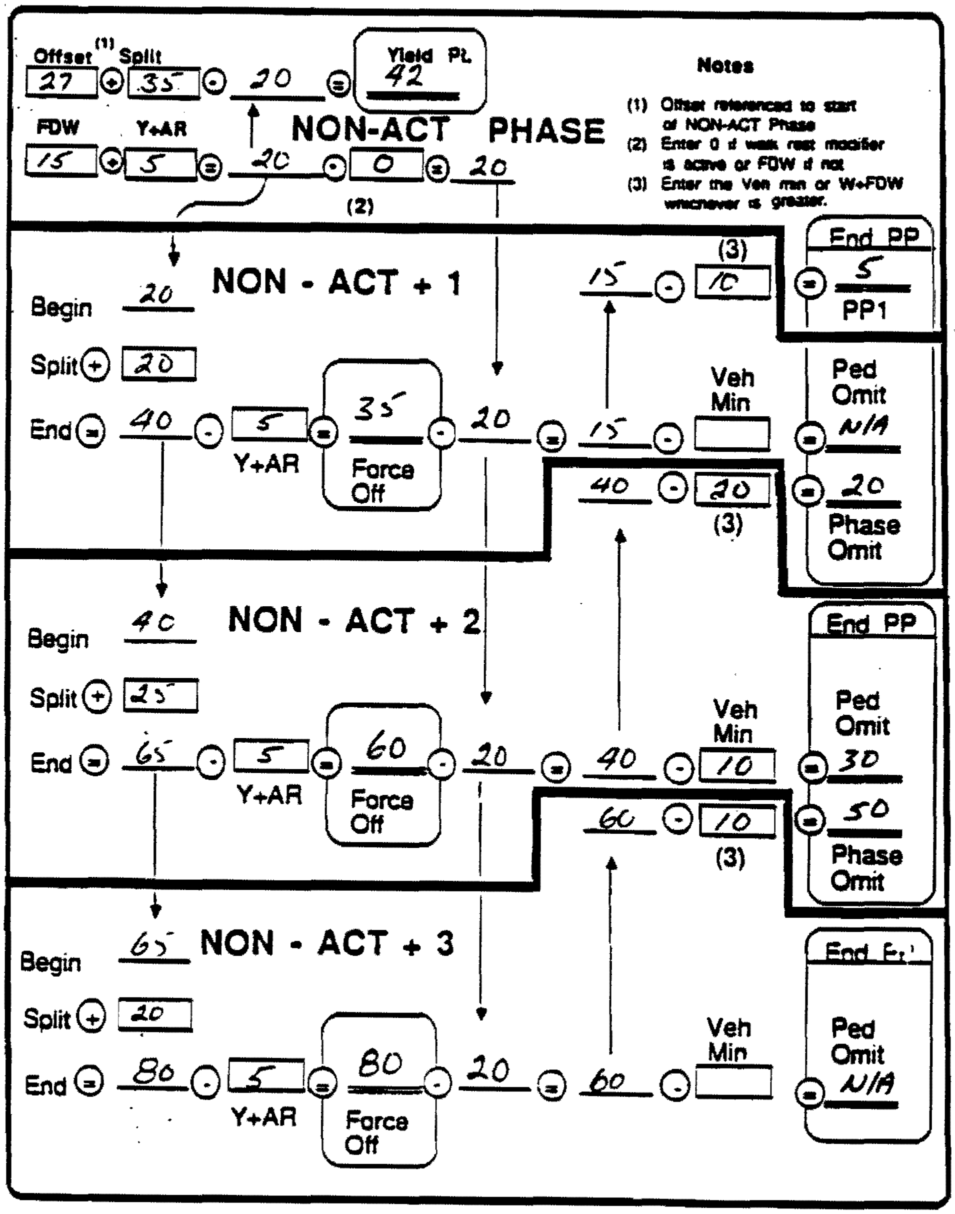


Figure 6-5. Sample Calculation of Yield Point, Force-Offs, and Permissive Periods

To accomplish the objective of having good signal timing plans throughout the day, it is recommended that the analyst develop more than one timing plan. Each timing plan should be evaluated using the different traffic demand levels that exist during various periods throughout the day. Develop timing plans for the a.m. peak period traffic demands, the p.m. peak period traffic demands, and representative off-peak period traffic demands. Analyst should analyze each timing plan using the traffic demand data for the a.m. peak, p.m. peak and off-peak periods. The most appropriate signal timing plan should be selected based on engineering judgment, attempting to accommodate the majority of the traffic demand as well as possible.

One should also examine each plan for major problems, such as oversaturation or queue spillback. In short, plan selection should be a thoughtful and objective process, not a purely quantitative assessment.

Selection of Timing Plans for Multiple Dials. If the system can deal in multiple control periods, the analyst is less constrained as to the control parameters; what is likely to be constrained, however, is the phase sequences. Perform an analysis similar to the example above, but using the "best" phase sequences from each control period to evaluate using the other traffic conditions. As mentioned above, pick the best overall phasing sequence and those phase sequences will apply all day.

6.8 Fine Tuning the Timing Plan

The following discussion follows suggestions and guidelines presented by Yauch and Gray (19). The final step in the implementation phase of retiming signals is fine tuning the signal timing plan. Fine tuning involves observing the signal timing plan in operation after its installed in the controller and determining if the new plan operates effectively. Based on observations, minor adjustments may be needed to improve the performance of the timing plan in the real world setting. Most adjustments will be made to the phase lengths or offsets.

Results from signal timing optimization computer runs should not be considered absolute or completely correct. Input data may not reflect the real world situation. While signal optimization software are tools to help produce a good timing plan, engineering judgment and field observation must also be part of the implementing process.

Fine Tuning In-house. Before actual field observation, one should check the data used in the analysis for errors. The simulation of existing conditions should be verified before the optimization runs are made. Other reasons for field observation and fine tuning are that scaled measurements may have been used for distances or data may have been entered incorrectly into the controller. After an optimized solution has been reached, data input and results should be thoroughly scrutinized. The transposed data from the computer output to controller settings should be reviewed for accuracy. If one takes these steps before field implementation, adjustments in the field will be minor.

The public should be notified of proposed signal changes in advance of their implementation. This notification may be accomplished by the media or appropriate signing. When actual field modifications begin, proper traffic control should be used to protect the traveling public and workers implementing the new timing plans.

Fine Tuning in the Field. Fine tuning signal plans in the field involves the verification of plan implementation cycle length, phase splits, and offsets. Fine tuning also involves determining the effects of the new timing plan on traffic flow. Before determining the operational effects, controller settings should be verified first. Before actual field fine tuning takes place, the traffic should be allowed to "settle." Drivers may react hesitantly or erratically due to the change in signal timing and/or phasing. The true effect of the new control strategy on the traffic flow may not be apparent immediately due to the driver behavior. Therefore, observations and measurements should not be made until drivers become familiar with the new changes.

Cycle Length and Phase Splits. After modifying the controller settings, field observations should be made to ensure that the proper settings have been implemented. One can verify cycle lengths and phase lengths in the field with a stopwatch. For most full actuated controllers, the maximum green for each phase may be observed by locking "ON" VEH DET or MAX RECALL for each phase. Once the settings have been verified in the field, the functions should be locked "Off." Otherwise, the maximum times will be assigned to each phase whether or not it is needed, and most benefits from actuated control will be lost.

Implementation of new timing plans, especially those involving new phase sequences, may cause drivers to be hesitant; or, drivers may refer back to the old phase sequence out of habit. Analyst should take this into account when observing the overall effectiveness of the changes. If other problems observed in the field, such as excessive queues and poor green time allocation, are not predicted by PASSER II-90 or TRANSYT-7F, the traffic signal analyst should check the input data and controller settings again.

Fine tuning timing plans in the field can significantly affect the performance of the signal timing plan. Minor changes, such as a two second increase for a phase, will result in 60 additional vehicles per phase discharging at the approach. This process should be followed for each timing plan implemented at intersections along the arterial. **Engineering judgment, combined with signal timing tools and public feedback, is key developing a good retiming plan.**

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7.0 PROJECT DOCUMENTATION

Assessing the benefits of the new signal timing plan is an important final step in the signal retiming process. The following sections discuss two types of documentation. First, traffic signal analysts are interested in the benefits of implementing a new timing plan. Traffic control improvement plans require justification to decision makers before they allocate expenditures. Verifying estimated improvements or better operations along the arterial assists the analyst in future fund allocations for projects. Second, the traffic signal analysts are interested in documenting any decisions pertinent to the signal timing process for future reference.

7.1 Estimation of Benefits

To evaluate the results of a new timing plan, before and after studies often prove useful. Analysts often use measures of effectiveness, such as delay, stops, fuel consumption, queues, and v/c ratios, as a basis of comparison. The objectives or goals of the project should first be established before undertaking the project. Some objectives may include:

1. Improve safety along the arterial;
2. Reduce system delay on the arterial;
3. Improve air quality;
4. Reduce fuel consumption; and
5. Increase arterial operational efficiency.

From these goals, one chooses measures of effectiveness for use in the before and after analysis. Analysts can use either PASSER II or TRANSYT-7F to estimate chosen measures for both the before (existing) and after (optimized) conditions. The same program, however, should be used for MOE estimation for both conditions; i.e., one should not use PASSER II in the before condition and TRANSYT-7F in the after condition. The differences in the before and after conditions demonstrate the benefits of the new signal timing plan. Because both arterial signal timing program's analysis period equal one hour, the benefits should be multiplied by unit costs and then converted to daily and annual totals for the life of the project.

It is important to remember that when estimating benefits, one should use actual traffic volumes rather than the adjusted traffic volumes used to determine optimum signal timings during the peak hour; i.e., one should only attribute benefits to the actual number of vehicles at the intersection. It is also desirable to have field data from the before and after conditions that verify the magnitude of the estimated benefits.

One should note that PASSER II-90 and TRANSYT-7F can be used to estimate benefits for both pretimed and actuated control. In both cases, the benefits attributable to signal retiming result from the difference between the before and after conditions. Actuated control, however, will yield better operation than that predicted by PASSER II-90, as long as the volume to capacity ratios at the intersection equal less than 0.95. The improvement due to actuated control is an approximate 15 percent reduction in individual MOEs, when volume to capacity ratios equal less than 0.85, and a correspondingly lesser reduction as volume to capacity ratios approach capacity.

Example Calculations. In an example problem that represents a signal retiming project, PASSER II-90 was used to evaluate existing conditions at 17 intersections along an arterial street, shown in Figure 7-1, and then to produce an optimized timing plan. PASSER II reports the following measurements of effectiveness: stops, delay, and fuel consumption.

Example calculations show the before and after conditions along an arterial street are illustrated in Table 7-1. The difference in the before conditions (existing) and the after conditions (optimized) is:

Stops =	16,704 stops/day	(5.9 percent reduction)
Delay =	318.6 delay/day	(19.4 percent reduction)
Fuel Consumption =	303 gallons/day	(4.6 percent reduction)

Typically, benefits for retiming signals range from reductions in stops, delay and fuel consumption of 5 to 20 percent, depending on the type of retiming strategy used (20). Generally, optimization of green splits or cycle length optimization will produce improvements of around 5 percent, while geometric and signal hardware improvements may show as much as a 20 percent overall improvement. The percentage of improvement also depends on how bad the signal timing plan was before it was optimized.

To estimate the total benefits of an optimized signal system, multiply the delay reduction (or other improvements reported by an analysis tool such as PASSER II) by the number of hours a timing plan is in operation. If three timing plans are used in a day, typically the a.m. and p.m. peak timing plans will be used for one to two hours each, and the off-peak timing plan will be used for eight to ten hours for benefit analysis; i.e. twelve to fifteen hours of the day will be used for benefit analysis. The following steps show how one may calculate benefits per day, per year, and for the life of the project:

1. **Compute Hourly Benefits.** For each timing plan, the improvement in measures of effectiveness, such as stops, delay, and fuel consumption, are calculated. For example, the delay due to signalization for the optimized (after) timing plan is subtracted from the delay due to signalization for the existing (before) timing plan.

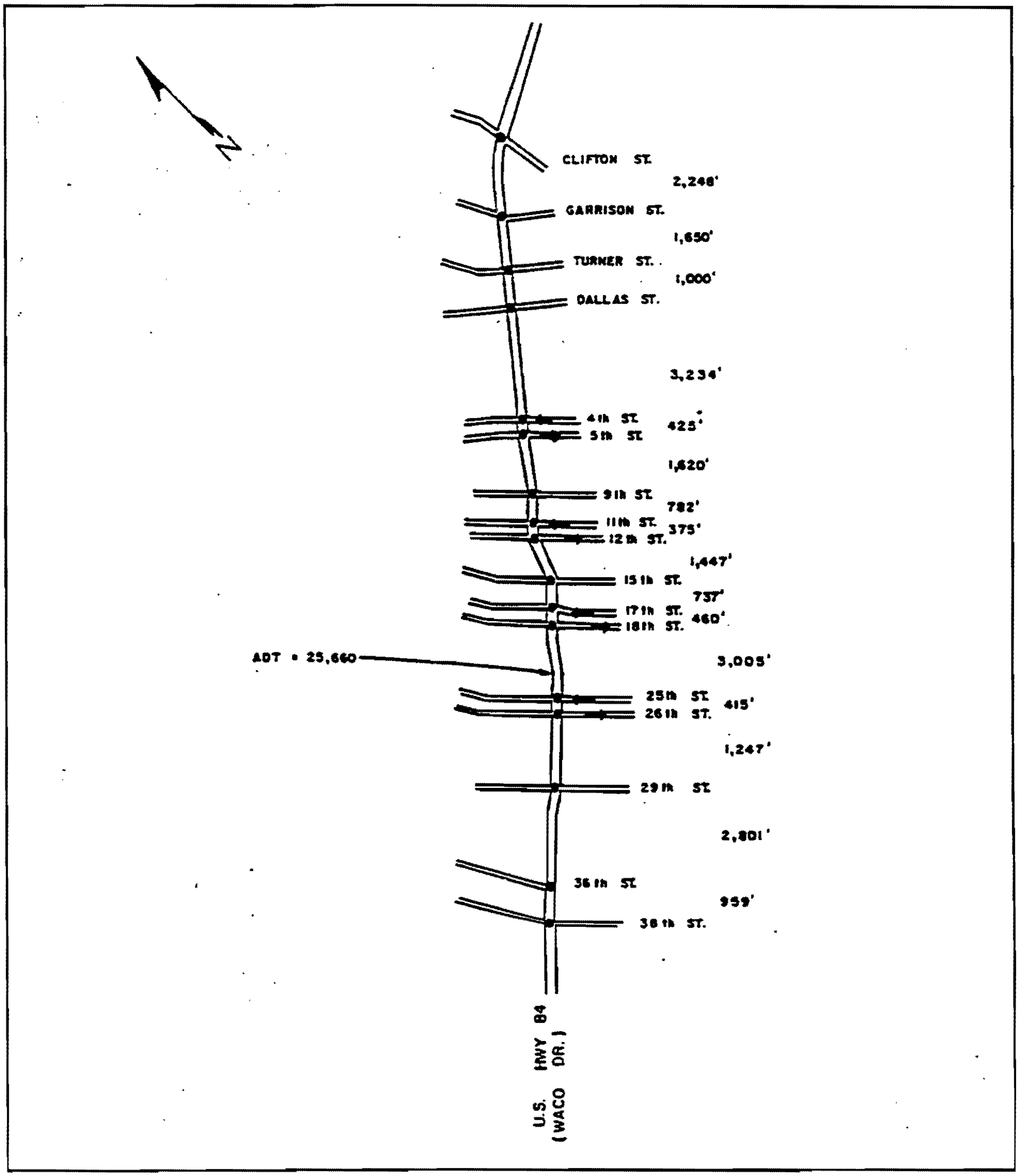

Figure 7-1. Example Arterial Street System

Table 7-1. Benefits of an Arterial Signal Retiming Project

		STOPS		TOTAL SYSTEM DELAY (veh-hrs)		FUEL (gals)	
		BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
HOURLY VALUES	AM	28981	26005	165.6	124.7	688	617
	OFF	25496	24138	142.3	119.2	594	574
	PM	30703	29333	220.5	164.5	769	738
DIFFERENCES	AM	2976		40.9		71	
	OFF	1358		23.1		20	
	PM	1370		56		31	
HRS/DAY	AM	1.5		1.5		1.5	
	OFF	7.5		7.5		7.5	
	PM	1.5		1.5		1.5	
DAILY	AM	4464		61.35		106.5	
	OFF	10185		173.25		150	
	PM	2055		84		46.5	
	TOTAL	16704		318.6		303	
UNIT VALUES		$0.014		$10.00		$1.00	
ANNUAL SAVINGS		$70,157		$955,800		$90,900	
PROJECT COST :		$45,417		TOTAL ANNUAL SAVINGS :		$1,116,857	

2. **Compute Benefits for Each Timing Plan.** For each timing plan, multiply the savings (stops, delay, or fuel consumption) by the number of hours that the timing plan is in operation. As discussed previously, the a.m. peak reduction may be multiplied by 1.5 hours, the p.m. reduction by 1.5 hours, and the off-peak reduction by 7.5 hours.

3. **Compute Daily Benefits.** Next, sum the reductions (stops, delay, and fuel consumption) for each timing plan; (a.m. reduction * 1.5) + (p.m. reduction * 1.5) + (off peak reduction * 7.5). This sum equals the total reduction for each measure of effectiveness in stops per day for stops, vehicle-hours per day for delay, and gallons per day for fuel consumption.

4. **Compute Annual Benefits.** To estimate the annual benefits, multiply these reductions per day by 300 (for approximately 300 days per year not counting weekends). Express the yearly reductions in stops per year for stops, vehicle-hours per year for delay, and gallons per year for fuel consumption.

5. **Compute Benefits for Life of Project.** Typically the life of a signal timing plan is three to five years. To estimate the benefit of reductions over the life of a project, multiply the yearly reductions (stops, delay, and fuel consumption) by the life of the project. To allocate a dollar amount to the savings due to these reductions, select a cost from a reference such as the AASHTO Manual on User Benefit Analysis of Highway and Bus-Transyt Improvement (21) per stop, per vehicle-hour of delay, and per gallon of fuel.

Some cities have published information regarding the benefits of signal retiming to motorists. This information allows local citizens and public officials to recognize the benefits gained through traffic signal retiming projects. A previous study conducted on signal retiming in 44 Texas cities (2,243 signals retimed) resulted in annual reductions in fuel consumption, delay, and stops of 9.1 percent (30 million gallons), 24.6 percent (43 million hours), and 14.2 percent (1.7 billion stops) (22). It is important to reiterate that signal retiming benefit citizens directly by reducing fuel consumption, delay time, and the number of stops at a signalized intersection.

7.2. Benefit-Cost Analysis

When considering the question of how much to budget for signal retiming projects, one should consider total costs as well as potential benefits. For example, say a district has 450 signals and a total budget for the signal section of $1,387,000,such as shown in Figure 7-2. If $160,000 of the total budget (approximately 10 percent) is used primarily for signal timing, this expenditure would equal $356 per signal per year, or $1067 per signal every three years. One can see that even a small reduction in stops, delay, and fuel consumption would easily pay for the cost of retiming.

Other considerations in determining benefits from a new timing plan involve the cost of preparing and implementing the new timing plan. One can estimate costs in terms of person-hours used to collect and prepare data for analysis, computer costs, and person-hours needed to implement the timing plan in the field. An example of an analyst's cost estimate may look like the example in Table 7-2. Note that this cost estimate is for retiming six intersections and includes the purchase of new hardware.

Some estimates of retiming costs given by various agencies range from $500 to $1800 per intersection (23). Another estimate figured one person per week for retiming a signal, which corresponds to one person timing 50 signals in a year; of course, several persons work on one project at a time. These estimates include data collection and development of timing plans. Costs will be higher for geometric improvements or major signal hardware replacement.

After computing benefits and costs of the signal retiming project, it is a simple matter to calculate a benefit-cost ratio for the project. Typical results ranges from past projects range from $20 to $100 dollars in motorist benefits for every dollar spent in the signal retiming projects. One should note from the previous example (Table 7-1) that motorists saved 24.6 dollars for every dollar spent in signal timing project.

After implementing, fine tuning, and documenting the new signal timing plan, the need for future field observation does not end. Further fine tuning may be necessary as time progresses. If events cause future traffic volume shifts, the process of evaluation, optimization and implementation will need to be repeated. Careful planning of new signal design projects will ease the problems of future traffic growth. If possible, analysts should install the most versatile controller equipment and signal hardware to accommodate future growth and fluctuations. As demonstrated by this example, retiming signals can prove a cost effective means of improving intersection capacity and movement.

Salaries and Fringe Benefits	
Signal Engineering - $266,667 x 60% =	$160,000
Signal Shop - $900,000 x 60% =	$540,000
Overtime and Standby Pay for Signal Maintenance	$ 32,000
Motor Pool Charges for Signal Surveillance and Maintenance Vehicles	$120,000
Supplies	$ 25,000
Repairs of Equipment by Vendors (including Maintenance of Central Computer Equipment)	$ 15,000
Signal Parts and Components for Maintenance	
Funded from Operating Budget	$170,000
Capital Improvements Funds (knockdowns, replacement of controllers and detectors) estimated	$325,000
TOTAL	$1,387,000

Figure 7-2. Example District's Budget for a Signal Section

Table 7-2. Analyst's Cost Estimate for a Typical Retiming Project

COST ITEM	LEVEL/TYPE	TIME	COST	COMMENTS
Personal	Director	20 hrs	$715.60	$37.78 per hour
	Oprtns. Supt	32 hrs	$743.68	$23.24 per hour
		40 hrs	$990.00	$24.75 per hour
	Traffic Tech.	32 hrs	$427.52	$13.36 per hour
		115 hrs	$1,656.00	$14.40 per hour
	Total		$4532.80	Hourly rates include salary plus 30 percent overhead and fringe benefit allowance.
Expenses	Equipment		$33,000.00	6 Eagle EPAC 300 Controllers
	Vehicle	90 hrs	$585.00	Bucket Truck
	Training		$444.00	PASSER II Training
Total Local Costs			$34,029.00	
Consulting	Timing Plans		$7,250.00	
	Install Controllers		$15,000.00	
	Total		$22,250	
Total Project Cost			$56,279.00	

7.3 Documentation of Decisions

As in all other aspects of engineering and TxDOT projects, liability is an important concern. The analyst should document the final signal timing plan agreed upon for implementation. This documentation includes steps taken toward developing the timing plan. Documentation of tasks performed and decisions made concerning signal retiming should be made. Information may include pedestrian considerations, clearance time calculations, left-turn phasing, etc. One should record and explain any unusual design procedures or engineering judgement decisions.

Documentation is recommended when implementing and fine tuning timing plans including traffic control and safety procedures taken to protect the traveling public. It is recommended that one copy of the signal timing plans currently in operation be kept in the controller and at least one copy of the plans be kept in the office or project files. It also is recommended that two copies of the signal's maintenance records be kept, as these records are becoming increasingly important in tort liability cases. As with signal timing plans, one copy of the maintenance records should be kept in the controller and the second copy should be kept in the office.

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