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16. Abstract

This report represents the development and findings of a research project conducted by the Texas Transportation Institute entitled "Reduced-Delay Optimization and Other Enchancements to **PASSER II-80.**" The research was sponsored by the Texas Department of Highways and Public Transportation in cooperation with the U.S. Department of Transportation, Federal Highway Administration. The brief six-month research effort was directed toward several topic areas which included: development of a practical procedure which could be used to fine-tune the offsets of traffic signals to minimize total delay and maximize progression of traffic in a progression system, development of methods that can better estimate delay to travel in a nearly saturated traffic system, and development of methods to estimate fuel consumption associated with arterial travel movements in an urban network. An enhanced version of the popularly used PASSER II program - **PASSER II-84**, which deals with the design and operation of signalized intersections, was programmed on SDHPT's computer system. Program documentation and revised data coding instructions were also prepared.

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ANALYSIS OF REDUCED-DELAY OPTIMIZATION

and

OTHER ENHANCEMENTS TO PASSER II-80 -- PASSER II-84 -- FINAL REPORT

by

Edmond Chin-Ping Chang
Engineering Research Associate
Texas Transportation Institute

and

Carroll J. Messer
Research Engineer
Texas Transportation Institute

and

Blair G. Marsden
Traffic Engineer
File D-18T
Texas State Department of Highways
and Public Transportation

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Texas A&M University
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ABSTRACT

This report presents the development and findings of a research study conducted by the Texas Transportation Institute entitled **"Reduced-Delay Optimization and Other Enhancements to PASSER II-80."** The research was sponsored by the Texas Department of Highways and Public Transportation (SDHPT) in cooperation with the U.S. Department of Transportation, Federal Highway Administration. The brief six-month research effort was directed toward several topic areas which included: development of a practical procedure which could be used to fine-tune the offsets of traffic signals to minimize total delay and maximize progression of traffic in a progression system, development of methods that can better estimate delay to travel in a nearly saturated traffic system, and development of methods to estimate fuel consumption associated with arterial travel movements in an urban network. An enhanced version of the popularly used PASSER II-80 program, **PASSER II-84**, was programmed on Texas SDHPT's computer system. Program documentation and revised data coding instructions were also prepared.

SUMMARY

The continued demand for urban mobility requires the highest degree of traffic service be obtained from existing urban arterial streets and intersections. The ability of signalized intersections to move traffic is determined by the physical features of the intersection as well as the type of signalization used. Thus, total system design of a signalized arterial involves concurrent evaluation of existing traffic control devices and proper signal timing settings as they function together on the street as an integrated unit.

To better improve the popularly used PASSER II-80 computer program, the Texas State Department of Highways and Public Transportation sponsored a research project entitled "Reduced-Delay Optimization and Other Enhancements to PASSER II-80". This report describes the development of the fundamental procedures of fine-tuning offsets to minimize delay while preserving the convenience of bandwidth maximizing computations in multiphase traffic signal timing optimization.

These delay reduction procedures have several common assumptions:

1. The cycle length, green split, phase sequence, and progression speed are known for each signal.
2. The optimal time-space diagram, using a maximum bandwidth technique, is provided as the starting solution and becomes a constraint for link-to-link, delay-offset analysis.
3. The interactions and offsets between two intersections depend only on the signal phase pattern, traffic volumes, and offsets of neighboring intersections.

The purpose of the study was to find an efficient and usable delay-based search algorithm for selecting a minimum delay, arterial signal timing plan that optimizes the phasing sequence, cycle length, and offsets based on a maximum bandwidth solution as the starting point.

At first, specific enhancements to improve the performance of PASSER II-80 as a maximum bandwidth based procedure were identified. Then, the existing PASSER II-80 program was extended to provide a maximum bandwidth based minimum delay solution and, at the same time, to minimize delay, stops, and fuel consumption on arterial streets. Finally, using NETSIM, an experimental design was structured to compare the calculation results from the current version of PASSER II with other existing signal timing programs for improving arterial signal operations.

The results of this study yielded the following findings:

1. Delay was reduced from 5 to 15 percent in all cases tested using the reduced-delay procedure.
2. Short spaced intersections had the greatest improvement.
3. The difference between a maximum bandwidth solution and a minimum delay solution is based on the tradeoffs of:

$$\frac{\Delta \text{ delay}}{\text{delay}} \quad \text{vs.} \quad \frac{\Delta \text{ queue}}{\text{queue}}$$

   for different offsets on a link-to-link basis.

4. Selection of adjustments to offsets depends on intersection volume level, saturation flow rate, and the amount of original offset relative to travel time between neighboring intersections.

In summary, the overall result of fine-tuning offsets confirmed the feasibility and benefits of minimizing delay by adjusting offsets based on the optimal setting calculations from the maximum bandwidth algorithm. When minimum delay and maximum progression are used, an improved level of service results. This study also indicated the advantages and drawbacks of combining the two major state-of-the-art traffic signal control strategies; i.e., the bandwidth maximization procedure and the delay minimization technique.

IMPLEMENTATION

This report provides documentation of research results currently being used in the development of PASSER II-84, the latest version of arterial signal traffic timing computer model of the Texas State Department of Highways and Public Transportation (SDHPT). No modifications to the existing user's manual nor data coding are required to use this enhanced version of PASSER II. The basic program is currently operational on the Texas SDHPT district remote computer terminals.

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INTRODUCTION

This report presents documentation of the research project entitled "Reduced-Delay Optimization and Other Enhancements to the PASSER II-80." Included are both the description of the research conducted and new material for inclusion in a revised user's manual on the Texas State Department of Highways and Public Transportation's (SDHPT) arterial signal timing and progression computer program, PASSER II-80, now 84, which has been developed in a series of previous research studies.

STUDY BACKGROUND

Problems of increasing traffic demand and resultant traffic congestion along Texas city corridors suggest the need to effectively manage traffic and better utilize existing facilities to improve traffic flow under various operating conditions in urban signal networks.

Despite a variety of traffic signal timing methods currently available, many traffic engineers continue to prefer maximum bandwidth settings because of easily understood time-space diagrams and the apparent benefit favoring progressive movement along a major arterial street system (1,2,3,4,5,6). The benefit of signal synchronization can be confirmed visually by the public when progression is used. Therefore, it minimizes the complaints from a demanding public. In addition, several studies (e.g., Wagner, Gerlough and Barnes, [1969], Wallace, [1979], and Rogness, [1981]) together with much practical experience demonstrate that the bandwidth method does yield consistently good and fast results on arterial progression systems (7,8).

Computer techniques for off-line fixed-time signal timing plan optimization have received widespread interest, but the integrality constraint on offsets has restricted development to only a few models, all of which can optimize merely a portion of the signal timing plan variables one step at a time. **PASSER** (Progression Analysis and Signal System Evaluation Routine) **II-80** has received widespread usage because of its ability to select multiple phase sequences in an easy, understandable maximum bandwidth progression solution format. However, the heavy reliance on bandwidth optimization alone to achieve maximum progression on the major arterial might somehow limit its optimal solution capability to minimize systemwide vehicular delay.

By applying the new reduced-delay algorithm for fine-tuning intersection offsets within a given time-space diagram and fuel consumption computations, improved signal timing can be expected for PASSER II users in the future.

STUDY OBJECTIVES

The Texas Transportation Institute initiated a brief six-month research effort from March to September 1983, to study the problem areas previously described. During this study period, five specific project objectives were addressed. These were as follows:

1. Identify specific enhancements to improve operational performance of the PASSER II-80 program package for selecting a bandwidth maximizing, delay minimizing signal timing plan for arterial signal operation.

2. Develop a new mechanism (PASSER II-80 enhancement) for fine-tuning the bandwidth based computer program to reduce delay, stops, and fuel consumption in arterial signal timing.

3. Conduct an experimental analysis using the NETSIM program for validating, evaluating, and comparing the calculation results from the current version and new enhancements of PASSER II-80 for arterial signal operation.

4. Prepare PASSER II-84 upon acceptance for operation on SDHPT's computer system.

5. Complete documentation of the new enhancements on PASSER II-84 in the existing PASSER II-80 format.

The following chapters of this report describe the research conducted and results obtained toward satisfying these study objectives.

STUDY BACKGROUND

NEED FOR STUDY

The problems of increasing traffic demand and resultant traffic congestion along signalized arterials in Texas cities suggest the need for effective traffic management and better utilization of existing facilities. There are a wide variety of approaches to study traffic problems analytically, including mechanical analogies, mathematical analysis, and simulation and analytical representation. A major development and the first application of a computerized signal timing algorithm for optimizing signalization along a street system occurred in the early 1960's with the solution of coordinated offsets for maximum throughput (9,10,11).

Little's early work [1964-1966] enabled the calculation of maximum progression bandwidth along an arterial street (by computing offsets) for given cycle time, red times, distance between signals, and travel speed (12,13,14). Brook's algorithm [1966] improved Little's program by solving a progression scheme, that maximizes the total of the two-direction throughbands over the cycle length (i.e., efficiency) including a set of offsets, cycle lengths and link speeds (15). Bleyl [1967] then extended the maximum bandwidth computer optimization development by varying Brook's algorithm for maximizing progression efficiency and selecting the offsets that minimize the total interference to the progession band (or correspondingly assuring the bandwidth maximization) (16). Messer and others [1974] developed the PASSER II computer program by expanding Bleyl's development for arterial street signal optimization (4,17). PASSER II has received widespread usage because of its ability to select multiple phase sequences in an easy, understandable maximum bandwidth progression solution format.

In 1975, Little further extended maximum bandwidth optimization by formulating the signal synchronization problem as a mixed-integer linear program (18,19). Despite its advantageous generality and use of special constraints, the approach did not become popular due to the substantial effort required in program formulation, and the inefficiency and expense of solving mixed-integer problems at that time (5,20).

Despite the variety of traffic signal setting methods currently available, many traffic engineers continue to prefer maximum bandwidth settings because of easily understood time-space diagrams and the apparent benefit of favoring progressive movement along a major arterial street system (1,2,3,4,5,6). In addition, several studies (e.g., Wagner, Gerlough and Barnes, [1969], Wallace, [1979] and Rogness, [1981]) together with practical experience demonstrate that the bandwidth method does yield consistently good results on arterial progression systems (7,8,21,22).

STUDY SCOPE

PASSER II-80's capability for optimum phase selection was unique among existing arterial and network timing optimization programs. However, the heavy reliance on bandwidth variation alone to achieve maximum progression on a major arterial street might somewhat limit its optimal solution capability to minimize systemwide vehicular delay. By applying new minimum delay based optimal search techniques and fuel consumption calculations, more efficient and useful solutions can be expected for PASSER II users in the future.

Therefore, the objective of this study was to develop, compare, and evaluate the effectiveness of modifications to the PASSER II signal timing plan for an arterial street system by using both a MAXIMUM BANDWIDTH procedure and MINIMUM DELAY signal timing optimization algorithm, including environmental considerations. The specific purpose was to find an efficient and usable delay-based search algorithm for selecting a minimum delay arterial signal timing plan that optimizes phasing sequence, cycle length, and offsets based on maximum bandwidth calculations.

This research mainly addresses fixed-time, common cycle, and coordinated traffic signals with multiphase control for arterial streets. The major application is for linear, high-type, and signalized intersections.

ORGANIZATION

This study was structured to develop four major items: a fine-tuning capability, a delay calculation methodology, an offset optimization routine, and fuel consumption computations. At first, NETSIM was used to study the capability for fine-tuning individual intersection offsets to achieve better arterial system operations without significant adverse effects on the original signal settings calculated from the bandwidth-maximizing time-space relationships. Next, the delay calculation method in the present PASSER II-80 program was modified by using the procedure followed in PASSER III and TRANSYT-7F. Third, the offset optimization routine was expanded by the state-of-art approach used in TRANSYT-7F and MAXBAND. Finally, the fuel consumption computations of TRANSYT-7F were followed and added to PASSER II-80 with the capability for future coefficient modifications as provided by FHWA.

The study tools used in this research included computerized calculation procedures currently available to the practicing traffic engineers, such as in PASSER II-80, PASSER III, TRANSYT-7F, MAXBAND and NETSIM. Mainly, emphasis was placed on developing a fine-tuning capability, a delay calculation methodology, an offset optimization routine and fuel consumption computations.

LITERATURE REVIEW

Computer techniques for off-line, fixed-time signal timing plan optimization have received widespread interest, but the integrality constraint on offsets has restricted development to only a few models, all of those in use can optimize merely a portion of the signal timing plan variables, one step at a time. Above all, the models involving a non-linear formulation still cannot guarantee an optimal solution. Even though the basic scheme of Little's MITROP procedure or the subsequent MAXBAND program can obtain optimality mathematically, it has suffered from its heuristic problem solving structure as compared to other models (2). Mainly, there are two major approaches for coordinating traffic signals along arterial streets: (1) the bandwidth maximization based procedure and (2) minimization of a disutility function such as delay, stops, fuel consumption or air pollution. The former includes: PASSER, MILP and MAXBAND. The latter includes TRANSYT-7F, MITROP and SIGOP as a typical example. Recently, several studies found that the combination of these two methods would have the psychological advantages of maximum progression and provide less delay and stops, reducing fuel consumption and travel time experienced by the motorists (28,50,51).

BANDWIDTH-MAXIMIZATION PROCEDURES

Due to the easily understood solution based on the time-space diagram and the apparent benefit of favoring progressive movement perceived by the traffic engineers and the general public, several procedures based on maximum bandwidth have been developed in the past. However, the relative efficiency of progression depends on the distances between signalized intersections, the speed of traffic, the cycle length, the roadway capacity, and the side friction along the arterial.

PASSER II

PASSER (Progression Analysis and Signal System Evaluation Routine) is an acronymn for a series of practical computer programs developed cooperatively by the Texas Transportation Institutue and Texas State Department of Highways and Public Transportation, which calculates the arterial phase sequences, cycle length, green splits, and offsets to provide the minimum interference for the best arterial progression bandwidth efficiency. The optimization procedure will select, from four possible arterial phase sequences for each intersection, the sequence that maximizes the overall arterial progression bandwidth efficiency. The PASSER II maximum bandwidth solution has been well accepted and implemented throughout the country. The theory, model structure, methodology, and logic of PASSER II have been evaluated and documented, (4,17).

The PASSER model was first developed by Messer et al (4) and modified to an off-line computer program (PASSER II) by Messer et al (17). It was developed primarily for high-type arterial streets with protected left-turn lanes and phases. It is applicable for the timing of modern eight-phase controllers. PASSER II can be classified as a macroscopic, deterministic optimization model. It uses a platoon level representation for fixed (uniform) traffic volumes and speeds. The optimization procedure is an implicit enumeration of the minimum interference values and uses a variant of the half-integer synchronization approach for relative offsets. The two measures used to determine the operational performance of the solution for signalized arterials are efficiency and attainability. Efficiency is the average fraction of the cycle plus progression. Attainabliity is the average fraction of the arterial minimum plus through greens used for progression.

MILP

Little extended the arterial Mixed-Integer Linear Program formulation (MILP) to consider the arterial system which is formed by interlocking arterial street signals at respective intersections. The network program consists of arterial "program blocks" for the individual arterial streets, plus cycle constraints for the loops that exist and satisfy the maximum arterial bandwidth objective function. However, the formulation does not include several of the arterial signal timing decision variables, such as speed variation and multiple phase calculation (18,19,20).

MAXBAND

Recently, MILP introduced by Little for setting traffic signals to achieve maximal bandwidth was extended in several ways and developed into a portable, off-line, Fortran IV computer program called MAXBAND. The program produces cycle time, offsets, speeds, and left-turn phase sequences to maximize bandwidth among different combinations by applying Land & Powell's MPCODE branch-and-bound algorithm for optimization.

In addition to arterials, the program can also handle a three-arterial triangular loop with arbitary weighting of each arterial bandwidth in the overall objective function (8,30,31).

DELAY MINIMIZATION PROCEDURE

Delay is well recognized by traffic engineers as a useful measure of effectiveness in a traffic control system (34).

Generally, the offsets which minimize stops or stop delay (or maximizes progression) are slightly shorter than those that minimize delay (21). Appropriate traffic signal settings can be determined that help smooth the traffic flow through a street network, thereby reducing delay and stoppage (2,18,22).

TRANSYT

The TRANSYT computer program developed by Robertson [1969] can determine optimum phase splits and offsets that minimize a performance index of a linear combination of stops and delays, using the delay difference-of-offset method together with random component effects (5,23). The optimization procedure used by TRANSYT is a sequential flow algorithm with a gradient search technique to minimize delay from subsequent macroscopic simulation runs (3).

TRANSYT, however, is restricted by the following features (14):

1. Inability to analyze alternative phase sequences for performance index minimization;
2. Incapabity of guaranteeing an optimum solution with its non-linear programming formulation and gradient search technique;
3. Inability to produce easily understandable time-space diagrams.
4. Reliance on the accuracy of traffic demand measurements.

Regardless of these limitations, TRANSYT has been widely accepted and is the "common" optimization computer program for analyzing an urban street network. The platoon dispersion model of TRANSYT has proved to be a good descriptor and predictor of platoon behavior. The optimized signal timing plans determined by TRANSYT have been found to give better results than other existing optimization programs (2,24,25).

Research by Huddert [1969] indicated the possibility of arriving at a compromise between the method of maxmizing bandwidth and minimizing delay (using a stop penalty) in computing traffic signal progression (26). Wallace [1979] also encouraged the use of PASSER II as a preprocessor for TRANSYT (27) to minimize systemwide delay.

Rogness [1981] used a heuristic procedure to compare and study the relative performance of PASSER II and TRANSYT programs under synthetic scenarios of cycle length, intersection spacing, and phasing sequence for single arterial street signal timing optimization (50). He further concluded and reconfirmed the potential of obtaining good to optimal solutions in network optimization by combining the use of PASSER II and TRANSYT with some recommended enhancements. Cohen [1981] suggested a similar heuristic using MAXBAND with TRANSYT (28).

MITROP

Little, et al., further expanded the computerized arterial system signal timing program (MILP) by adding their 1973 developments, which (1) optimize the network traffic signal settings by mixed-integer linear programming (MITROP) for determining offsets of all signals given common cycle length and green splits, and (2) simultaneously determine offsets, green splits, and the common cycle length. The MITROP objective function is to minimize the vehicular travel disutility using piece-wise linear performance functions (7,8,28,29).

The computer program uses mixed-integer linear programming and heuristic branch-and-bound solution techniques. It requires that the phase sequences and combinations be explicitly defined if control strategy evaluation is for more than two-phase signal operation (6).

SIGOP III

The SIGOP III prototype model was developed after TRANSYT and attempted to incorporate its "good" features and improve its limitations (32). The objective function was to minimize a combined measure of total vehicular delays, total number of vehicle stops, and excessive queue lengths. The optimization procedure was an iterative sequential suboptimization of all signals which provide a minimum disutility.

Because of the non-linear program formulation, global optimality cannot be guaranteed. Other limitations resulting from its development are the truncation of volumes to obtain workable under-saturated conditions, incapability for optimizing phase sequences, and the inflexibility of minor phase durations while reallocating the remaining slack time (13).

The SIGOP III model has not been widely used, primarily because of its inability to provide better results than TRANSYT (2,33). However, the development of the SIGOP model did create attention in forcing improvements in the TRANSYT model, such as TRANSYT 5, 6, 6C, 7, 7F, and 8. Therefore, SIGOP III provided benefits to the profession regardless of its dissemination.

EVALUATION PROGRAM

All the signal timing optimization programs incorporate procedures to select an optimal solution, but most of them are limited or confined to an indirect measure or only an approximate measure of effectiveness (MOE). The NETSIM computer program developed by FHWA, has been applied to relatively sophisticated network traffic signal control strategies, validated against field data, and proved successful in various applications (7,39,40,41,42).

NETSIM provides quantifiable results for comparison (stops, delay, fuel consumption) and other measures of effectiveness (i.e., queue length, stop delay, average speed, lane distribution, saturation ratio, and cycle failures) (8,21).

Though being a generally used traffic signal simulation tool, it is felt that NETSIM needs improvement on: multiphase signal operations, modelling under long cycle lengths, ability to simulate actuated signal systems, and application to over-saturated conditions (1,2).

FEASIBILITY STUDY

A preliminary study was conducted beforehand to evaluate the feasibility of this research. The main purpose was to examine the effect of fine-tuning relative offsets of the non-critical intersections in a synthetic four intersection arterial street signal system, based on the slack time allowance indicated by the maximum bandwidth time-space diagram.

At first, an actual arterial street system -- Skillman Avenue in Dallas, Texas was chosen, and the signal timing parameters were collected. By varying the spacing beween individual intersections, several scenarios and optimal signal settings were calculated using PASSER II-80 with maximum bandwidth optimization. Based on the maximum bandwidth time-space diagram, as illustrated in Figure 1, the "slack time allowance" was identified manually as the difference between the "through (or green) band" and the cutoff of optimal PASSER II phasing length of the critical intersections. Then, NETSIM simulation runs were made by changing the relative offsets proportionally within the slack time allowance, while keeping all other signal timing parameters constant. Finally, comparisons were made among the NETSIM simulation runs of the "base case" and the "offset fine-tuned case", using the aggregate average delay per vehicle on influenced links in the arterial street system as the performance measure.

It was found in this feasibility study that:

1. Delay was reduced 5 to 15 percent in all cases tested.
2. Shortly spaced intersections have the greatest improvement.
3. Maximum improvement was found at the adjustment of all the "slack time allowance."
4. Fine-tuning offsets may result in less delay in one direction.
5. Selection of adjusted offsets should be based on the intersection volume level, saturation condition, and amount of original offset relative to the travel time between neighboring intersections.

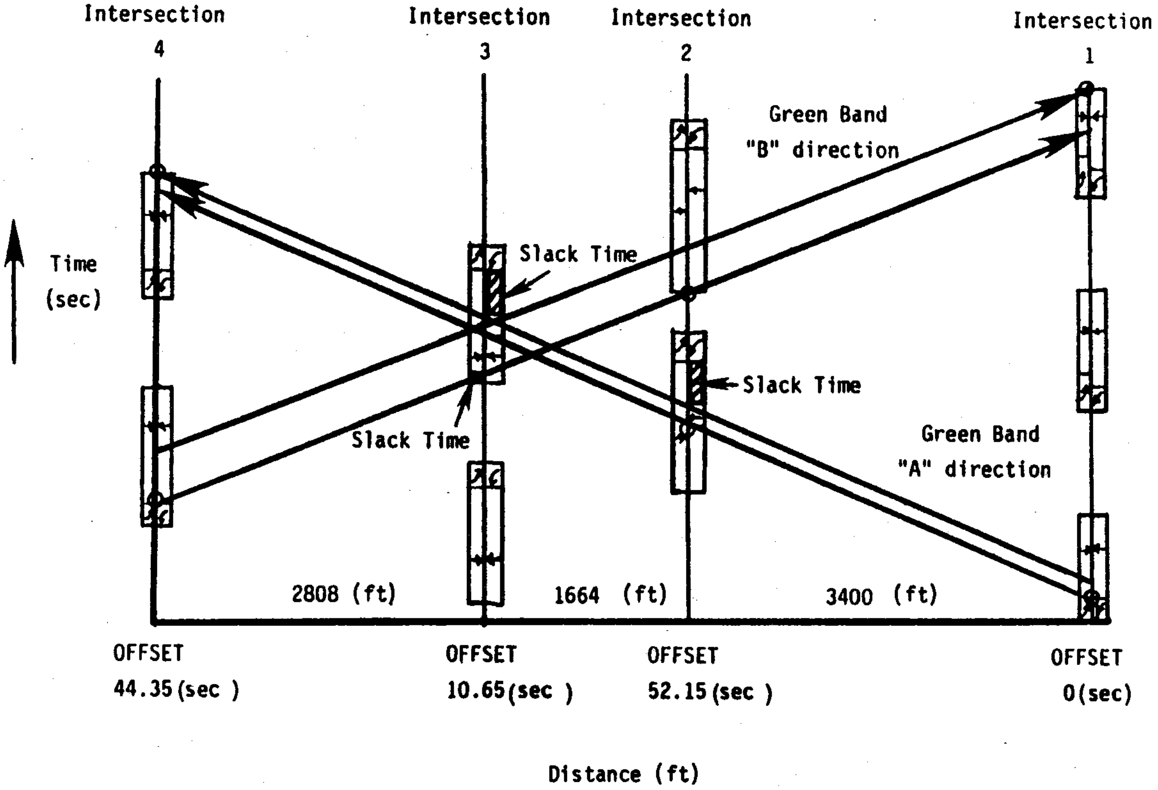


Figure 1. Example of PASSER II's Time-Space Diagram.

In summary, the overall result of fine-tuning offsets reconfirmed the feasibility and potential benefit of this research for adjusting offsets based on optimal setting calculations from the maximum bandwidth algorithm. The combination of the maximum bandwidth procedure and the minimum delay algorithm would certainly have the psychological advantage of good progression, and provide less delay and stops, reducing fuel consumption and travel time experienced by motorists. Delay and stops on a coordinated arterial street depend on the signal settings, offset, bandwidth, platoon size, dispersion, and platoon speed. The objective of the combined approach is to choose offsets, which provides a satisfactory green through band and ensures at the same time less delay and stops than other combinations of offsets providing a comparable bandwidth.

PASSER II ENHANCEMENTS

Efforts were made to improve the effectiveness of the Department's PASSER II-80 arterial signal progression program (43,44). Some internal refinements were made to the existing program reflecting user's experience with it. The revisions do not affect input or output formats.

A major task was undertaken to add an arterial signal system offset optimization routine to the basic PASSER II program. An economic approach was desired both from the research viewpoint and also in the operational usage of the program. The new extensions began by fine-tuning the offsets starting from an existing solution. Only straightforward, deterministic, and non-iterative approaches were considered.

PASSER II-80 provided an initial set of outputs to maximize arterial signal progression, as shown in Figure 2. The lower dashed-line section of Figure 2 summarizes those outputs which have been added to PASSER II-80 by modifying the existing Webster's delay estimation equation, fine-tuning the offsets of the existing time-space diagram, and adding fuel consumption calculations.

DELAY CALCULATION METHOD

One of the most important measures of effectiveness (MOE) in traffic studies is the delay to vehicles and motorists in the system. Delay represents indirect costs to motorists in terms of time lost and a direct cost in terms of fuel consumption during idling. Excessive delay at signalized intersections reflects inefficient signal timing.

Webster Delay Equation

Analytical estimates of delay are commonly used in many computer models. The most widely used analytical model is Webster's model (2), expressed as follows:

$$d = \frac{C(1 - \lambda)^2}{2(1 - \lambda x)} + \frac{x^2}{2q(1 - x)} - 0.65 \left(\frac{C}{q^2}\right)^{1/3} x^{(2 + 5\lambda)}$$

where

d = average delay on a particular approach, sec/veh

C = cycle length, sec

λ = proportion of the cycle effectively green for this approach (i.e., g/C)

q = traffic volume, veh/sec

X = degree of saturation (i.e., phase volume to saturation flow ratio

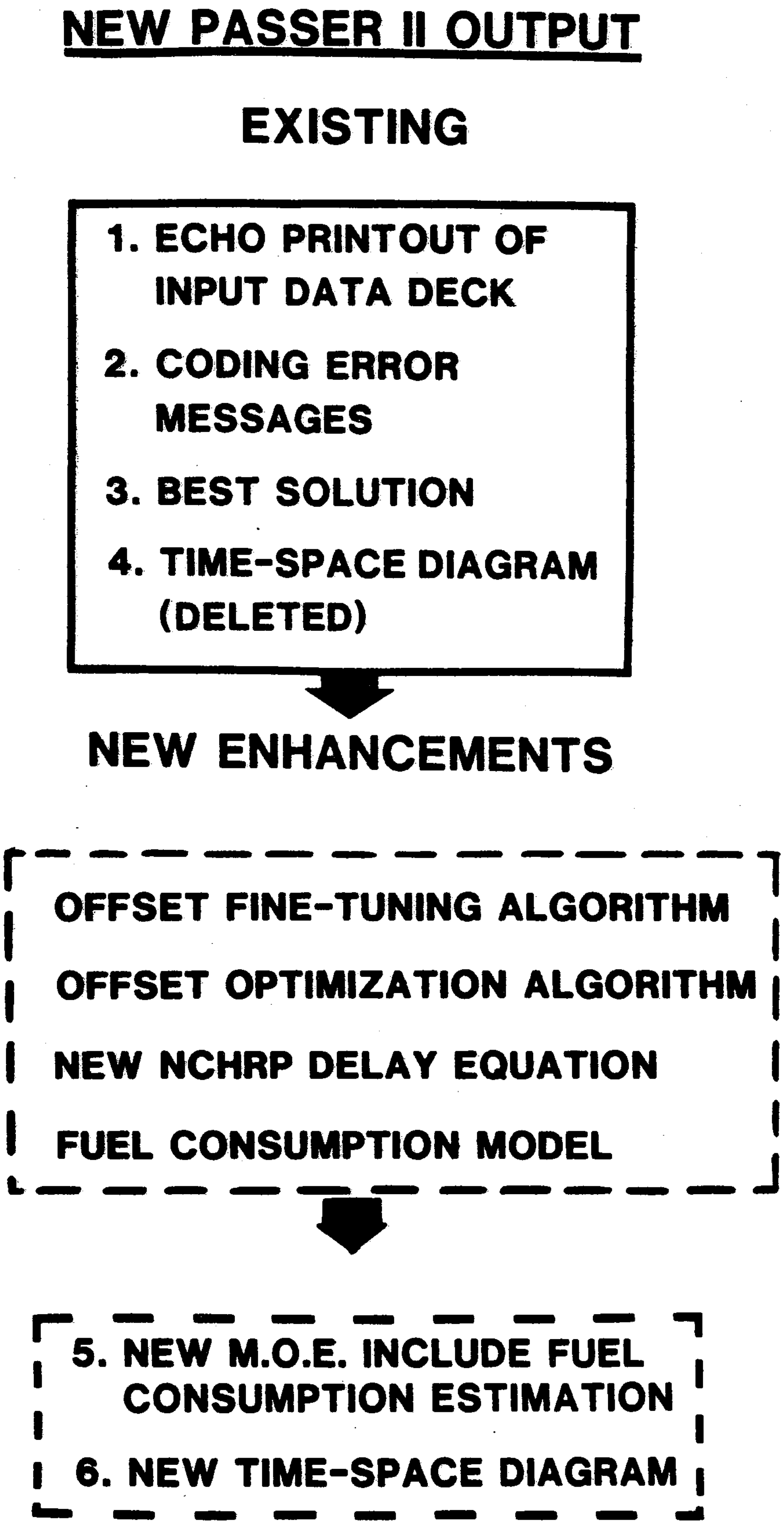


Figure 2. Schematic Layout of Elements in New PASSER II output.

The first component in Webster's model, d_1, is the delay due to recurring cyclic demands and stops, called the **uniform delay** component. The second component, d_2, is the **random delay** component, which adjusts for the random arrival of traffic. The last component, d_3, is an **empirically derived adjustment**, which adjusts the sum of the uniform and random elements to conform more closely with measured delay. Thus, total delay is expressed by the equation $D = d_1 + d_2 - d_3$.

Webster's model is plotted in Figure 3. Note that the model is not applicable as the saturation ratio approaches and then exceeds 1.0. Therefore, the model is only valid for a saturation ratio up to about 0.95.

NCHRP DELAY EQUATION

In the update of the 1965 Highway Capacity Manual, National Cooperative Highway Research Program (NCHRP) Project 3-28(2) developed a capacity and level of service method for urban signalized intersections. Specifically, a new delay estimation equation was developed to calculate delay and level of service for each lane combination (RT, THRU or LT lane), approach, and the overall intersection under normal, saturated, and over-saturated conditions. The delay equations for the basic delay conditions are summarized in Table 1 (45).

A two-term equation is used in the NCHRP delay equation; namely, terms for Uniform Delay and the Overflow Delay. **Uniform Delay (UD)** occurs when all queued vehicles clear the approach on each cycle. None of the queued vehicles have to wait through more than one red period. The **UD** formula estimates the average stopped delay per approach vehicle for lane groups with a v/c ratio less than or equal to the overflow condition. It is based on uniform arrivals and can be utilized for various analysis period lengths (5 minutes to several hours). The **Overflow Delay (OD)** occurs when on some cycles all queued vehicles clear the approach while on other cycles some of the queued vehicles do not clear the approach due to variation of the traffic volume. Overflow delay is estimated only when v/c is greater than the oversaturated conditions; that is an empirically derived estimate of the lowest v/c at which the overflow conditions begin to occur. The uniform delay component is not affected by the length of the analysis period. The overflow delay, because it is an estimate of arrival variations, is highly dependent on the analysis period. For the convenience of study, a 15 minute analysis period was assumed in the application in PASSER II-84.

The NCHRP delay estimation equation is valid for a v/c ratio above 1.00. However, the following guidelines should be noted when the v/c ratio is over 1.00:

1. Use the actual approach volumes. Check the analysis to assure that the volumes have not been adjusted to analyze the peak 15-minute period or the worst lane.

2. Use the v/c that was derived from the actual volumes, not the adjusted volumes.

3. Use the time period that relates to the volumes and the v/c ratio.

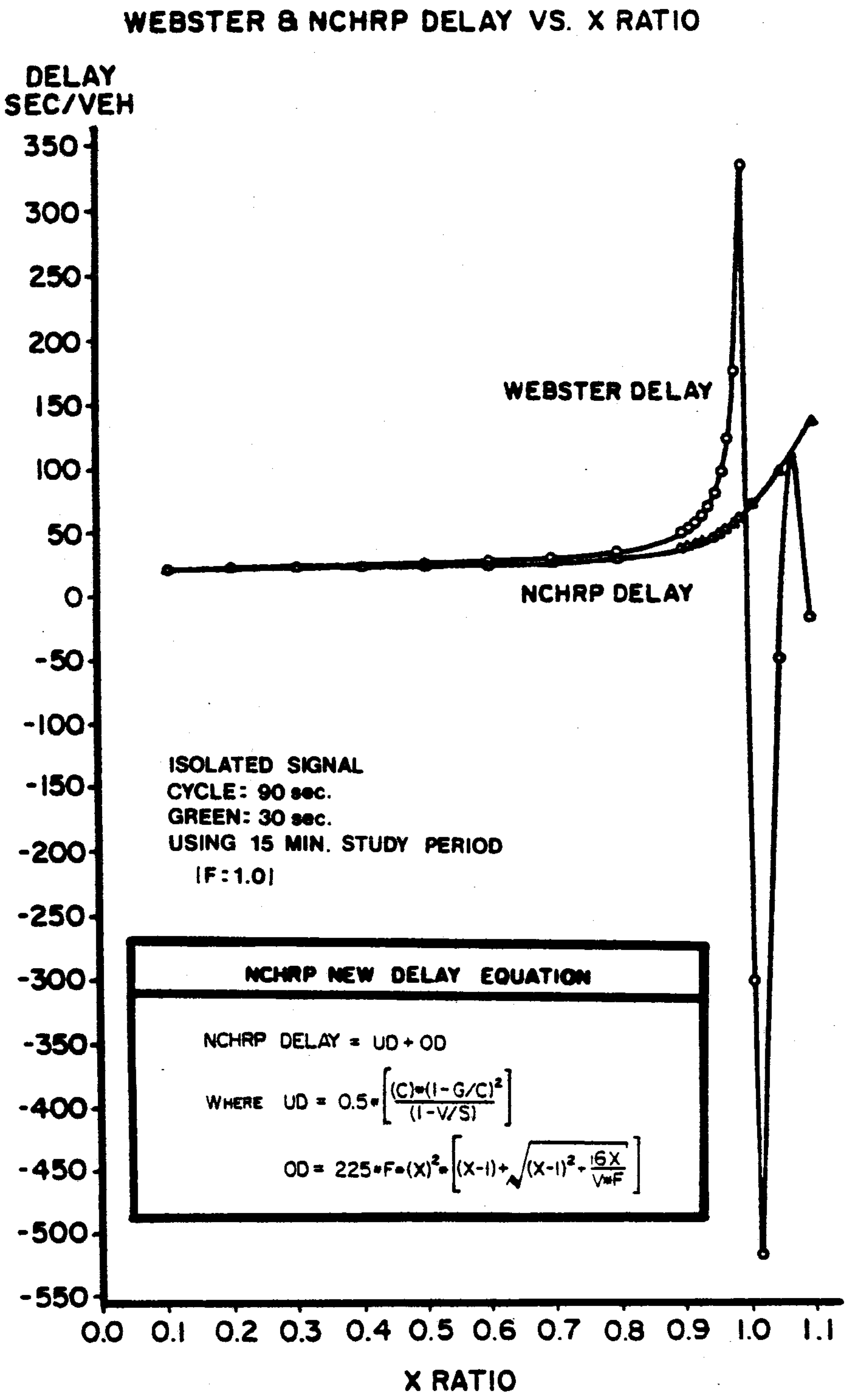


Figure 3. Webster & NCHRP Delay versus X-Ratio.

TABLE 1. NCHRP DELAY ESTIMATION EQUATION.

NEW NCHRP DELAY EQUATION

$$\text{NCHRP DELAY} = UD + OD$$

WHERE $$UD = 0.5 * \left[\frac{(C)*(1-G/C)^2}{(1-V/S)} \right]$$

$$OD = 225 * F * (X)^2 * \left[(X-1) + \sqrt{(X-1)^2 + \frac{16X}{V*F}} \right]$$

WHERE UD - UNIFORM DELAY
OD - OVERFLOW DELAY
C - CYCLE LENGTH
G - EFFECTIVE GREEN TIME
V - DEMAND VOLUME
S - SATURATION FLOW RATE
X - SATURATION FLOW RATIO
F - STUDY PERIOD ADJUSTMENT FACTOR
F= 1.0 WHEN STUDY PERIOD IS 15 MIN.
F= 4.0 WHEN STUDY PERIOD IS 1 HOUR

Figure 3, as described in the previous section, indicates that the NCHRP delay equation estimates the same or less delay than Webster's equation when v/c < 1.00 and predicted a much better estimate of delay for the v/c in oversaturated conditions. However, because the NCHRP delay equation was primarily designed for evaluations of uncoordinated signalized intersections, a version of this NCHRP delay equation was modified and added into the PASSER II-84 program after considering **"platoon interconnection,"** as described in the existing PASSER II-80 program and TTI Reports 178-2F and 203-1F (46).

OFFEST FINE-TUNING ALGORITHM

In order to improve the existing progression solution of the PASSER II-80 program, efforts were made to find an efficient and applicable calculation method used to fine-tune the relative offsets of individual intersections in the arterial system. Additionally, due to the particular phasing and green time arrangements, the end signal offset left-justification feature used in the subroutine TSCORD may sometimes produce an apparent "Plot-through-the-Red" condition on the time-space diagram. At the beginning of this study, it was determined that any new enhancements to PASSER II-80 should not conflict with the original maximum progression solution but rather fine-tune this base solution by adjusting the offsets within the existing time-space diagram.

As a result of this study, an **"Offset Fine-Tuning Algorithm"** was developed to find available slack time in the time-space diagram--slack time being defined as a portion of the green time available for directional through movements but not used in the progression band. The algorithm was also developed to check through band versus actual green time and to detect and correct the seldom **"Plot-through-the-Red"** condition. In addition, it should indicate the available slack-time allowance, to optimize the offset and to adjust the time-space coordinates accordingly. The **available slack-time** allowance is the slack time, for a particular direction at each signal, that the offsets could be adjusted without losing the benefits of the optimal progression solution and bandwidth.

In PASSER II-84, subroutine FINTUN first identifies the location of the green band on the time-space diagram, then reconstructs the time-space coordinates by travel time and distance calculations. All possible interactions between the locations of through band and actual green available for through movements are individually identified under each selected signal phasing sequence at each signal. If any "Plot-Through-the-Red" condition occurs, the subroutine PUSHUP pushes the through band back into the through green time of that direction and adjusts the other time-space coordinates accordingly.

Then, all the slack time will be identified on both sides of the progression band for both directions of travel at each traffic signal. The minimum value of the slack time that can be adjusted on either side of the progression band will indicate the maximum amount of allowable green time capable of increasing or decreasing the existing offset at each signal without affecting the bandwidth of the current progression solution. This algorithm could further reduce the need for manual adjustments of offsets on the final time-space diagram and could provide a basic range of solutions for later **"Constrained Offset-Optimization"** instead of searching through the whole cycle length as in the ordinary delay-offset analysis procedure.

This offset fine-tuning algorithm is illustrated using the example time-space diagram of Skillman Avenue shown in Figure 4. At first, the slack time available for through movement but not used in the existing time-space diagram is identified as the "hashed area" in Figure 4. After the comparisons of relative magnitude of the slack time, the minimum values of slack time in each direction are identified as the allowable slack time ranges at each signal for "offset fine-tuning optimization," as described in the next section.

For example, in Figure 4, the slack times at the second signal are identified as 28 sec, 0 sec, 5.8 sec, and 18.2 sec in the A & B directions. But the slack time allowable for adjustment is only 5.8 sec downward without affecting the width of the progression band in either direction at intersection No. 2. The resultant "Allowable Slack Time Range" is found by this algorithm as 5.8 seconds, and the resultant "Allowable Offset Adjustment Range" is, therefore, from 26 seconds to 31 seconds.

OFFSET-OPTIMIZATION ALGORITHM

The progression portion of PASSER II-84, subroutines OFSE2, OFSE3, and TSCORD provide an optimum progression offset between each signal. Further "fine-tuning optimization" would be obtained by adjusting the **initial progression offset** to some other **fine-tuned offset** within the allowable slack time range if the adjustment reduces the total two-way link delay to some lower local minimum value. Subroutine FINTUN, OFFSET, and GREEN perform these offset optimization functions.

In this offset optimization algorithm, progression remains the highest priority optimization objective and serves as the base for further fine-tune optimization. The delay-offset analysis method only fine-tunes the offset with the allowable slack time range, as described in the previous section. Mainly, the delay-offset subroutine from PASSER III was modified and used in PASSER II-84.

The operational performance of the intersection is evaluated primarily on the basis of average vehicle delay experienced by all vehicles using the intersection. Because the total vehicles operated in the arterial street system at a fixed time period is a constant, the different signal settings will only provide various traffic distributions and resultants on the network. The only difference is the total delay incurred to the vehicles travelling on all the links between the pair of intersections. Vehicle delays occurring within the intersection pairs are calculated by a version of the deterministic delay-offset technique (23). Applications of the delay-offset technique in PASSER III have been described by several excellent papers applied to signalized diamond interchanges (47,48,49).

As shown in Figure 5, a traffic link is defined as a section of an arterial street carrying a traffic movement in one direction between two signalized intersections. Delay occurs at the downstream signal of the link, i.e., the exit end of the signalized traffic flow. The offset across any link or at the signal for a particular travel direction may be defined as the time difference between the starting point of green phase at the upstream signal of the link and the starting point of the next green phase at the downstream signal. This section describes the flow of traffic through the link exit signal and the computational procedure for obtaining a delay-offset

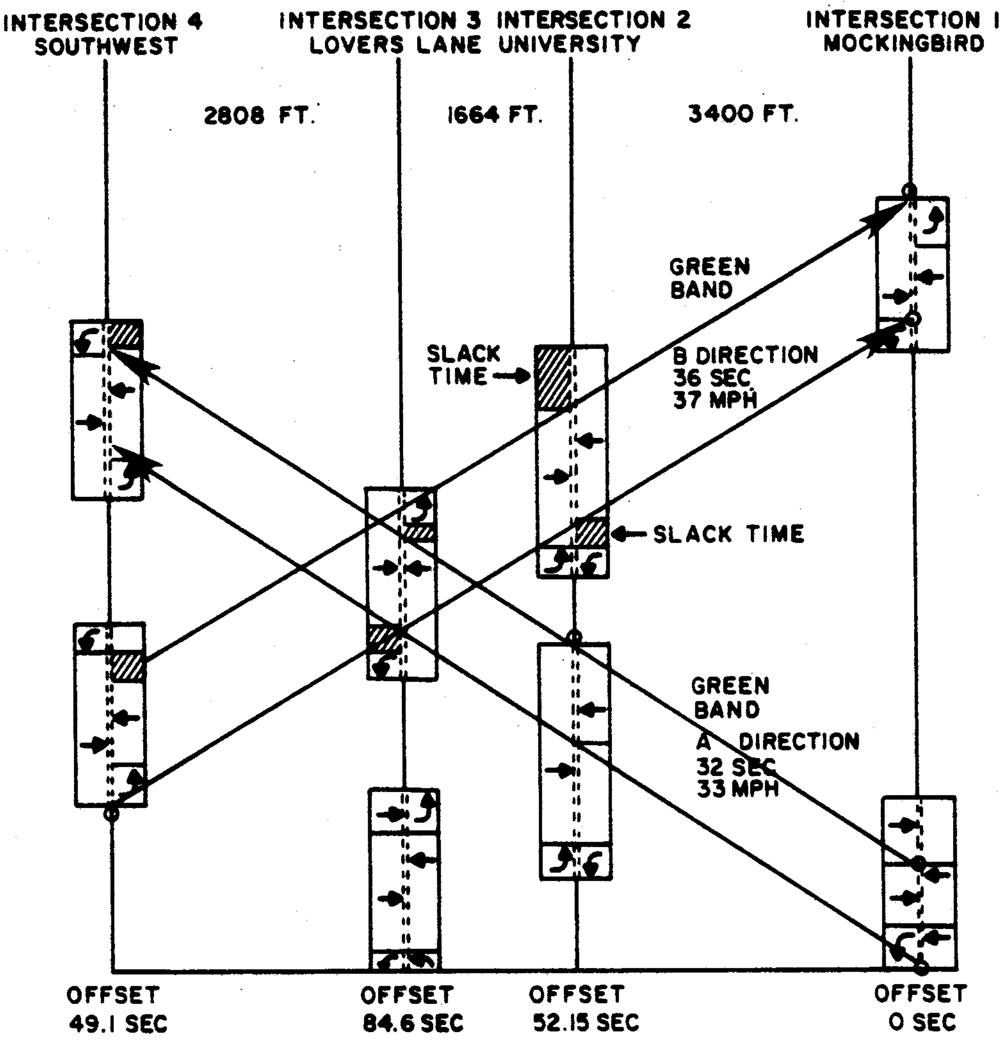


Figure 4. Example of Slack Time, Slack Time Allowance and Allowable Offset Range in the Time-Space Diagram. (Skillman Avenue, Dallas, Texas).

OFFSET FINE-TUNING ALGORITHM

PASSER II-84

MOVEMENTS ORIENTED

TIME-SPACE (TRAVEL TIME) DIAGRAM

FIND SLACK-TIME ALLOWANCE

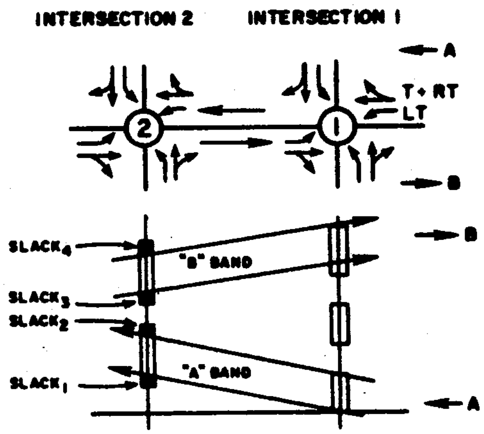


Figure 5. PASSER II-84 Offset Fine-Tuning Algorithm.

relationship, given the cyclic flow pattern on the link. A more detailed analysis, as described in the PASSER III study of TTI Report No. 178-2F, has been applied to the PASSER III program to analyze delay-offset at diamond interchange operation.

For the purpose of simplification, the following assumptions were made:

1. Arrivals are **periodic**; no significant mid-block traffic exists.
2. The signal is **undersaturated.**
3. The arrival rate during the green time does **not exceed** the saturation flow rate.

These assumptions also imply that:

1. Queue is **always empty** at the end of the green period.
2. All vehicles arriving during a cycle **can be accommodated** and reduce the minimum analysis period to a signal cycle length period.

The reference period consists of the effective red and the effective green periods of the signal cycle. In PASSER II-84, the arrival rate can be any one of the five values resulting from the multiphase signal phasing relationship:

1. Platoon saturation flow rate at first Phase movement A.
2. Normal flow at green when platoon has cleared at first Phase Movement.
3. Platoon saturation flow rate at second Phase Movement.
4. Normal flow at green when platoon has cleared at second Phase Movement.
5. Zero flow at red phase.

The upstream departure rate and the arrival/departure rate of the downstream signal could be derived by the same upstream-downstream, input-output flow analysis. Therefore, the queue length at any time within the cycle length could be calculated from the difference between the cumulative number of arrivals and departures.

The delay incurred by the total queueing vehicles during a specific time interval is the product of the total queue times the time interval. Therefore, the total delay time incurred by traffic during one cycle is calculated by the area under the queue-length curve according to a particular exit signal offset. The average delay per vehicle can then be obtained from dividing the total delay by the total number of arrivals during one cycle. This procedure yields one point of the delay-offset curve. The complete delay-offset relationship for a particular link could be obtained by repeating this procedure, while altering the arrival rate and the relative phasing sequence between the exit signal settings.

According to the principles of the combination method, where two or more links occur in parallel, joining two nodes, the delay function of the individual links can be combined with reference to the same offset to yield a total delay function. Then, the total delay function could be calculated by combining all the individual delay-offset functions of the left-turn and through links on both the A & B directions. The average combined delay function can also be obtained by dividing the total delay of the adjacent signal pairs with the total link traffic volumes. An optimal offset, between the adjacent pair of signals, is readily obtainable by searching for the minimal value of the combined function.

This combined delay-offset relationship applied in the enhanced version of PASSER II-84 is explained in Figures 6 and 7. Figure 6 illustrates the internal link-node simplification applied in the offset optimization algorithm. A total of four links, D1(T+R), D2(LT), D3(T+R), and D4(LT) are included in this two-node network representing the left turn movement and the through-plus-right-turn movements for links connecting a pair of adjacent signalized intersections, node 1 and node 2. For example, the D1(T+R) represents the delay function No. 1 by accumulating the delay incurred to all queued vehicles in through and right-turn movements from intersection 1 to intersection 2. The D2(LT) is the delay function No. 2 of delay incurred to queued left-turn vehicles from intersection 1 to intersection 2.

Figure 7 illustrates the basic theory of the constrained delay-offset analysis in PASSER II-84. As shown in Figure 7, the delay-offset curves D1, D2, D3, and D4 for each internal link are first developed. Then, the total delay-offset curve between a pair of signalized intersections is derived by accummulating the delays on each link at respective offset locations. The "TD" curve shown on Figure 3 is volume-weighted instead of the sum of D1, D2, D3, and D4.

In this way, the offset fine-tuning optimization algorithm could be further reduced to a **"Constrained Offset-Optimization Problem."** As demonstrated on the lower portion of Figure 3, the optimization problem becomes:

> **"Find a new reduced delay offset (NEW) within the slack time allowance (- DOWN $\leq$ SLACK $\leq$ UP +) for a given combination of fixed cycle, phase sequence, green split, initial progression offset, and four delay curves (D1, D2, D3, D4) of left turn, right turn, and through movements in both A & B directions."**

In this algorithm, both the combination of the original Maximum Bandwidth procedure and the Minimum Delay algorithm are considered. The **Maximum Bandwidth solution (OLD)** can be improved by using this modified delay-offset algorithm to a **Reduced Delay solution (NEW)** under multiphase operation on an arterial system. The detailed evaluation procedure and study results are further discussed in the next section, "Evaluation of Solution Methodology."

OFFSET OPTIMIZATION ALGORITHM(1) PASSER II-84

LINK-NODE SIMPLIFICATION: 4 INTERNAL LINKS & 4 DELAY FUNCTIONS

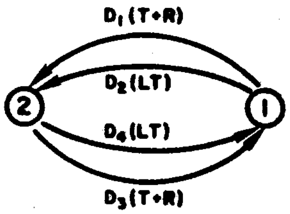
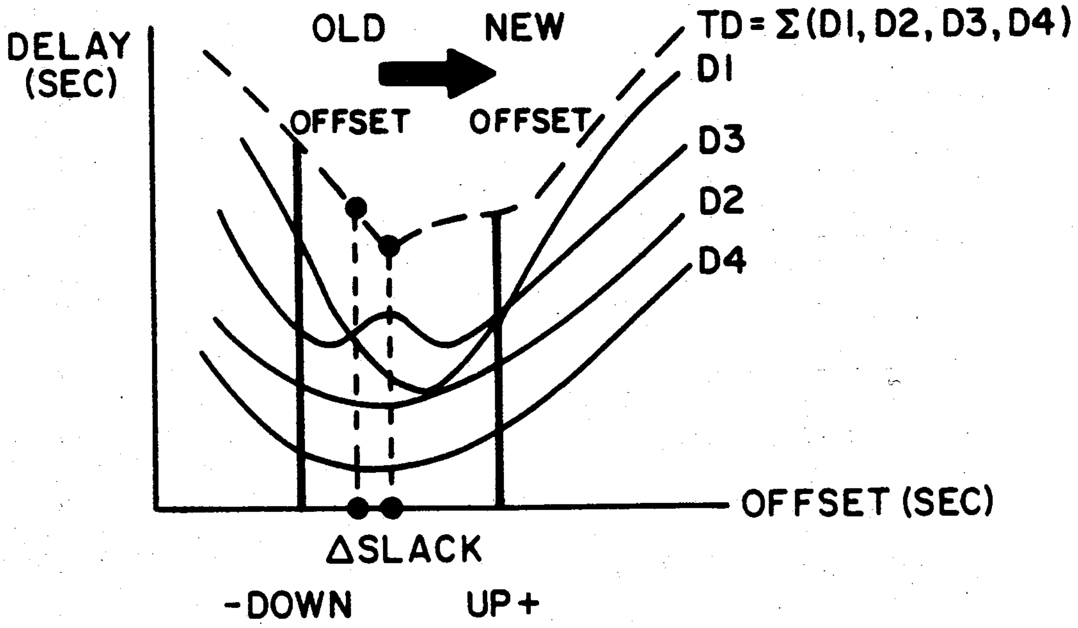


Figure 6. Internal Link-Node Simplification in the PASSER II-84 Offset-Optimization Algorithm.

OFFSET OPTIMIZATION ALGORITHM

DELAY-OFFSET ANALYSIS



LEGEND:

OLD - PASSER II - 80 SOLUTION
NEW - PASSER II - 84 SOLUTION

*OPTIMIZATION PROBLEM-
GIVEN: FIXED CYCLE, PHASE SEQ., GREEN, INITIAL OFFSET AND 4 DELAY CURVE (D1, D2, D3, D4)
FIND: NEW OFFSET WITHIN SLACK TIME ALLOWANCE

Figure 7. Delay-Offset Analysis in the PASSER II-84 Offset-Optimization Algorithm.

FUEL CONSUMPTION MODEL

Faced with fuel shortages and price increases for gasoline prevalent in the 1970's, users, analysts, and traffic engineers became more and more sensitive to the consequences of delay and stops. In order to provide a more realistic evaluation of alternative traffic signal strategies, an effort was made to develop a fuel consumption estimation model using the measure of effectiveness from PASSER II-84. It would be capable of accepting any future FHWA modifications to the fuel consumption equations used in NETSIM.

After reviewing the available fuel consumption estimation models, the fuel consumption routine used in TRANSYT-7F was modified and applied to PASSER II-84. Basically, the model was developed from a series of stepwise multiple regression analyses of data collected and programmed by the Transportation Research Center of the University of Florida (52).

The basic form of the fuel consumption model is as follows:

$$\begin{aligned} F = \; & (A11 + A12*V + A13*V**2) * TT \\ & + (A21 + A22*V + A23*V**2) * D \\ & + (A31 + A32*V + A33*V**2) * S \end{aligned}$$

where

F = estimated total arterial system fuel consumption, gal/hr

TT = total travel, veh-mile/hr

D = total delay, veh-hr/hr

S = total stops, veh/hr

V = cruise (free) speed, mph

A_{ij} = model coefficients

where

$$A_{ij} = \begin{bmatrix} 0.075283 & -1.5892\ \text{E-3} & 1.50655\ \text{E-5} \\ 0.73239 & 0.0 & 0.0 \\ 0.0 & 0.0 & 6.14112\ \text{E-6} \end{bmatrix}$$

The parameters of the TRANSYT-7F fuel model were estimated from experimental studies in which a test vehicle was driven through numerous driving cycles, using both typical urban conditions and test cycles to simulate under different combinations of the stops, delay, and cruise speed.

It was found by Wallace that the model closely matches a similar fuel model developed by Clatley and Robertson in TRRL (2,3,5). However, he also stated that the fuel consumption model does have some limitations for making absolute rather than relative measurements:

1. The model parameters were determined from studies conducted with only one test vehicle, but the model coefficients were adjusted to be representative of an "average" vehicle as defined in Reference (6).

2. No explicit consideration was given to factors, such as traffic congestion, vehicle type mix (i.e. trucks and diesel engines) or geometric and environmental factors, such as road gradient, curvature, surface quality, temperature, and other factors.

Among these measures of effectiveness used in the fuel consumption model, the total stops in vehicles per hour was the only variable not available in PASSER II-80. Therefore, a modified formula, developed by Akcelik and Miller was applied to estimate the total stops for coordinated multiphase traffic signals operated on arterial streets (52,54).

In summary, the recommended formula for estimating the stop rate, i.e. the average number of complete stops per vehicle, is:

$$h = 0.9 * \left(\frac{(1-g/C)}{(1-v/s)} + \frac{No}{VC} \right)$$

where

v = arrival flow rate, veh/sec

C = cycle time, sec

g/C = effective green time/cycle time ratio

v/s = flow/saturation flow ratio

No = average overflow queue, veh/sec

where

$$No = EXP\left(\frac{1.33 * \left(\frac{(1-vC/gs)*}{(vC/gs)} \right) (s * g)\ 1/2}{2 - vC/gs} \right)$$

$$X = \frac{v/s}{g/C}$$

$$= (v/s) * (c/g)$$

$$= vc/gs$$

The total number of (complete) stops per hour is calculated from H = qh. A convenient formula for calculating the number of stopped vehicles directly is:

$$H = \left(\frac{3240}{C} * \frac{vr}{1-g/s} \right) + N_o$$

The effect of "Platoon Interconnect" is also considered in the Akcelik equation by modifying the arrival flow rate with the resultant arterial downstream through traffic flow in PASSER II-84.

PERFECT ONE-WAY PROGRESSION

Due to the physical restrictions and unique traffic characteristics of the urban street network, the PASSER II program may sometimes be used to provide one-way progression. It can give an optional time-space diagram for the one-way street or for an arterial street system with heavy directional peak-hour travel.

The coding instructions of the existing PASSER II input data contain one option of **"Min. 'B' Direction Band Split,"** which stated "Code one (1) or ninety-nine (99) for Perfect One-way Progression in the 'A' or 'B' Directions." However, in reality, the perfect one-way progression band is very hard to achieve because of Bleyl's "Minimum Interference Theory" employed in the current version of the PASSER II program.

A subroutine ONEWAY, similar to the one in the PASSER III program, was modified in this study to calculate externally the offsets and overwrite the time-space coordinates for a "perfect" one-way progression solution by fine-tuning the offsets.

Figure 8 is an example of the result from the subroutine by specifying one (1) for "perfect" one-way progression option in the "B" direction.

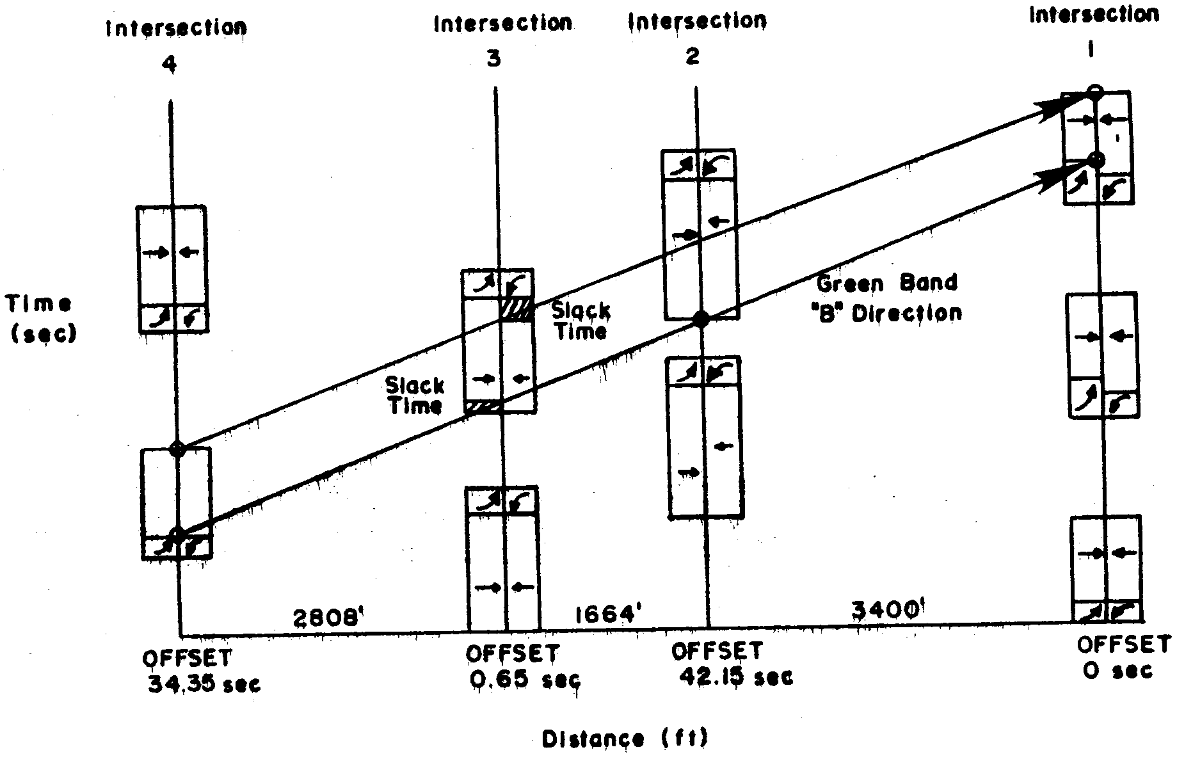


Figure 8. Example of Time-Space Program for Perfect One-Way Progression on Skillman Avenue in "B" Direction.

NEMA & PASSER's PHASE MOVEMENT TRANSLATIONS

Two phase movement designations have been used in PASSER II-80, i.e., NEMA (National Electrical Manufacturers' Association) and PASSER phase definitions. As shown on Table 2 and Appendix D, PASSER II-80 uses PASSER's phase designation as default input with the option to use the NEMA movement phase as an alternative. The NEMA designation could be considered as swapping the major street movements 3 & 4 with the minor street movements 5 & 7 as compared to PASSER's designation. As indicated in Table 2, PASSER II-84 will still have the existing PASSER II-80 options to choose between: the NEMA (option 1) and the PASSER phase definition (option 0). In addition, if the user wants to use PASSER's phase definition as input but chooses the NEMA phase definition as output, then a two (2) may be entered. Vice versa, if the user prefers to use the NEMA phase as input but desires the PASSER's phase definition for output, a three (3) may be entered in the data field. PASSER II-84 recognizes the options selected (or default) and provides proper phase movement designations in both the echo printout of input data deck and the final printout of the PASSER II-80 "BEST SOLUTION".

TABLE 2. NEMA AND PASSER II'S MOVEMENT TRANSLATION.

INPUT OPTION OUTPUT OPTION		INPUT ECHO	
		P2	NEMA
OUTPUT	P2	0	3
	NEMA	2	1

In summary, significant programming efforts have been completed. The results comprise the revised PASSER II-84 program with the new delay calculation and offset optimization routine, as shown in Figure 9. Discussions in "Evaluation of Solution Methodology" and Appendix C provide the detailed description of the internal mechanism and program flow chart of the enhanced PASSER II-84 Program. This effort provided the methodology that permits the user to determine the optimal signal settings parameters for progression operation on signalized arterial streets without having to hand-adjust the offsets of the final time-space diagram from the computer printout.

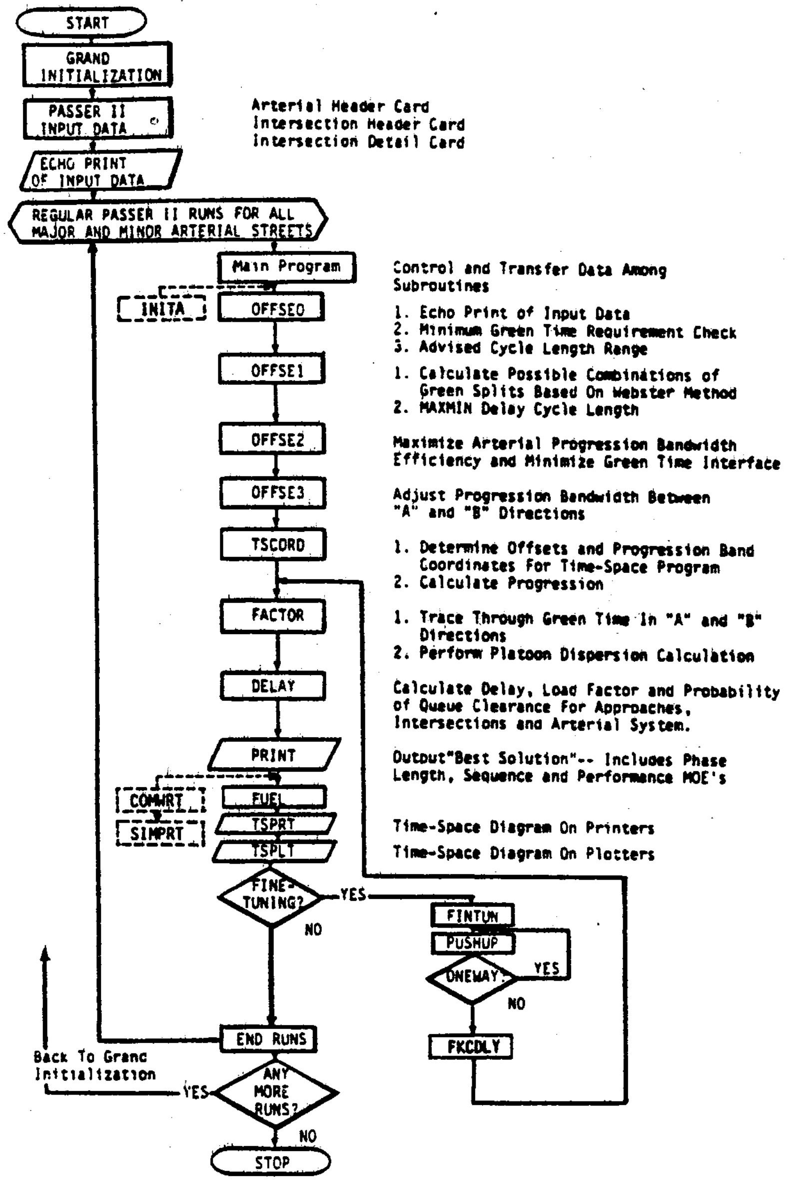


Figure 9. PASSER II-84 Program Flow Chart.

EVALUATION OF SOLUTION METHODOLOGY

EXPERIMENTAL DESIGN

Due to the actual traffic fluctuation and its inability to achieve specific experimental conditions, the NETSIM simulation program was selected as the basic bench mark model for testing.

The objective of this study task was to compare and evaluate the effectiveness of modifications to the signal timing plan (PASSER II-80) for an arterial street system by fine-tuning slack time within the time-space diagram. After the major study variables and the optimal signal strategies were identified, a set of test cases was constructed from the Skillman example to perform before-and-after comparisons among resultant MOE's of optimal settings from the simulation and optimization runs of PASSER II-80, PASSER II-84, TRANSYT-7F, and MAXBAND by using NETSIM simulated evaluations (21,50). A version of PASSER II was modified with simplified output to enumerate explicitly the offset-delay relationship from the arterial base case.

STUDY AREA

The arterial street selected, Skillman Avenue, was not considered ideal for either progression or minimum delay objectives. Figure 10 shows the four intersections used. In general, all intersections are high-type and all signalization is multiple phase with protected turning. Figure 11 shows the full-scale intersection spacing. However, because of the limited techniques used in this study, more emphasis was placed on the four intersections illustrated. They are the intersections of Mockingbird Avenue, University Drive, Lovers Lane, and Southwest Street with Skillman Avenue. The network representation of the Skillman Avenue arterial system is illustrated in Figure 12; Node 20, 21, and 22 are dummy nodes used in this link-node diagram to represent correctly the allowance for discrepancy between the original and destination traffic flow inside the Skillman Street network.

TEST PROCEDURE

The procedure used in the evaluation of solution methodology is to examine whether the enhanced PASSER II-84 program could provide better combinations of reduced delay offsets for a given progression solution as the starting point. Since the initial solutions of green split, phase sequence and offsets between intersections were given at the beginning of this study, the evaluation of solution methodology focused mainly on the algorithm of offset fine-tuning optimization. The major factors considered are the relative offsets between the consecutive intersections and the resultant delay-offset relationship.

As demonstrated in Figure 13, the test procedure follows a straightforward analysis. At first, NETSIM was selected as the evaluation model. Then, the Skillman arterial system was chosen and coded. The effectiveness of various offset optimization results could be obtained by changing the different combinations of relative offsets in NETSIM.

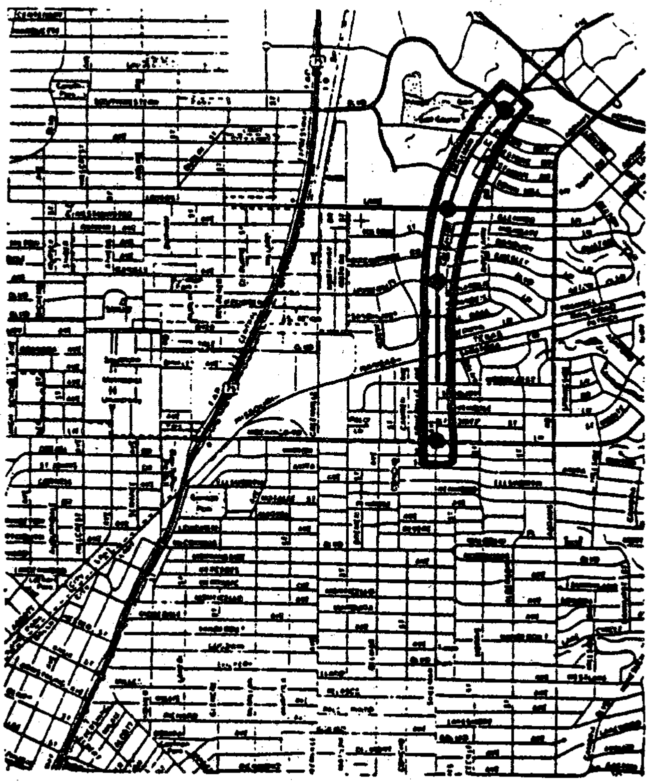


Figure 10. Location of the Study Area - Skillman Avenue, Dallas, Texas.

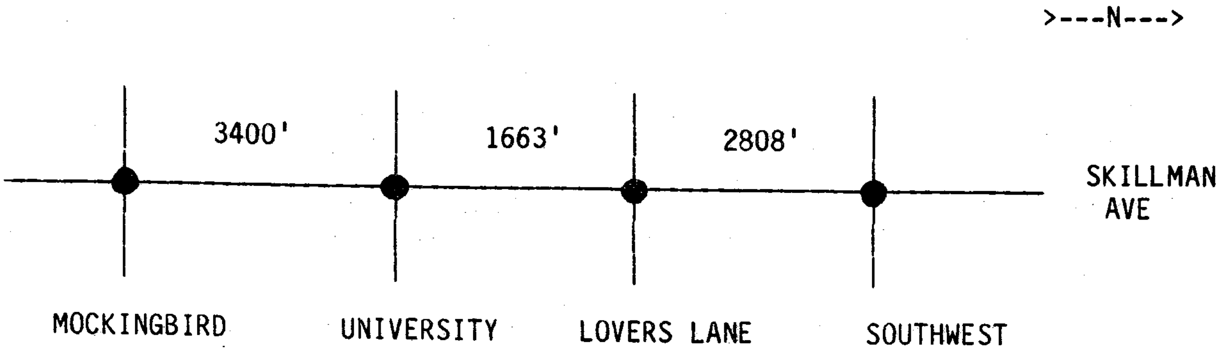
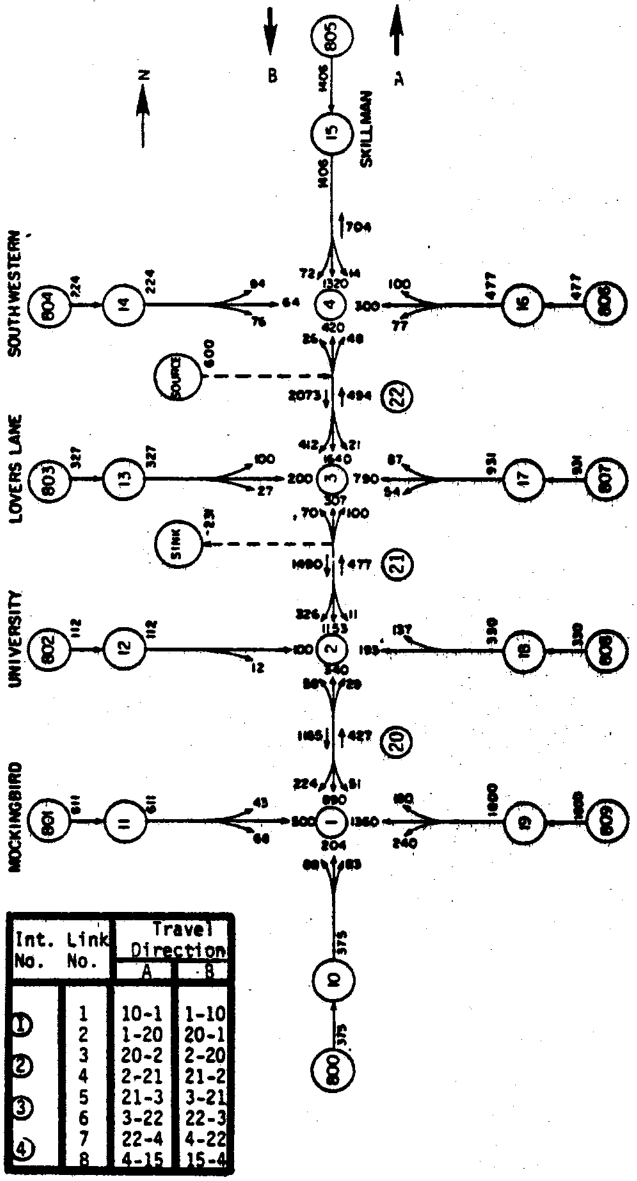


Figure 11. Study Area - Skillman Ave, Dallas, Texas.



Int. No.	Link No.	Travel Direction A	Travel Direction B
①	1	10-1	1-10
	2	1-20	20-1
②	3	20-2	2-20
	4	2-21	21-2
③	5	21-3	3-21
	6	3-22	22-3
④	7	22-4	4-22
	8	4-15	15-4

Figure 12. NETSIM Link Volume Statistics
(Skillman Avenue, Dallas, Texas).

Because additional computer funds became available from Texas A&M University, all integer combinations of offsets in the allowable slack time ranges and some incremental offsets outside the allowable slack time range throughout the cycle range of each signal were evaluated. Over 310 NETSIM case runs were made to investigate and establish a common comparison for evaluating all possible results from various offset optimization routines in the different computer programs.

The NETSIM evaluation can provide very microscopic, link-to-link statistic simulation analysis, but the resultant solution is very hard to compare, except on the total systemwide basis. Due to the lack of recognized post-processor of the NETSIM program supported by the FHWA, a combination of the Statistical Analysis System (SAS) and a set of WYLBUR EXEC Files (Command Language Files on the local computer system) were designed to summarize and select a specified value in the NETSIM program output for link statistics evaluation on the individual link, link pairs, arterial travel directions, and on the total arterial system.

Table 3 summarizes the systemwide MOE's studied in the evaluation of the relative effectiveness of the offset fine-tuning optimization. Basically, this table illustrates the analysis of delay and stops versus relative offsets using NETSIM. Among them, the MOE's of the stop delay, percentages of stop delay in total delay, and average stops per vehicle are found to be closely related to the maximum bandwidth procedure. In other words, these measurements are close to the minimum value in the range of the NETSIM offset-optimization evaluation. The average delay per vehicle and total system delay are close to the optimum minimum value if the Minimum Delay Calculation Criterion is used.

Table 4 indicates how the systemwide MOE's are calculated in the NETSIM Delay and stops versus relative offset analysis. The original offsets calculated by PASSER II-80 are labelled by "OFFSET #", such as "OFFSET 3" is the original offset of intersection No. 3 of 85 second. The relative offsets, as calculated by substracting the original offsets from the original offsets of previous signal, is used in the reduced-delay and offset analysis of PASSER II-84. The slack time allowance, as described previously, is the green time interval available for through movement but was not used in the time-space diagram of the PASSER II-80 solution. The enhanced reduced-delay algorithm in PASSER II-84 will search these slack time allowance regions and minimize the systemwide delay measurements by changing the relative offset for each traffic signal understudy. Figure 14 demonstrates the comparisons of MOE's in NETSIM Simulation Analysis at different combinations of offsets and relative offsets for the study test model on Skillman Avenue, Dallas, Texas.

The sample outputs of the NETSIM simulation analysis, as summarized by SAS (Statistical Analysis System), are shown on Figures 15 through 17 for easier comparisons. PASSER II-80 solutions, as simulated by NETSIM, are labelled as **"OLD"** while the enhanced PASSER II-84 solution is represented as **"NEW"**. Figures 15, 16, and 17 indicate the average delay per vehicle, average stops per vehicle and percentage of stop delay of total delay versus relative offset at intersections No. 2, 3, and 4, respectively. The results of the NETSIM simulation evaluation of the PASSER II-80 and PASSER II-84 programs are illustrated in the Appendix F.

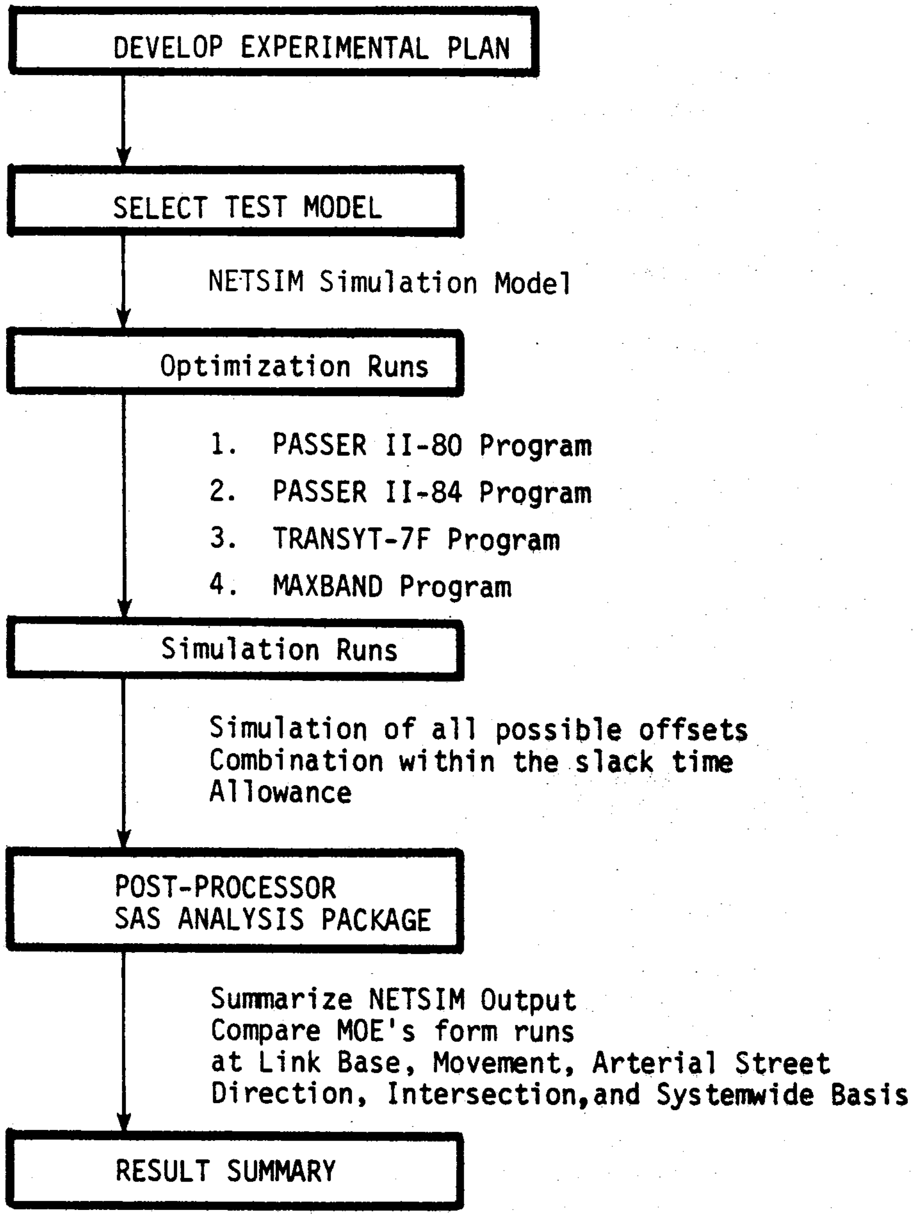


Figure 13. Evaluation of Solution Methodology.

Table 3. Calculations of Systemwide MOE in NETSIM Delay and Stop Versus Offset Analysis.

	SYSTEMWIDE M.O.E.	AVERAGE/TOTAL		UNIT	CALCULATION METHOD
Max Bandwidth	1. Stop Delay (Avg Stop Dly) (ASTP)	---	Total	(SECS)	Total Delay*%$\frac{\text{Stop Dly}}{\text{Tot Dly}}$*60
	2. Avg Stop Delay (Stop Dely) (STPD)	Average	---	(SECS/VEH)	Stop Delay/VTRIP
	3. Avg Delay/VEH (SD)	Average	---	STOPS/VEH	Simulated No. of Vehicles That Stopped
Min Delay	4. Avg Delay/VEH (AD)	Average	---	(SECS/VEH)	Total Delay/VTRIP
	5. Total Delay	---	Total	(SECS)	Simulated total delay time

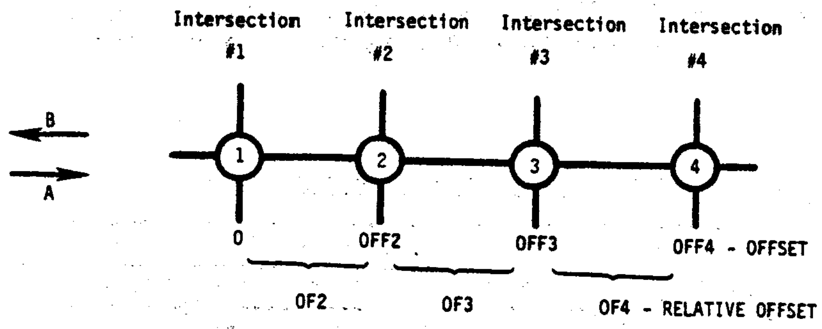
Table 4. Original Offsets, Allowable Slack-Time, Relative Slack-Time Range, and Possible Optimum Offset Range.

OFFSET & POSSIBLE OPTIMUM OFFSET RANGE

OFFSET SLACK	INT. #2		INT. #3		INT. #4	
	OFFSET 2	OF2	OFFSET 3	OF2	OFFSET 4	OF2
	26	26	85	59	49	54
OFFSET SLACK ALLOWANCE	26-32		83-92		46-49 136-139	
RELATIVE SLACK RANGE	26-32		57-66		51-54	
POSSIBLE OPTIMUM OFFSET RANGE	26-32		57-60 51 66		47-53 44 56	

NETSIM SIMULATION ANALYSIS

Compare M.O.E.'s at different combinations of offsets



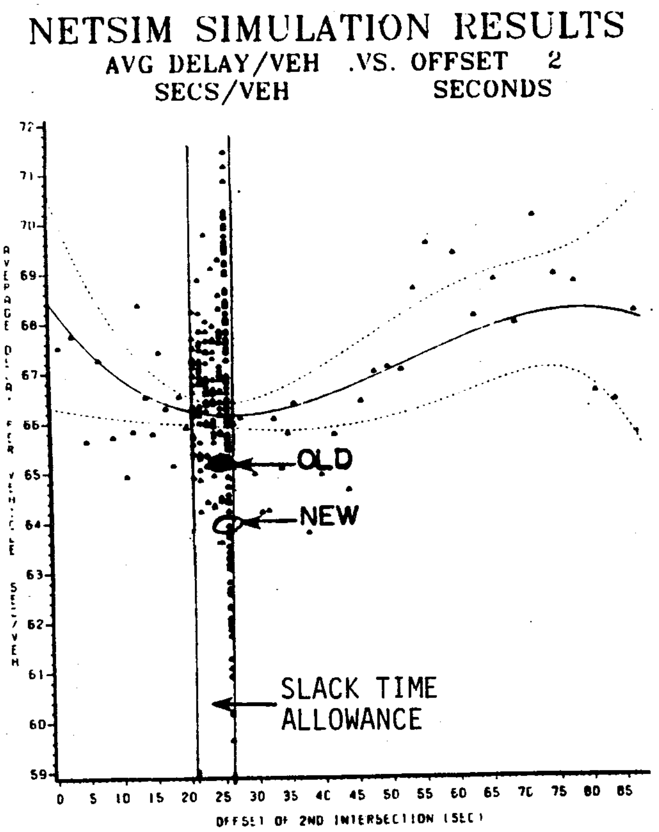
COMPARISONS

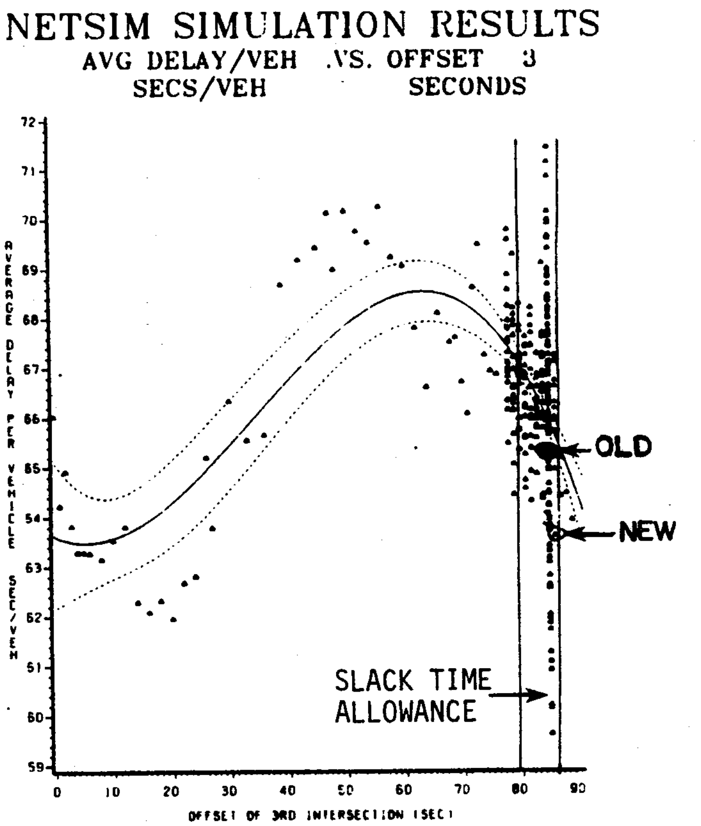
SYSTEMWIDE M.O.E. OFFSET X .VS. AVE STOPS/VEH (MAX. BAND)
2 AVE STOP DLY/VEH
3
4 % STOP DELAY OF TOTAL DELAY
AVE DELAY/VEH (MIN. DELAY)
TOTAL DELAY

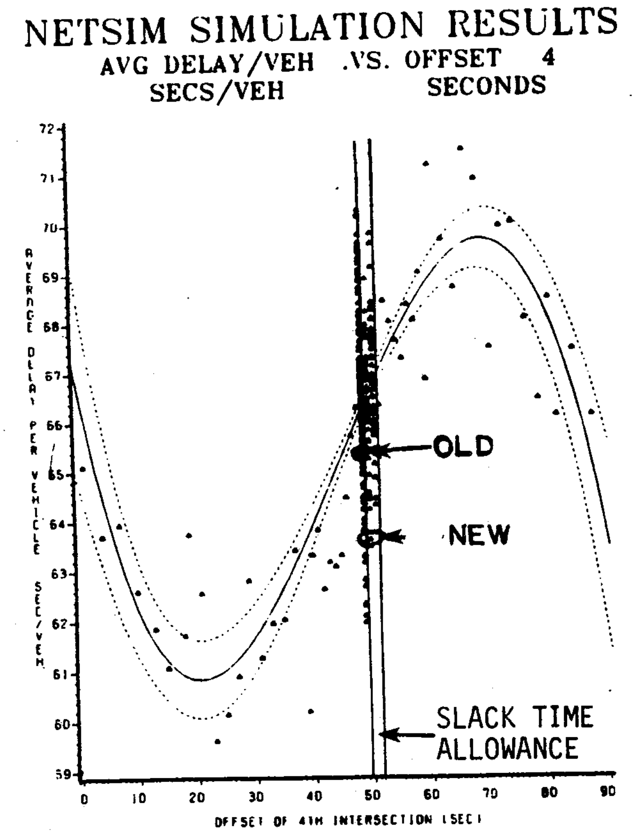
LINK SPECIFIED M.O.E. OF X .VS. AVERAGE DELAY PER VEHICLE
2
3
4
RELATIVE OFFSET

1-2	2-3	3-4	TOTAL
AVGDB2	AVGDB3	AVGDB4	TOARTB
AVGDA2	AVGDA3	AVGDA4	TOARTA
AVGD2	AVGD3	AVGD4	TOARTD

Figure14. NETSIM Simulation Analysis of the Comparisons of the MOE's at Different Combinations of Offsets and Relative Offset.



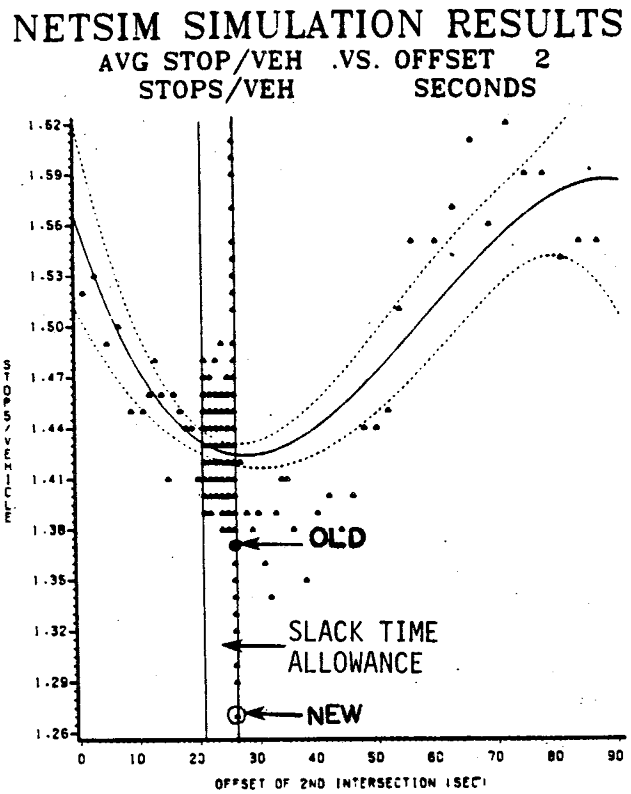


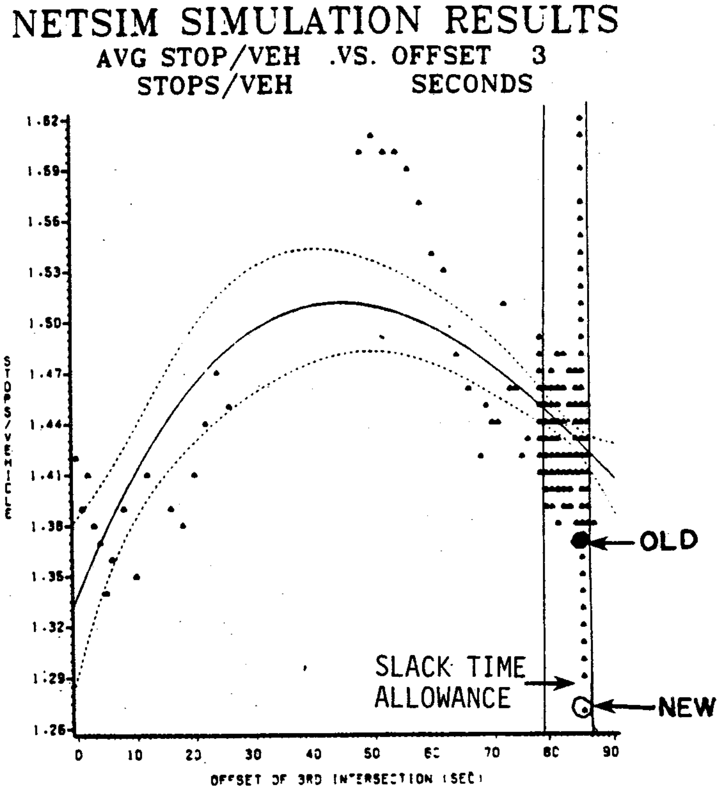


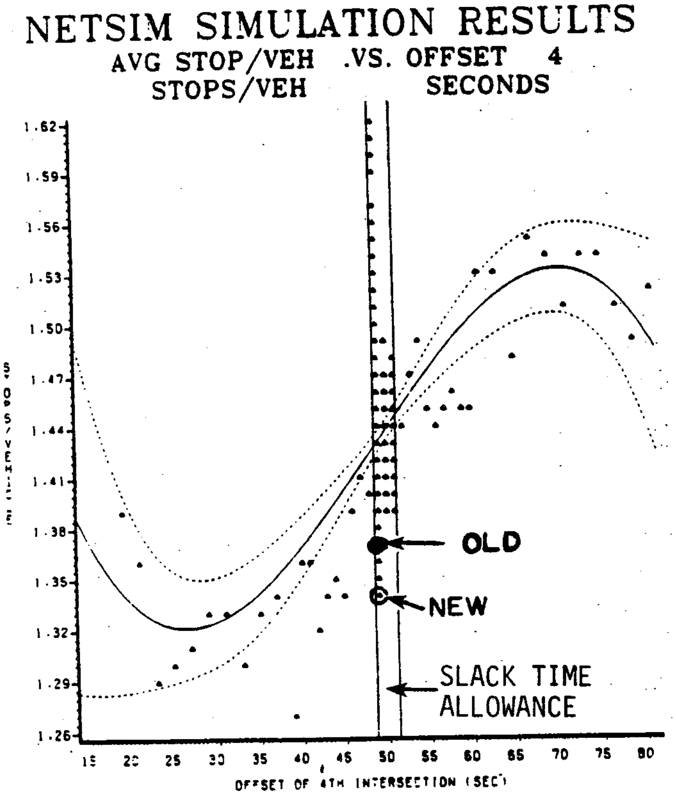
LEGEND:

- • - Individual NETSIM Run
- — - Approximated Regression by SAS
- --- - 95% Confidence Limits for Mean Prediction
- OLD - PASSER II-80 Program Result
- NEW - PASSER II-84 Program Result

Figure 15. Summary of NETSIM Simulation Result - Average Delay per Vehicle Vs. Relative Offset.



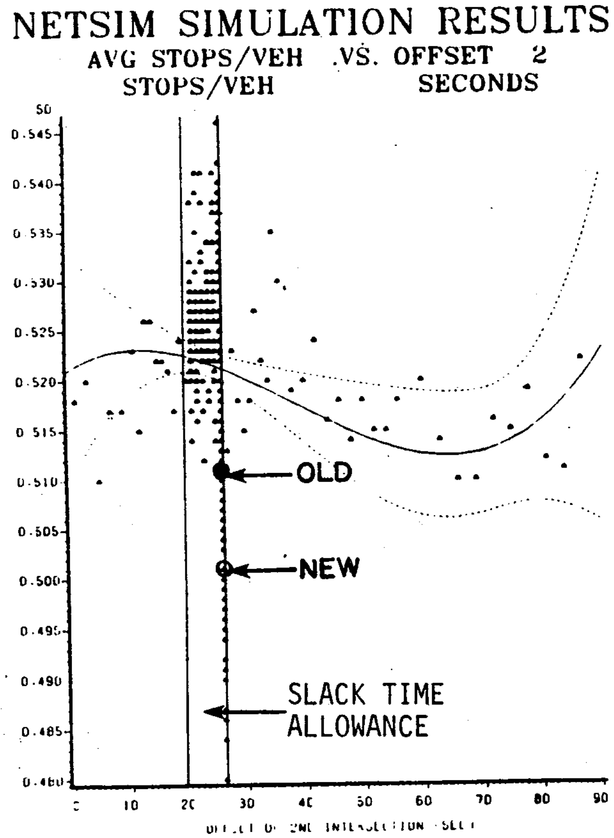


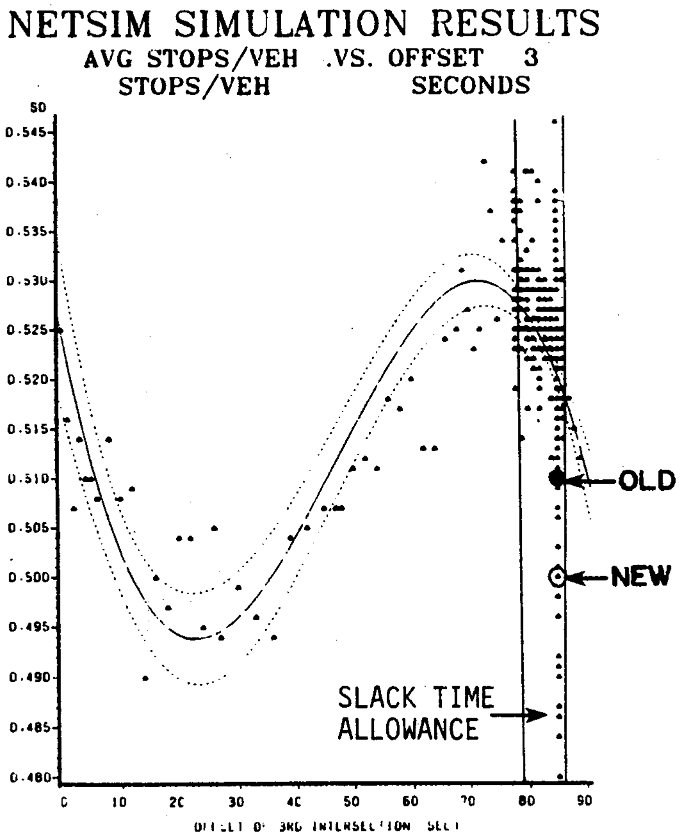


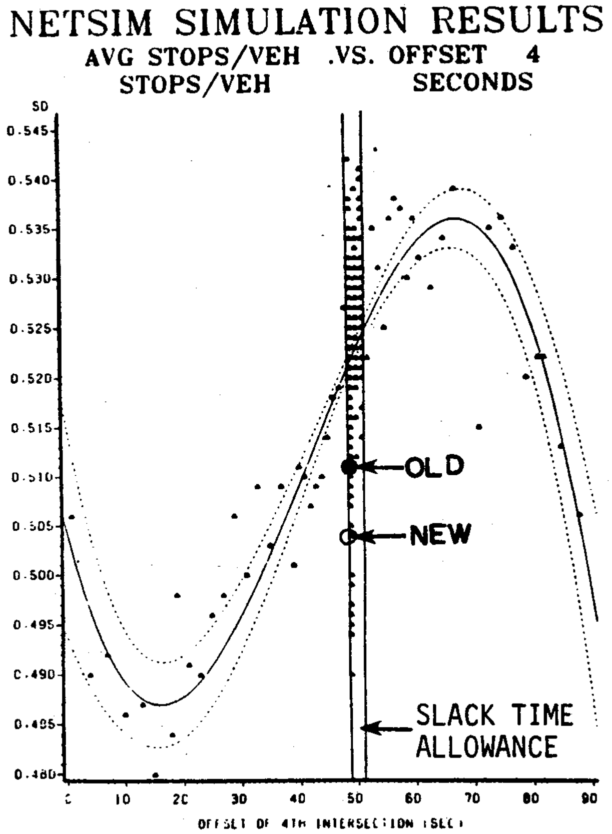
LEGEND:

- • - Individual NETSIM Run
- —— - Approximated Regression by SAS
- \--- - 95% Confidence Limits for Mean Prediction
- OLD - PASSER II-80 Program Result
- NEW - PASSER II-84 Program Result

Figure 16. Summary of NETSIM Simulation Results - Average Stops per Vehicle Vs. Relative Offset.







LEGEND:

- • - Individual NETSIM Run
- —— - Approximated Regression by SAS
- --- - 95% Confidence Limits for Mean Prediction
- OLD - PASSER II-80 Program Result
- NEW - PASSER II-84 Program Result

Fugure 17. Summary of NETSIM Simulation Results - Percentage of Stop Delay in Total Delay per Veh. Vs. Relative Offset.

RESULT SUMMARY

The following are the results of this study:

1. Delay was reduced 5 to 15 percent in all the cases being tested by using the reduced-delay procedure.

2. Shortly spaced intersections experienced the greatest improvement.

3. The difference between the maximum bandwidth solution and minimum delay solution is based on the tradeoffs of:

$$\frac{\Delta \text{ delay}}{\text{delay}} \quad \text{vs.} \quad \frac{\Delta \text{ queue}}{\text{queue}}$$

   for different offsets on the link-to-link basis.

4. Selection of adjusting offsets should depend on the intersection volume level, saturation flow rate, and the amount of original offset relative to the travel time between neighboring intersections.

In summary, the overall result of fine-tuning offsets confirmed the feasibility and benefits of minimizing delay by adjusting offsets based on the optimal setting calculations from the maximum bandwidth algorithm. This study also indicated the possibilities and drawbacks of combining the two major state-of-the-art traffic signal control strategies, i.e., the bandwidth maximization procedure and the delay minimization technique.

PASSER II-84 OPERATIONS

PROGRESSION OPTIMIZATION

The progression optimization model of PASSER II seeks to maximize the total two-way progression bandwidth efficiency. The objective function is to (43,44,51):

$$\text{Maximize} \quad E = \frac{B_a + B_b}{2C}$$

where

E = progression bandwidth efficiency, ratio

B_a = bandwidth in "A" direction, sec

B_b = bandwidth in "B" direction, sec

C = cycle length, sec

PASSER II varies the signal phasing and offset at each intersection together with the cycle length and arterial progression speeds to find the optimal set which maximizes progression bandwidth efficiency, E.

PASSER II-84 PROGRAM FLOW

The calculation method and execution steps of the enhanced PASSER II-84 program are illustrated in the functional flow chart shown in Figure 16. Generally, the "BEST SOLUTION" of signal settings are generated following the calculation procedure as described in Appendix A, entitled "Fixed-Time Signal Timing Procedure."

At first, the green splits are calculated using the Webster-Messer green split routine with the objective to equalize the specific volume-to-saturation flow ratios on critical movements followed by local intersection delay minimization. Then, optimal progression solutions are calculated using Brook's Minimum Interference Theory to optimize phasing sequence and offset arrangements. Meanwhile, the coded preferable speed and optimal cycle length are also selected according to the options in the input data stream.

Finally, the progression bandwidths are further adjusted according to the sum of the total link volumes in both the A & B directions. After these calculations, the same "BEST SOLUTION" and resultant time-space diagram, as in PASSER II-80, provide the initial solution to PASSER II-84. The enhanced version of PASSER II, PASSER II-84, will further provide the following additional capabilities:

1. Check the through progression band versus the actual green time interval. Detect any situation of "Plot-Through-the-RED" and correct it, and then indicate the available slack time allowance in the time-space diagram.

2. Optimize the offsets between intersections using link-to-link delay-offset analysis. Adjust the time-space coordinate and provide the information needed for a new time-space diagram.

3. Calculate the average delay per vehicle using the modified NCHRP delay estimation equation to account for the over-saturation condition with saturation ratio greater than 1.0.

4. Estimate the total fuel consumption (Gal/Hr), applying the modified fuel consumption estimation model used in TRANSYT-7F.

5. As an option, compute the perfect one-way progression solution with the allowable slack time allowance time-space diagram.

6. Provide the optional translation of NEMA and PASSER II's phase movement definitions.

Essentially, the result of these enhanced calculations will supply a new fine-tuned "BEST SOLUTION," including a time-space diagram and fuel consumption estimations.

STUDY AREA

The arterial street selected, Skillman Avenue, was not considered ideal for either progression or minimum delay objectives. Figure 10 shows the four intersections used. In general, all intersections are high-type and all signalization is multiphase with protected turning. Figure 11 shows the full-scale intersection spacing. However, because of the limitation of techniques being used in this study, more emphasis will be placed on the four intersections illustrated. They are the intersections of Mockingbird Avenue, University Drive, Lovers Lane and Southwestern Street with Skillman Avenue.

INPUT DATA CODING

Much of the input data required by PASSER II-84 is similiar to those needed by the other signal timing programs. They are the same data required for the existing PASSER II-80 program. In order to perform the arterial progression analysis, information is required from each intersection and between intersections which include traffic turning movements, intersection approach saturation flow rate, minimum green times, perferred phase movement, intersection separation distances, progression speeds, and allowable cycle lengths. Detailed program coding instructions are provided in Appendix D.

All the information needed to code Skillman Avenue are presented in Figure 18.

SHEET ________ OF ________

DATE ________

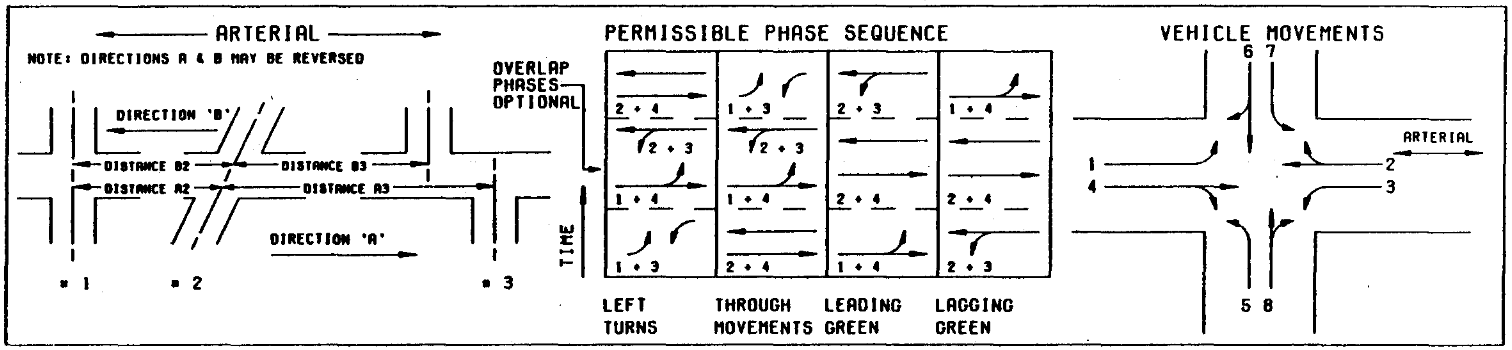
PREPARED BY ________

TEXAS STATE DEPARTMENT OF HIGHWAYS
AND PUBLIC TRANSPORTATION

PASSER II-84

ARTERIAL HEADER CARD
ONE PER ARTERIAL

RUN NO.	NAME OF CITY	NAME OF ARTERIAL	DISTRICT	DATE	NO. OF INTERSECTIONS	ISOLATED	PROGRESSION	CYCLE LENGTHS (SEC.) LOWER	CYCLE LENGTHS (SEC.) UPPER	CYCLE LENGTH INCREMENT- SEC.	MIN. 'B' DIRECTION BAND SPLIT	SPEED SEARCH ?	PRINTER PLOT ?	LINE PLOT ?	X-SCALE 1"= ? SEC.	Y-SCALE 1"= ? FEET			NEMA
1	DALLAS	SKILLMAN	18	62283	4		1	85	95	5		1	1						



INTERSECTION HEADER CARD - ONE CARD PER INTERSECTION

STREET NAME	INTERSECTION NO.	DISTANCE 'A' (FEET)	DIRECTION 'A' AVG. SPEED M.P.H.	DISTANCE 'B' (FEET)	DIRECTION 'B' AVG. SPEED M.P.H.	QUEUE CL. 'A' SIDE (SEC.)	QUEUE CL. 'B' SIDE (SEC.)	LEFT TURNS	THROUGH MOVEMENTS	LEADING GREEN	LAGGING GREEN	LEFT TURNS	THROUGH MOVEMENTS	LEADING GREEN	LAGGING GREEN
MOCKINGBIRD	1	0	0	0	0			2	2	2	2			2	
UNIVERSITY	2	3400	34	3400	38			2	2	2	2		2		
LOVERS LANE	3	1663	32	1663	36			2	2	2	2	2			
SOUTHWESTERN	4	2808	30	2808	34			2	2	2	2	2			

INTERSECTION DETAIL CARDS - THREE PER INTERSECTION

	NO.	MAJOR STREET (ARTERIAL)				MINOR STREET (CROSS STREET)			
		MOVEMENT #1	MOVEMENT #2	MOVEMENT #3	MOVEMENT #4	MOVEMENT #5	MOVEMENT #6	MOVEMENT #7	MOVEMENT #8
VOLUMES	1	88	1114	51	287	240	568	43	1560
SAT CAP	1	1700	3500	1700	3500	1700	5250	1700	5250
MIN GRN	1	10	21	10	21	10	16	10	16
VOLUMES	2	58	1479	11	369		112		330
SAT CAP	2	1700	3500	1700	3500		2600		2600
MIN GRN	2	10	15	10	15		16		16
VOLUMES	3	70	2052	21	407	54	227	100	877
SAT CAP	3	1700	5250	1700	5250	1700	5250	1700	5250
MIN GRN	3	10	21	10	21	10	21	10	21
VOLUMES	4	26	1392	14	468	77	138	84	400
SAT CAP	4	1700	3500	1700	3500	1700	1750	1700	1750
MIN GRN	4	10	19	10	19	10	21	10	21
VOLUMES									
SAT CAP									
MIN GRN									
VOLUMES									
SAT CAP									
MIN GRN									

PROGRAM 145101

FORM 1444 - 1

Figure 18

EXPLANATION OF OUTPUT

PASSER II calculates almost all of the signal timing information needed for plan development and field implementation. Figure 19 demonstrates the schematic layout of the new PASSER II-84 output, which is similar to existing PASSER II-80 format with the added fine-tuned "Best Solution", time-space diagram, and fuel consumption estimates.

The output first presents an echo printout of input information describing the arterial. Then, the input data is followed by intersection signal timing and evaluation results. The progression values include the optimum cycle length, widths of the progression bands in seconds for the A and B directions, the average band speeds, and two other descriptions of the quality of the progression solution. These two descriptions are bandwidth efficiency and attainability. **Efficiency** is the average fraction of the cycle available for progression. **Attainability** is the average fraction of the arterial minimum through greens used for progression.

The initial result given for an intersection is the progression offset of the start of the first arterial phase with respect to the start of the first arterial phase of the first intersection in the "A" direction. Also shown is the arterial phase sequence selected by the program for this intersection. Signal timing information is then presented for the intersection beginning with the arterial phases followed by the cross street phases. Each phase is defined by the movement combination forming the phase. The green time shown for each phase includes the yellow clearance time. Measures of effectiveness are calculated for all movements, intersections, and total arterial systems, and can be used to make an objective evaluation of expected traffic conditions. Check the general balance of all measures and the level of service for each analysis group. The movements experiencing Level of Service D or greater are likely to experience both large delays and numerous failures of the stopped queues to clear during the green.

The table of "progression efficiency versus cycle length" can provide the relative indications of the progression quality within the "allowable cycle length range" and the workable cycle length range suggested by PASSER II-84.

Figures 20 through 25 are printouts of the principal data of an example problem that was coded and input into the program. The user should check input data by referring to this printout so that no mistake was made in coding or reading. A complete description of the error messages, codes, and suggested actions are given in Appendix C. Figures 26 through 31 are printouts of the "Best Solution" for timing the signals at the intersections as computed by the program from the user's input data. Figure 31 is a simulated printer plotted time-space diagram which is available as an option to the user: "***" indicate a dual left turn phase, "===" indicate a dual straight thru phase, "+++" indicate a leading green phase, and "---"indicate a lagging green phase. The "..." define the locations of the progression bands.

The simulated printer plot can be used to determine the most logical progression solution for a problem. Several sets of input cards can be coded, and the best solution for each set of data can be plotted by the printer. Once the most logical solution is determined, the corresponding data can then be rerun and a digital line plot available from File D-19 can be requested.

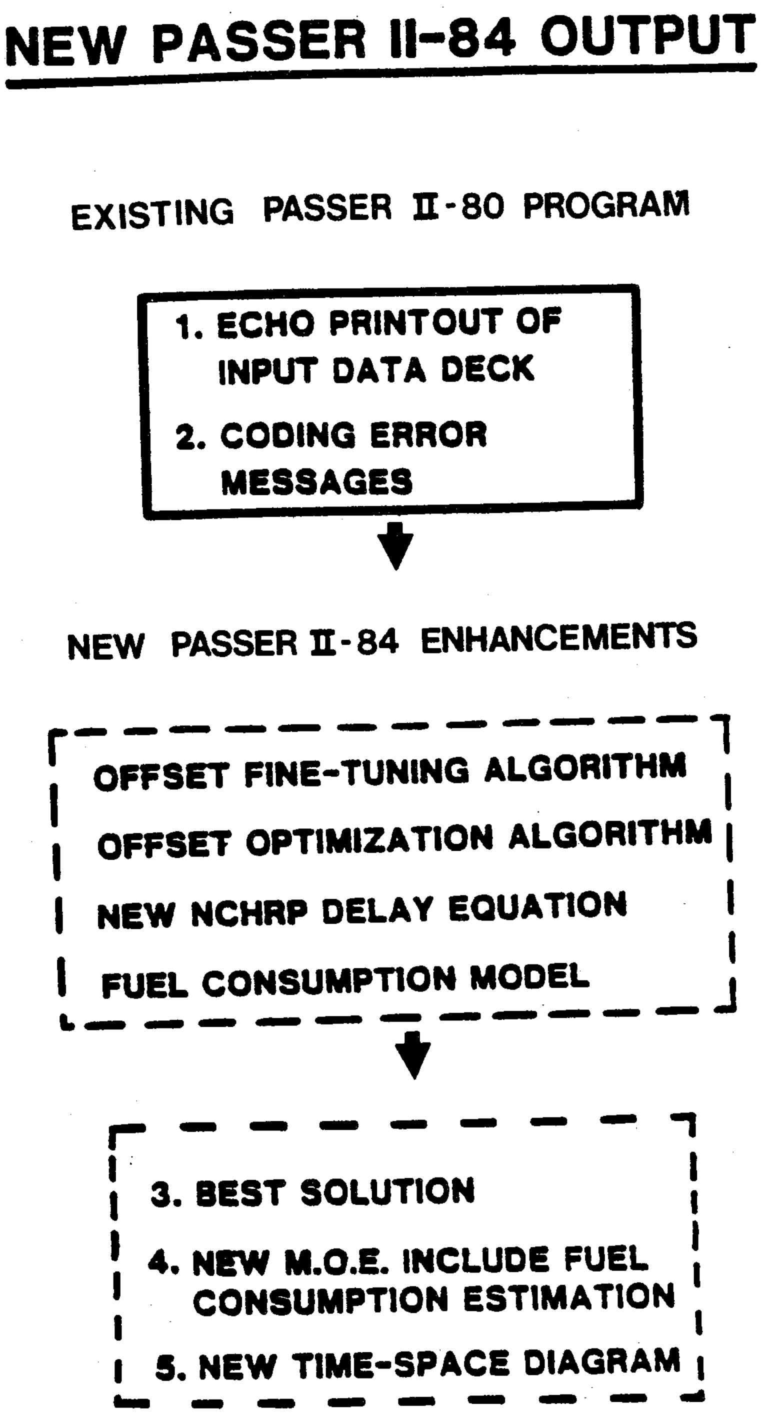


Figure 19. Schematic Layout of the PASSER II-84 Output.

APPLICATION CONSIDERATIONS

PASSER II was primarily designed to calculate green timings, phase sequence, and offsets for signalized intersections along an arterial that would maximize arterial progression and reduce delay for a given set of traffic flow conditions.

The program only calculates--it does not engineer. Several program runs may be needed before the final progression solution is calculated. The PASSER II-84 program indirectly recommends the "minimum delay cycle length" for each intersection calculated by the modified Webster method (Appendix B). The maximum value of the "minimum delay cycle length" may be used in PASSER II since all intersections are assumed to be operated on the same cycle (no double cycling is permitted) and all are likely to have different "minimum delay" cycle lengths if they were operated isolated from the others. A comparison of progression efficiency versus the incremental cycle length within the allowable cycle length range coded will also be provided.

After a run, the calculated measures of effectiveness indicate whether there may be a need to increase the system cycle length to provide better green splits or improve the general operation of the system. Excessively long cycle lengths sometimes result in overloaded left-turn bays, which could promote through-lane blockages and reduce capacity. Cycle lengths above 80 seconds in length should be avoided if possible. If the system cycle length is determined to be in excess of 80 seconds, improvements should be made to increase the intersection capacity (i.e., add lanes, restrict parking, or restripe pavement).

Phase sequence selection is also an engineering judgment. Many factors must be considered, including (1) the type of equipment, (2) volume levels and directional loadings, (3) storage length of left-turn bays and left-turn volume levels, (4) effects of progression, (5) pedestrian signal timing, etc. It is suggested that program runs first be made for AM, PM, and off-peak traffic conditions with all phase sequences possible to determine what phase sequence(s) would provide the best progression under the three different traffic conditions. If the same phase sequence resulted at an intersection for all three traffic conditions, then the sequence would be the logical choice to use for progression solution. However, in the final AM, PM, and off-peak program runs, only one sequence at each intersection would normally be permitted. In addition, the unlimited sequence analysis will determine the actual drop in progression efficiency that might occur and provide the best possible progression from using only one sequence at an intersection in the final analysis runs. Final AM, PM, and off-peak program runs would then be made after a thorough study of all results. During the final analysis runs, only one phase sequence would normally be permitted for each intersection.

While PASSER II-84 can calculate movement green times and cycle lengths from volume data to develop an optimum progression solution, PASSER may also be used to develop or simulate a progression solution when the green times and cycle lengths are already known. This can be done by setting the upper and lower cycle limits the same as the given cycle length. The given green times for the movements, green plus yellow, and all-red are coded as the minimum greens. All volumes are left blank (zero). The program will use the minimum green as the actual green. Phase selection is made as appropriate.

Special coding instructions for "T"-intersections, "Splitting the Cross Street--Cross Street Phasing With No Overlap," and one-way streets are depicted in a more detailed discussion in Appendix D (43,44,53).

```
                                       TEXAS DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION
PASSER2                                       MULTIPHASE ARTERIAL PROGRESSION - 145101                                    VER 1.0 JAN 84
                                                          PASSER II-84

PPPPPPPPPPP    AAAAAAAAAA    SSSSSSSSSS    SSSSSSSSSS   EEEEEEEEEEEE  RRRRRRRRRR              IIIIIIIIIIIIIIIIIIIIII
PPPPPPPPPPPP  AAAAAAAAAAAA  SSSSSSSSSSSS  SSSSSSSSSSSS  EEEEEEEEEEEE  RRRRRRRRRRR             IIIIIIIIIIIIIIIIIIIIII
PP        PP  AA        AA  SS        SS  SS        SS  EE            RR        RR                 III      III
PP        PP  AA        AA  SS            SS            EE            RR        RR                 III      III
PP        PP  AA        AA  SS            SS            EE            RR        RR                 III      III
PP        PP  AA        AA  SS            SS            EE            RR        RR                 III      III
PP        PP  AA        AA  SSS           SSS           EE            RR        RR                 III      III
PPPPPPPPPPPP  AAAAAAAAAAAA   SSSSSSSSS     SSSSSSSSS    EEEEEEEE      RRRRRRRRRRR                  III      III
PPPPPPPPPPP   AAAAAAAAAAAA    SSSSSSSSS     SSSSSSSSS   EEEEEEEE      RRRRRRRRRR                   III      III
PP            AA        AA            SS            SS  EE            RR  RR                       III      III
PP            AA        AA            SS            SS  EE            RR   RR                      III      III
PP            AA        AA            SS            SS  EE            RR    RR                     III      III
PP            AA        AA            SS            SS  EE            RR     RR                    III      III
PP            AA        AA  SS        SS  SS        SS  EE            RR      RR                   III      III
PP            AA        AA  SSSSSSSSSSSS  SSSSSSSSSSSS  EEEEEEEEEEEE  RR       RR             IIIIIIIIIIIIIIIIIIIIII
PP            AA        AA   SSSSSSSSSS    SSSSSSSSSS   EEEEEEEEEEEE  RR        RR            IIIIIIIIIIIIIIIIIIIIII


                                      III                            III
                                      III                            III

                                           8888888888    444    444
                                          888888888888  4444    444
                                          888      888  444     444
                                          888      888  444     444
                                          888      888  444     444
                                          888      888  444     444
                                          888      888  444     444
                                          888      888  444     444
                                          888888888888  444     444
                                           8888888888   444     444
                                          888888888888  444444444444
                                          888      888   44444444444
                                          888      888          444
                                          888      888          444
                                          888      888          444
                                          888      888          444
                                          888      888          444
                                          888888888888          444
                                           8888888888           444
```

Figure 20

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                              TEXAS DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION
PASSER2                            MULTIPHASE ARTERIAL PROGRESSION - 145101                    VER 1.0 JAN 84
                                              PASSER II-84

          SKILLMAN AVE   DALLAS  FULL SPACING       DISTRICT 16      6/22/83     RUN NO.   1

  OPTIONS IN EFFECT ARE :  PROGRESSION MODE.    SPEED VARIATION.

          INPUT DATA

     NUMBER OF            LOWER CYCLE         UPPER CYCLE         CYCLE
     INTERSECTIONS        LENGTH              LENGTH              INCREMENT

        4                    85                  95                  5

************************************************************************************************************************

  **** INTERSECTION  1      MOCKINGBIRD

     DISTANCE  0 TO  1      SPEED                                  DISTANCE  1 TO  0      SPEED
          0. FT              0. MPH                                      0. FT              0. MPH

     A SIDE QUEUE CLEARANCE          B SIDE QUEUE CLEARANCE
              0 SECS                          0 SECS

  ARTERIAL PERMISSIBLE PHASE SEQUENCE         CROSS ST PHASE SEQUENCE IS LEADING GREEN            WITH OVERLAP
     LEFT TURNS FIRST            WITH OVERLAP
     THROUGH MOVEMENTS FIRST     WITH OVERLAP
     LEADING GREEN               WITH OVERLAP
     LAGGING GREEN               WITH OVERLAP

                                                   MOVEMENTS  (PASSER)

                                  1         2         3         4         5         6         7         8

     VOLUMES (VPH)               88      1114        51       287       240       568        43      1560

     SAT. CAPACITY (VPHG)      1700      3500      1700      3500      1700      5250      1700      5250

     MINIMUM GREEN (SEC)         10        21        10        21        10        16        10        16
```

Figure 21

```
                         TEXAS DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION
PASSER2                       MULTIPHASE ARTERIAL PROGRESSION - 145101                       VER 1.0 JAN 84
                                          PASSER II-84


           INPUT DATA CONTINUED

***********************************************************************************************************

  **** INTERSECTION  2      UNIVERSITY

       DISTANCE  1 TO  2     SPEED                                  DISTANCE  2 TO  1     SPEED
         3400. FT            34. MPH                                  3400. FT            38. MPH

       A SIDE QUEUE CLEARANCE          B-SIDE QUEUE CLEARANCE
               O SECS                          O SECS

    ARTERIAL PERMISSIBLE PHASE SEQUENCE         CROSS ST PHASE SEQUENCE IS THROUGH MOVEMENTS FIRST   WITH OVERLAP
       LEFT TURNS FIRST            WITH OVERLAP
       THROUGH MOVEMENTS FIRST     WITH OVERLAP
       LEADING GREEN               WITH OVERLAP
       LAGGING GREEN               WITH OVERLAP

                                                 MOVEMENTS  (PASSER)

                                 1        2        3        4        5        6        7        8

       VOLUMES (VPH)            58     1479       11      369        O      112        O      330

       SAT. CAPACITY (VPHG)   1700     3500     1700     3500        O     2600        O     2600

       MINIMUM GREEN (SEC)      10       15       10       15        O       16        O       16
```

Figure 22

```
                          TEXAS DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION
PASSER2                         MULTIPHASE ARTERIAL PROGRESSION - 145101                         VER 1.0 JAN 84
                                             PASSER II-84


            INPUT DATA CONTINUED

*************************************************************************************************************

  **** INTERSECTION  3      LOVERS LANE

     DISTANCE  2 TO  3      SPEED                                     DISTANCE  3 TO  2     SPEED
       1663. FT             32. MPH                                     1663. FT            36. MPH

     A SIDE QUEUE CLEARANCE         B SIDE QUEUE CLEARANCE
             O SECS                         O SECS

  ARTERIAL PERMISSIBLE PHASE SEQUENCE        CROSS ST PHASE SEQUENCE IS LEFT TURNS FIRST         WITH OVERLAP
     LEFT TURNS FIRST           WITH OVERLAP
     THROUGH MOVEMENTS FIRST    WITH OVERLAP
     LEADING GREEN              WITH OVERLAP
     LAGGING GREEN              WITH OVERLAP

                                                 MOVEMENTS  (PASSER)

                              1        2        3        4        5        6        7        8

     VOLUMES (VPH)           70     2052       21      407       54      227      100      877

     SAT. CAPACITY (VPHG)  1700     5250     1700     5250     1700     5250     1700     5250

     MINIMUM GREEN (SEC)     10       21       10       21       10       21       10       21
```

Figure 23

```
                            TEXAS DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION
PASSER2                         MULTIPHASE ARTERIAL PROGRESSION - 145101                              VER 1.0 JAN 84
                                              PASSER II-84


                INPUT DATA CONTINUED

*****************************************************************************************************************

  **** INTERSECTION  4      SOUTHWEST

       DISTANCE  3 TO  4     SPEED                                  DISTANCE  4 TO  3     SPEED
         2808. FT            30. MPH                                  2808. FT            34. MPH

       A SIDE QUEUE CLEARANCE          B SIDE QUEUE CLEARANCE
                O SECS                          O SECS

   ARTERIAL PERMISSIBLE PHASE SEQUENCE         CROSS ST PHASE SEQUENCE IS LEFT TURNS FIRST          WITH OVERLAP
       LEFT TURNS FIRST             WITH OVERLAP
       THROUGH MOVEMENTS FIRST      WITH OVERLAP
       LEADING GREEN                WITH OVERLAP
       LAGGING GREEN                WITH OVERLAP

                                                  MOVEMENTS  (PASSER)

                                  1         2         3         4         5         6         7         8

       VOLUMES (VPH)             26      1392        14       468        77       138        84       400

       SAT. CAPACITY (VPHG)    1700      3500      1700      3500      1700      1750      1700      1750

       MINIMUM GREEN (SEC)       10        19        10        19        10        21        10        21
```

Figure 24

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                         TEXAS DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION
PASSER2                       MULTIPHASE ARTERIAL PROGRESSION - 145101                VER 1.0 JAN 84
                                           PASSER II-84


           CODING ERROR MESSAGES

      NO APPARENT CODING ERRORS
```

Figure 25

```
                                   TEXAS DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION
PASSER2                                 MULTIPHASE ARTERIAL PROGRESSION - 145101                               VER 1.0 JAN 84
                                                    PASSER II-84

               SKILLMAN AVE   DALLAS  FULL SPACING        DISTRICT 16      6/22/83     RUN NO.   1


               BEST SOLUTION             *** PASSER PHASE DESIGNATIONS ***

          CYCLE LENGTH =  95 SECS      BAND A =  33 SECS   BAND B =  38 SECS     0.38 EFFICIENCY  1.00 ATTAINABILITY
          AVERAGE PROGRESSION SPEED -  BAND A =  32 MPH    BAND B =  36 MPH

********************************************************************************************************************

   **** INTERSECTION  1   0.0 SECONDS OFFSET   ARTERIAL PHASE SEQUENCE IS LEADING GREEN
    MOCKINGBIRD           0.0 % OFFSET     CROSS STREET PHASE SEQUENCE IS LEADING GREEN

                                        ARTERIAL                                           CROSS STREET

          MOVEMENTS                 1+4        2+4        2+3   TOTAL MAJOR ST       5+8        6+8        6+7   TOTAL MINOR ST

          GREEN TIME (SECS)        10.0       23.5       14.7       48.2             26.0       10.8       10.0       46.8
          GREEN TIME (%)           10.5       24.7       15.5       50.7             27.4       11.4       10.5       49.3

                                   ----------------------- MEASURES OF EFFECTIVENESS -----------------------

          MOVEMENTS (PASSER)        1          2          3          4          5          6          7          8


           X-RATIO                 0.82       0.88       0.27       0.26       0.61       0.61       0.40       0.86

           LEVEL OF SERVICE         D          E          A          A          B          B          A          E


           DELAY (SECS/VEH)        76.1       32.6       38.8       24.6       35.2       37.2       44.5       33.1

           LEVEL OF SERVICE         E          C          C          B          C          C          D          C


           PROBABILITY OF
           CLEARING QUEUE          0.44       0.70       1.00       1.00       0.96       0.99       0.98       0.83

           LEVEL OF SERVICE         E          D          B          B          B          B          B          C


           STOPS (STOPS/HR)         80.       844.        43.       195.       195.       475.        38.      1315.


               TOTAL INTERSECTION DELAY                MINIMUM DELAY CYCLE
                     34.2 SECS/VEH                           93 SECS
```

Figure 26

```
                        TEXAS DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION
PASSER2                       MULTIPHASE ARTERIAL PROGRESSION - 145101                       VER 1.0 JAN 84
                                           PASSER II-84


            BEST SOLUTION CONTINUED   *** PASSER PHASE DESIGNATIONS ***

*************************************************************************************************

  **** INTERSECTION  2  32.7 SECONDS OFFSET   ARTERIAL PHASE SEQUENCE IS LEFT TURNS FIRST
   UNIVERSITY           34.4 % OFFSET     CROSS STREET PHASE SEQUENCE IS THROUGH MOVEMENTS FIRST

                                 ARTERIAL                                  CROSS STREET

      MOVEMENTS               1+3        2+3        2+4    TOTAL MAJOR ST        6+8        6+7        5+7    TOTAL MINOR ST

      GREEN TIME (SECS)       10.0       0.0        64.0        74.0             21.0       0.0        0.0         21.0
      GREEN TIME (%)          10.5       0.0        67.4        77.9             22.1       0.0        0.0         22.1

                         ------------------------ MEASURES OF EFFECTIVENESS ------------------------

      MOVEMENTS (PASSER)      1          2          3          4          5          6          7          8


       X-RATIO                0.54       0.67       0.10       0.17       0.00       0.24       0.00       0.71

       LEVEL OF SERVICE       A          B          A          A                     A                     C


       DELAY (SECS/VEH)       48.4       3.9        42.0       8.7        0.0        33.5       0.0        41.4

       LEVEL OF SERVICE       D          A          D          A                     C                     D


       PROBABILITY OF
       CLEARING QUEUE         0.90       1.00       1.00       1.00       1.00       1.00       1.00       0.89

       LEVEL OF SERVICE       C          B          B          B                     B                     C


       STOPS (STOPS/HR)       52.        249.       10.        165.       0.         87.        0.         283.


            TOTAL INTERSECTION DELAY                 MINIMUM DELAY CYCLE
                12.6 SECS/VEH                              57 SECS
```

Figure 27

```
                         TEXAS DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION
PASSER2                      MULTIPHASE ARTERIAL PROGRESSION - 145101                         VER 1.0 JAN 84
                                          PASSER II-84


           BEST SOLUTION CONTINUED   *** PASSER PHASE DESIGNATIONS ***

************************************************************************************************************

  **** INTERSECTION  3  93.4 SECONDS OFFSET   ARTERIAL PHASE SEQUENCE IS LEADING GREEN
   LOVERS LANE          98.3 % OFFSET     CROSS STREET PHASE SEQUENCE IS LEFT TURNS FIRST

                                 ARTERIAL                                      CROSS STREET

     MOVEMENTS                1+4       2+4       2+3   TOTAL MAJOR ST      5+7        5+8       6+8   TOTAL MINOR ST

     GREEN TIME (SECS)       10.0      38.5      11.0       59.5           11.1        3.4      21.0       35.5
     GREEN TIME (%)          10.5      40.5      11.6       62.6           11.7        3.6      22.1       37.4

                        ------------------------ MEASURES OF EFFECTIVENESS ------------------------

     MOVEMENTS (PASSER)      1         2         3         4         5         6         7         8


      X-RATIO                0.65      0.82      0.17      0.17      0.29      0.24      0.79      0.78

      LEVEL OF SERVICE       B         D         A         A         A         A         C         C


      DELAY (SECS/VEH)       54.9      18.8      41.3      11.5      39.1      33.5      66.5      38.4

      LEVEL OF SERVICE       E         B         D         A         D         C         E         C


      PROBABILITY OF
      CLEARING QUEUE         0.76      0.95      1.00      1.00      1.00      1.00      0.54      0.91

      LEVEL OF SERVICE       C         B         B         B         B         B         D         B


      STOPS (STOPS/HR)       63.       1261.     18.       168.      45.       176.      90.       749.


           TOTAL INTERSECTION DELAY               MINIMUM DELAY CYCLE
                 25.8 SECS/VEH                          84 SECS
```

Figure 28

```
                                  TEXAS DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION
PASSER2                                  MULTIPHASE ARTERIAL PROGRESSION - 145101                                 VER 1.0 JAN 84
                                                      PASSER II-84


                  BEST SOLUTION CONTINUED   *** PASSER PHASE DESIGNATIONS ***

************************************************************************************************************************

   **** INTERSECTION  4  50.3 SECONDS OFFSET   ARTERIAL PHASE SEQUENCE IS LAGGING GREEN
    SOUTHWEST            52.9 % OFFSET     CROSS STREET PHASE SEQUENCE IS LEFT TURNS FIRST

                                    ARTERIAL                                       CROSS STREET

        MOVEMENTS                 2+3       2+4       1+4   TOTAL MAJOR ST      5+7        5+8        6+8   TOTAL MINOR ST

        GREEN TIME (SECS)        10.0      36.4      10.0        56.4          10.0        5.0      23.6        38.6
        GREEN TIME (%)           10.5      38.3      10.5        59.4          10.5        5.3      24.8        40.6

                              ----------------------- MEASURES OF EFFECTIVENESS -----------------------

        MOVEMENTS (PASSER)        1         2         3         4         5         6         7         8


         X-RATIO                0.24      0.89      0.13      0.30      0.39      0.38      0.78      0.88

         LEVEL OF SERVICE         A         E         A         A         A         A         C         E


         DELAY (SECS/VEH)       42.6      30.6      42.1      16.4      39.8      32.9      69.6      50.4

         LEVEL OF SERVICE         D         C         D         B         D         C         E         D


         PROBABILITY OF
         CLEARING QUEUE         1.00      0.71      1.00      1.00      1.00      1.00      0.52      0.52

         LEVEL OF SERVICE         B         D         B         B         B         B         D         D


         STOPS (STOPS/HR)        23.     1158.       12.      263.       65.      108.       76.      349.


                  TOTAL INTERSECTION DELAY                MINIMUM DELAY CYCLE
                        32.9 SECS/VEH                           94 SECS
```

Figure 29

```
                             TEXAS DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION
PASSER2                            MULTIPHASE ARTERIAL PROGRESSION - 145101                          VER 1.0 JAN 84
                                               PASSER II-84


          *** PASSER II-84 BEST SOLUTION SUMMARY -  TOTAL ARTERIAL SYSTEM PERFORMANCE ***

          SKILLMAN AVE   DALLAS  FULL SPACING       DISTRICT 16      6/22/83     RUN NO.   1

    CYCLE LENGTH =  95 SECS      BAND A =  33 SECS   BAND B =  38 SECS     0.38 EFFICIENCY  1.00 ATTAINABILITY
    AVERAGE PROGRESSION SPEED -  BAND A =  32 MPH    BAND B =  36 MPH

**********************************************************************************************************************


  AVERAGE INTERSECTION DELAY     TOTAL SYSTEM DELAY     TOTAL NUMBER VEHICLES     MAXIMIN CYCLE
        27.4 SECS/VEH              96.9 VEH-HR/HR             12717.                  94 SECS


 TOTAL SYSTEM FUEL CONSUMPTION   TOTAL SYSTEM STOPS
       344.48 GAL/HR                 8657. STOPS


          EFFICIENCY VERSUS CYCLE LENGTH

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

           CYCLE LENGTH     EFFICIENCY
           ------------     ----------

                 85             0.33
                 90             0.37
                 95             0.38
    BEST SOLUTION      95             0.38
```

Figure 30

PASSER2

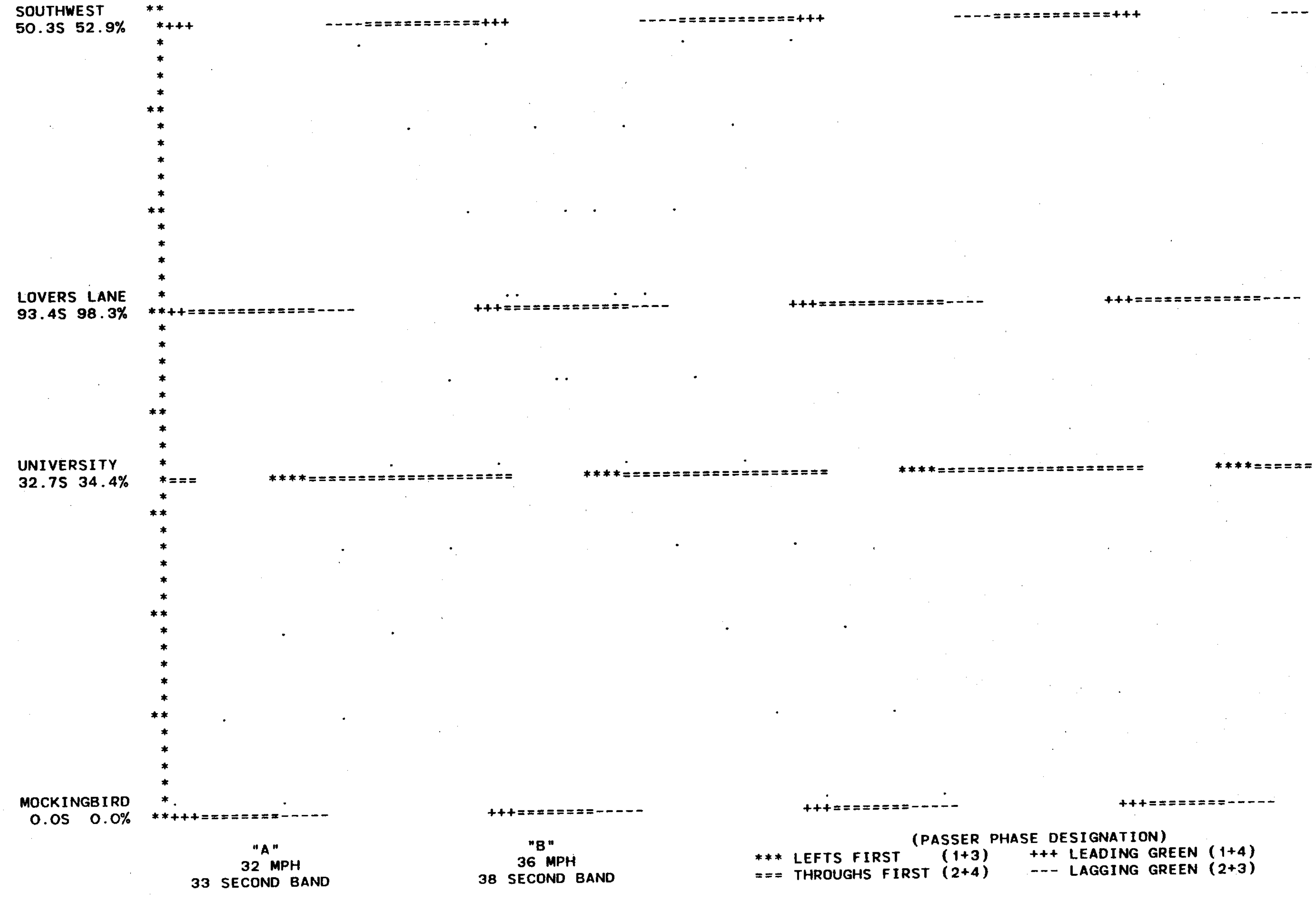
TEXAS DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION
MULTIPHASE ARTERIAL PROGRESSION - 145101
PASSER II-84

VER 1.0 JAN 84

SKILLMAN AVE DISTRICT 16 RUN NO. 1
DALLAS FULL SPACING 6/22/83

CYCLE LENGTH = 95 SECONDS

HORIZONTAL SCALE 1 INCH = 30 SECONDS
VERTICAL SCALE 1 INCH = 1000 FEET



(PASSER PHASE DESIGNATION)
*** LEFTS FIRST (1+3)
=== THROUGHS FIRST (2+4)
+++ LEADING GREEN (1+4)
--- LAGGING GREEN (2+3)

Figure 31

SUMMARY

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

To better improve the popularly used PASSER II computer program, the State Department of Highways and Public Transportation sponsored a research project entitled "Reduced-Delay Optimization and Other Enhancements to PASSER II-80". The purpose of the study was to find an efficient and usable delay-based search algorithm for practicing traffic engineers in selecting a minimum-delay, arterial signal timing plan that optimizes the phasing sequence, cycle length, and offsets based on maxmum bandwidth solution as the starting point. This study developed the fundamental procedures of fine-tuning offset to minimize the delay measurement and preserve the convenience of bandwidth maximizing computation in multiphase traffic signal timing optimization.

A new version of the popularly used PASSER II program, **PASSER II-84**, dealing with the design and operation of signalized intersections, was programmed on the SDHPT's computer system, and the program documentation and revised data coding instructions were also prepared. A comparison of the basic features of the existing PASSER II-80, enhanced PASSER II-84, TRANSYT-7F, and MAXBAND computer models is provided in Appendix G.

This report provides the documentation of research conducted and newly enhanced material for inclusion in a revised user's manual in the development of **PASSER II-84**. No modifications to the existing user's manual or data coding efforts are required to use this enhanced version of PASSER II. The basic program is currently operational on the Texas SDHPT district remote computer terminals.

CONCLUSIONS AND RECOMMENDATIONS

Traffic signal optimization is a very complicated process that determines the proper settings of cycle length, green time interval, phase sequence, and offsets between the signals. The optimization resulting from this calculation depends heavily on the relative relationships among the distances between signalized intersections, speed of traffic, cycle length, roadway capacity, and side friction along the arterial.

The global optimization is impractical, time-consuming and difficult to achieve without thoroughly understanding the interactions and sensitivities of the site-dependant variables. An alternative solution is to select proper independent variables, define relationships among them, and then solve the rest of the optimization problem heuristically.

The maximum bandwidth solution, based on the calculation of a time-space diagram is the most efficient way to provide optimal signal phasing sequence. This solution is less affected by the travel demand fluctuation than solutions of minimum delay. Substantial improvement of the total arterial system operations could be achieved by combining the apparent advantages of maximum bandwidth and minimum delay. The enhanced reduced-delay optimization provided in PASSER II-84 guarantees minimizing total arterial system delay within the slack time allowance of the original PASSER II solution. However, the general improvement that can be achieved by PASSER II-84 relies mainly on the quality of the original answer. If the green times were intentionally constrained, or the engineer was an expert, then the improvements would not be as significant as they would be for ordinary PASSER II solutions.

It was also found in several other related studies that tradeoffs of progression bandwidth in either arterial travel direction may further improve the total system performance, rather than just depending on the total directional traffic volume ratios and minimum green time constraints. Since the enhanced PASSER II-84 program does not have a microscopic simulation model to predict actual vehicular platoon dispersion effects on the downstream signals, the accuracy and estimation ability of the "Platoon Projection Model" or the "Platoon Interconnection Effect" is constrained by considering the site-dependent travel behaviors with different vehicular mixes and travel speeds.

Therefore, further research is recommended on: the calibration of platoon dispersion models, field validation of the reduced-delay offset-optimization algorithm, alternative strategies in allocating the directional bandwidths, revision of green split routine to account for the impact of green time adjustment on overall system delay, and the tradeoffs of local and system optimization problems in arterial signal optimization.

ACKNOWLEDGMENTS

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APPENDICES

APPENDIX A

FIXED-TIME SIGNAL TIMING CALCULATION PROCEDURE

1. Develop Expanded Turning Movement Volumes
    Step 1. Determine Peak Hourly Volume From Traffic Count
    Step 2. Adjust For Number of Trucks
    Step 3. Adjust for Future Growth

2. Select Vehicle Yellow Signal Interval
    - Based on Approach Speeds.
      May be Extended By An ALL-RED Interval
      PASSER uses a default value of 4 seconds

3. Determine Pedestrian Walk Time (PED.WALK)
    a.) High With Pedestrian Signal
    b.) Relatively High Without Pedestrian Signal
    c.) Occasional Pedestrian

4. Determine Pedestrian Clearance Time (PED.CLEAR)
    - Based on Pedestrian Walking Speed.
    a.) Near-Side Curb to Half-Farthest Lane
    b.) Near-Side Curb to Curb for Refuge Island
    Consider School Children and Senior Citizens.

5. Compute Minimum Pedestrian Interval = PED WALK + PED CLEAR
    (3) + (4)
    a.) Minimum Through Street Phase Length
    b.) Minimum Left-Turn Phase Length

6. Determine Minimum Green Time for Movements
    (Include Yellow and ALL-RED in PASSER II).
    Check Minimums of a.) Through Movements
    b.) Left-Turn Movements

7. Calculate Sum of Critical Lane Volumes
    - Combined Eight Separate Movements In Different Ways.
      One Sum With a Particular Phasing Sequence Will Yield the Largest (Critical) Lane Volume.

8. Determine Minimum Delay Cycle Lengths
    - From Figure A-1 in this Appendix and Appendix B.

9. Select Trial Green Times
    Both Desirable and Minimum Limits Must Never Be Less Than Sum of Minimum Conflicting Greens.

10. Calculate Trial Green Times

For Street A and Street B, (G_A or G_B)

$$G_A = (V_A / V) * (C - N_{A+B} * L) + (N_A * L)$$

For Phase Movements No. 1 on Street A or Street B, (G_1)

$$G_1 = \frac{V_1}{V_1 + V_2} * (G_A - N_A * L) + L$$

Check Minimums.

where

G_A = green time on Street A, sec

V_A = critical lane volume on Street A, vphpl

V = total critical volume on streets A & B, vphpl

C = trial cycle length, sec

N_A = no. of phases on Street A.

N_{A+B} = total No. of phases on Streets A & B.

L = lost time per phase 4 sec

V_1 = total critical volume for phase movement No. 1 on street A or Street B, vphpl

V_2 = total critical volume for phase movement No. 2 on street A or street B, vphpl

11. Adjust green splits to minimize local intersection delay using one-dimensional gradient search technique.

12. Calculate Measures of Effectiveness (MOE's).

    a.) Saturation Flow Ratio (X-Ratio),*
    b.) Delay (sec/veh),*
    c.) Probability of Queue - Clearance (%).*

* **Note** - Refer to Level-of-Service (L.O.S.) Criteria as shown on Table A-1.
** **Source** - TTI Report 203-1.

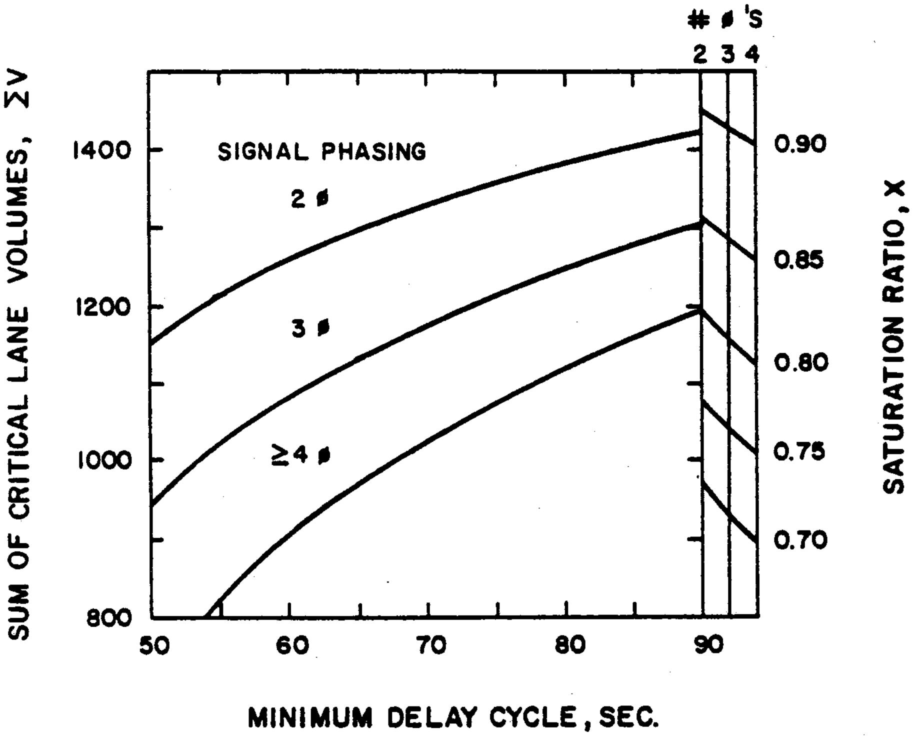


Figure A-1. Relationships Between Design Variable and Operational Measures of Effectiveness.

Table A-1. Level of Service Criteria for Signalized Intersections.

LEVEL OF SERVICE	TRAFFIC FLOW DESCRIPTION	TOTAL INTERSECTION DELAY*	INDIVIDUAL MOVEMENT DELAY*	SATURATION RATIO X	% OF QUEUE CLEARANCE PCQ
A	FREE FLOW	≤ 16	≤ 13	≤ 0.6	≥1.00
B	STABLE FLOW	≤ 22	≤ 26	≤ 0.7	≥0.90
C	STABLE FLOW	≤ 28	≤ 39	≤ 0.8	≥ 0.75
D	UNSTABLE FLOW	≤ 35	≤ 52	≤ 0.85	≥ 0.50
E	UNSTABLE FLOW	≤ 40	≤ 78	≤ 1.0	< 0.50
F	OVER CAPACITY	≥ 40	≥ 78	≤ 1.0	< 0.50

* Total Delay = 1.3 * Stop Delay as defined in the NCHRP Study.

SOURCE:
1. NCHRP Circular 212;
2. "NCHRP Signalized Intersection Capacity Method", JHK & Associate, May 1982.

APPENDIX B

WEBSTER'S METHOD FOR CALCULATING FIXED-TIME CYCLE LENGTHS AND SPLITS

PASSER II-84 uses the modified Webster method to calculate the cycle length and individual phase splits for fixed-time signals. The method could be summarized as follows:

To calculate cycle lengths (CYCLE)

$$\mathrm{Yi} = [(\mathrm{Ni}\ \mathrm{X}\ \mathrm{EFFi})\ /\ \mathrm{TIME}]\ \mathrm{X}\ \mathrm{SAT}$$

$$\mathrm{Y} = \sum_{i=1}^{N} \mathrm{Yi} \qquad \mathrm{N = NUMBER\ OF\ PHASES}$$

$$\mathrm{CYCLE} = [(1.5\ \mathrm{X}\ \mathrm{TLOST}) + 5\,]\ /\ (1\text{-}\mathrm{Y})$$

To calculate splits (Gi)

$$\mathrm{Gi} = [(\mathrm{Yi}/\mathrm{Y})\ \mathrm{X}\ (\mathrm{CYCLE}\text{-}\mathrm{LOST})] + \mathrm{ALi}$$

The variables are:

Y_i = The ratio between the actual volume and the saturation volume for the highest volume approach of a phase or the critical lane volume for movement "i".

N_i = Number of vehicles, for the highest volume approach "i" counted during the time interval "TIME" (Veh/lane). However, if the volume in one lane for an approach during the phase green for that approach is expected to be considerably higher than the other lane volumes for that phase under the new traffic signal operation, then use the number of vehicles for this critical lane.

EFFi = Effective or equivalent straight through passenger car factor for each phase "i" (takes into account the time needed for trucks and turning movements). Suggest values of 1.07 for protected phase movements and 1.12 for unprotected phase movements unless data from the intersection is available.

TIME = Time interval over which vehicle counts were made (in seconds).

ALi = Lost time per phase = STARTING DELAY TIME + ALL-RED INTERVAL + AMBER Taken as lost time

Starting delay time - (Value of 4.0 seconds recommended)
Amber taken as lost time - (Value of zero seconds recommended)

TLOST = Total lost time per cycle = $\sum_{i=1}^{N} AL_i$ N = Number of phases

Example: TLOST for 3 phases = $AL_1 + AL_2 + AL_3$

APPENDIX C

PASSER II-84 PROGRAM FLOWCHARTS

This section contains the flowcharts of all the components in PASSER II-84 which includes the total functional flowchart, the detailed functional flowchart of the main program, and the detailed flowcharts of individual subroutines.

The following materials contain:

C-1. **Total Functional Flowchart --**

It illustrates the major steps of PASSER II and the relations between the main program and all the subroutines.

(Figure C-1-1)

C-2. **Detail Functional Flowchart --**

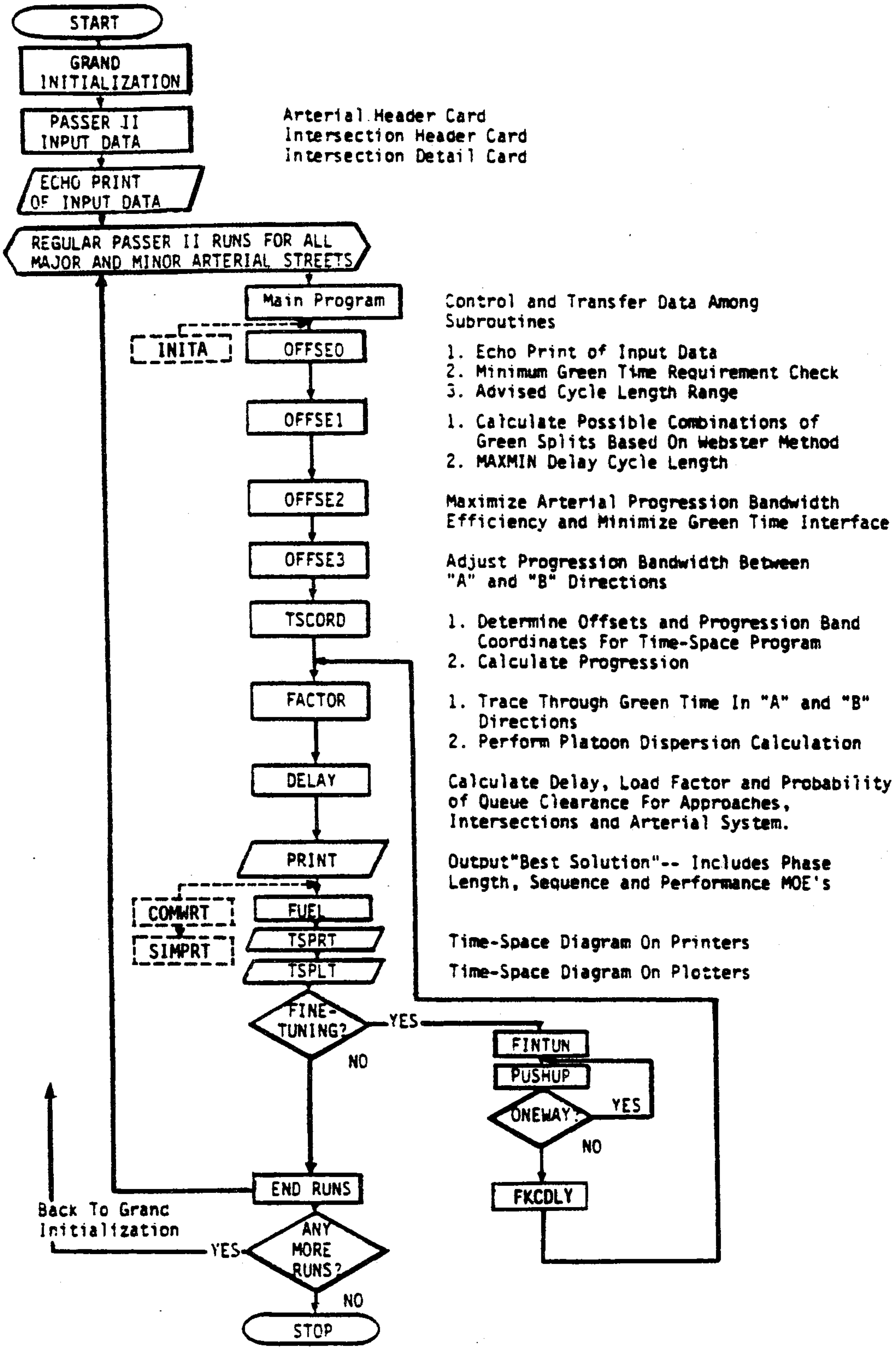
This section is a detailed version of the Total Functional Flowchart of the PASSER II-84 main program. It illustrates the major steps of program execution in each subroutine and the relation of every subprogram to the main program.

(Figures C-2-1 to C-2-3)

C-3. **Subroutine Flowchart--**

Each flowchart in this section illustrates the detailed program execution steps in every subprogram.

(Figures C-3-1 to C-3-18)



Arterial Header Card
Intersection Header Card
Intersection Detail Card

Control and Transfer Data Among Subroutines

1. Echo Print of Input Data
2. Minimum Green Time Requirement Check
3. Advised Cycle Length Range

1. Calculate Possible Combinations of Green Splits Based On Webster Method
2. MAXMIN Delay Cycle Length

Maximize Arterial Progression Bandwidth Efficiency and Minimize Green Time Interface

Adjust Progression Bandwidth Between "A" and "B" Directions

1. Determine Offsets and Progression Band Coordinates For Time-Space Program
2. Calculate Progression

1. Trace Through Green Time In "A" and "B" Directions
2. Perform Platoon Dispersion Calculation

Calculate Delay, Load Factor and Probability of Queue Clearance For Approaches, Intersections and Arterial System.

Output "Best Solution"-- Includes Phase Length, Sequence and Performance MOE's

Time-Space Diagram On Printers

Time-Space Diagram On Plotters

Figure C-1-1. PASSER II-84 Functional Flowchart.

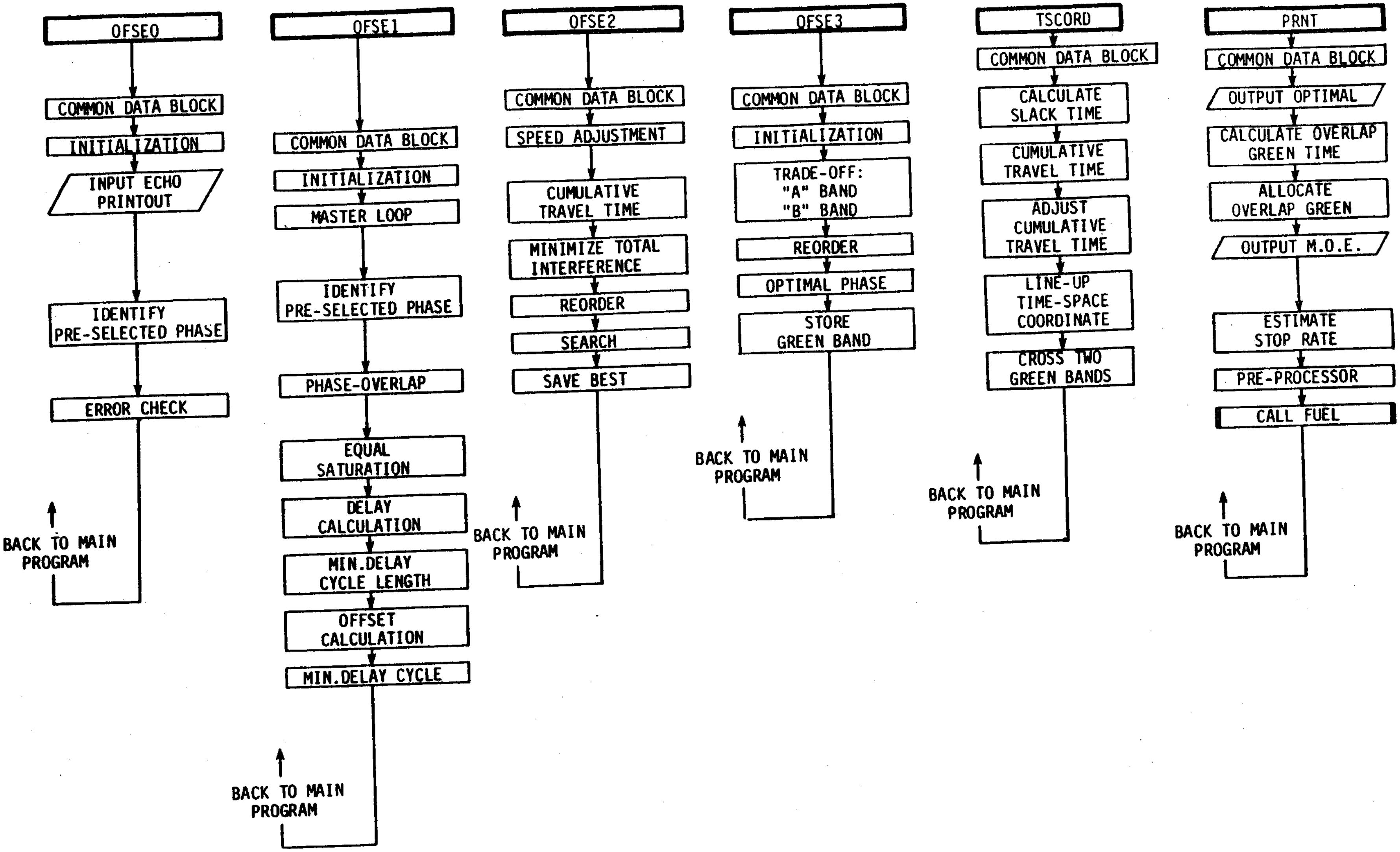


Figure C-2-1. Detailed Functional Flowchart.

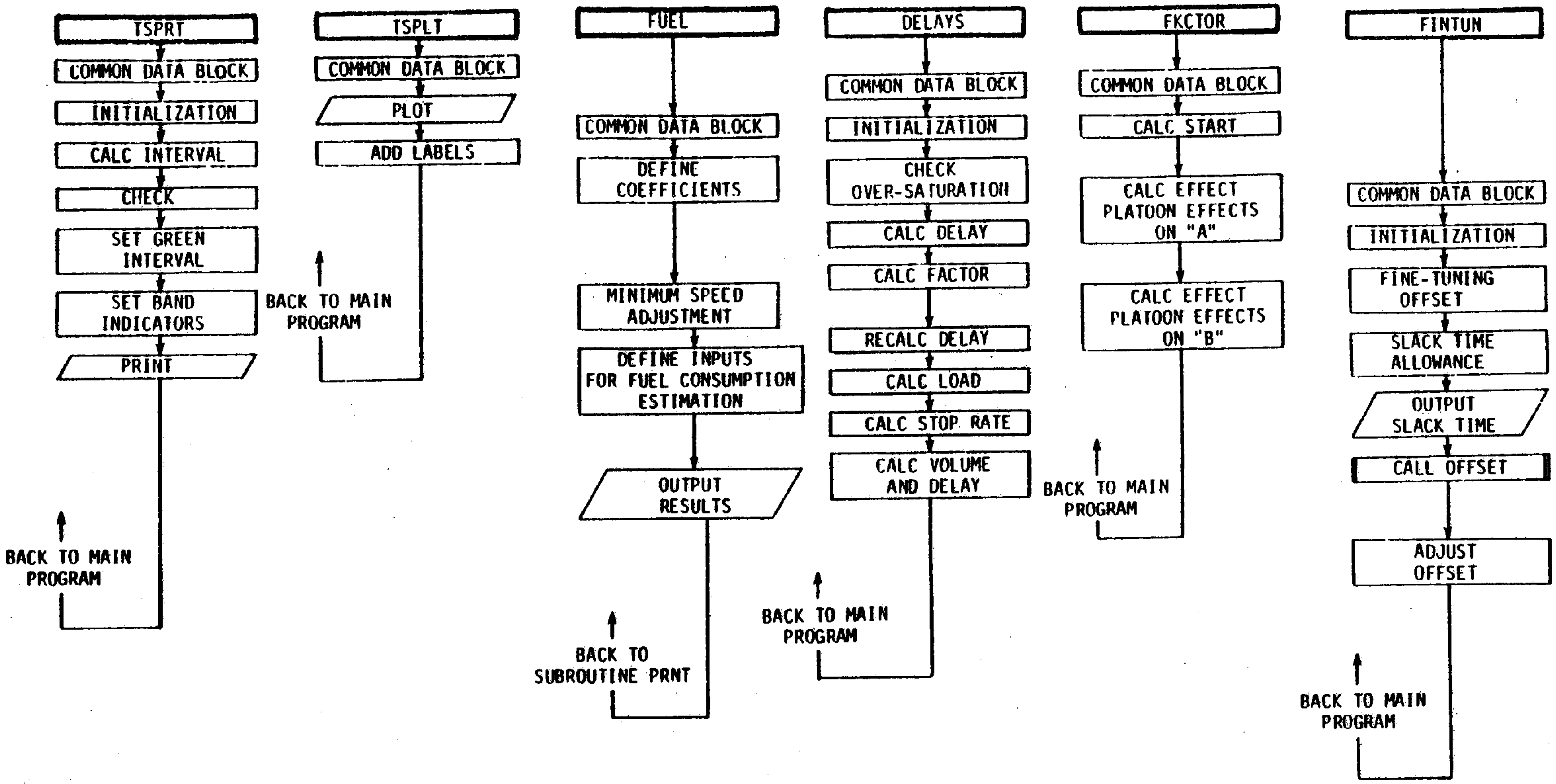


Figure C-2-2. Detailed Functional Flowchart.

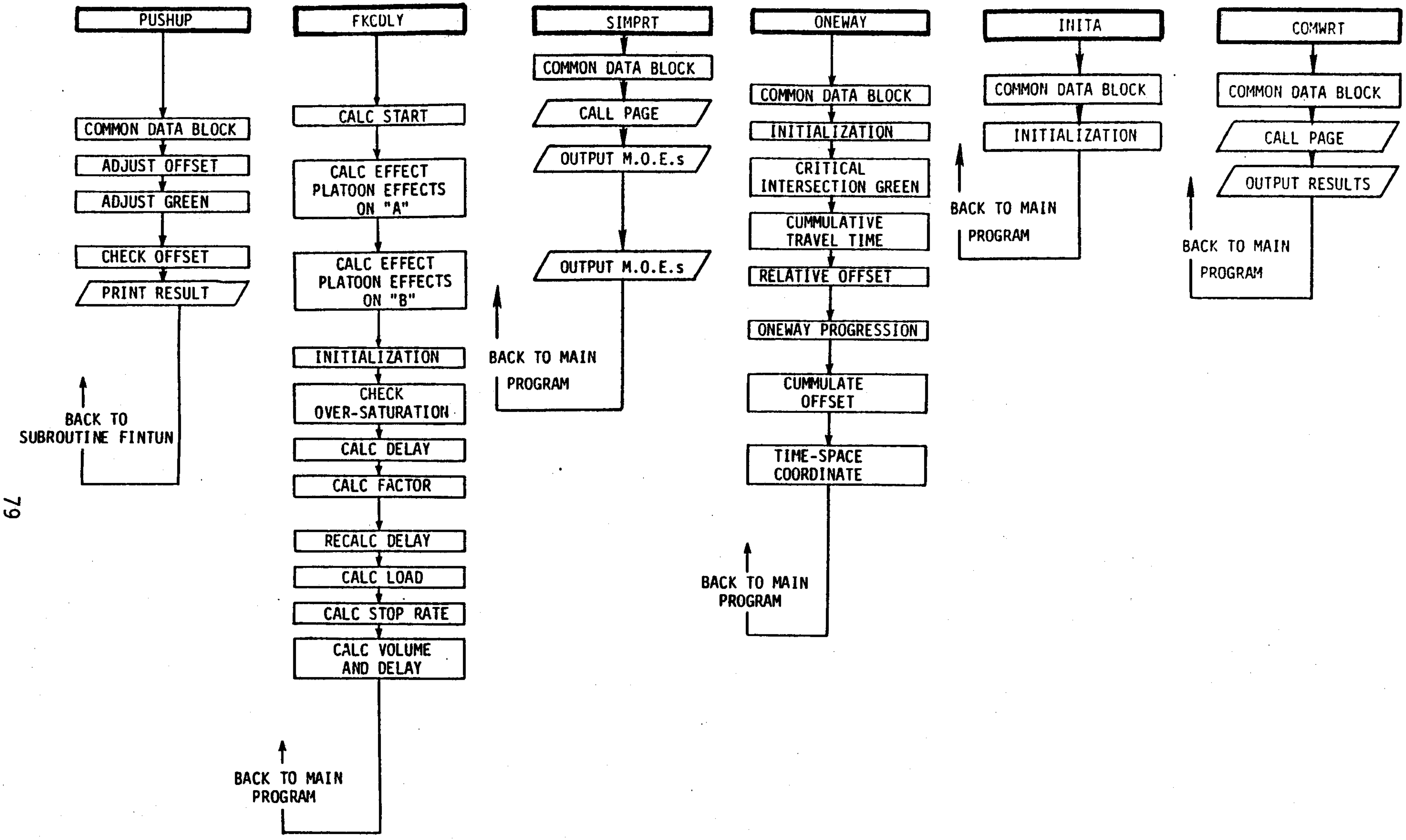
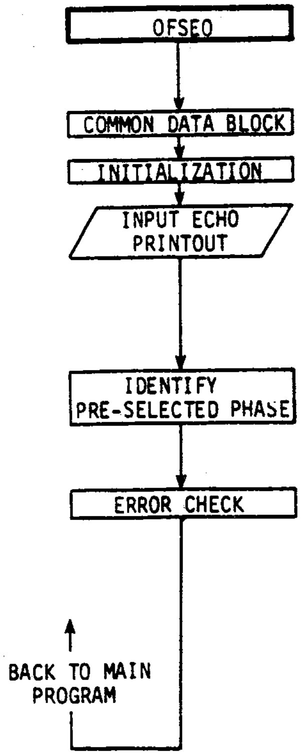


Figure C-2-3. Detailed Functional Flowchart.



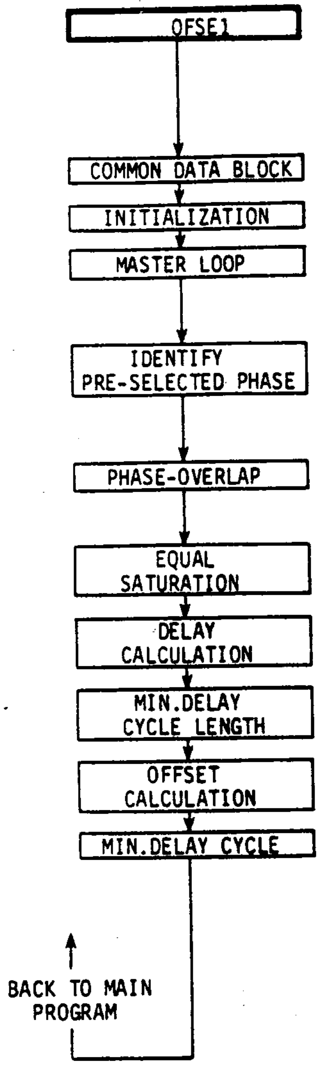
Read The Input Data and Make Preliminary Calculations
Also Called Real Time Data Subroutines
or Subroutine Data

-Input Data Echo Printout
1. Intersection Name
2. Distance, Speed In "A" and "B" Directions
3. Queue Clearance
4. Pre-Selected Phase Sequence
5. Movement Volume, Sat.Flow.Rate, Minimum Green

-Identify Input Phase-Movement Under
PASSER II and NEMA Movement Definitions
-Print Error Message For No Sat.Flow.Rate

-Min. Green Requirements Versus Critical Movements
-Min. Green For Left Turns and St. Through First
-Min. Green For Lead and Lag Greens

Figure C-3-1. Subroutine OFSEO.



Use Mod.Webster Method To Calculate Green Split and
Maxmin Delay Cycle Length
Also Called Green Times and Progression Input Data
Subroutine
or Subroutine Green

-Calculate Green Splits For All Intersections In Progression System
-Initialize Delay Based Optimizer and Split Optimizer

-Identify Pre-Selected Sequence
-Find Main Street Phase
-Find Cross Street Phase
-Find Movement Phase Sequence Numbers

-Check Phase Overlapping-1. Two Phases Without Overlapping
2. One Phase Without Overlapping
3. Other Phase Calculation

-Webster-Messer Green Split Routine

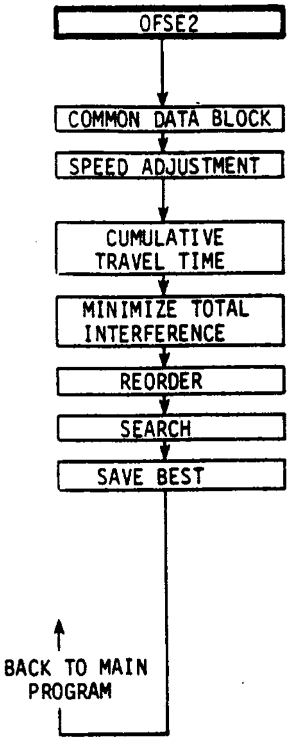
-Begin Delay Accumulation Using Webster's Mod.(90%) Equ.
-Start Local Minimum Delay Search

-Calculate Minimum Advisable Cycle Length Against Sum of Min.Green

-Begin Computation For Relative Progression Offset Calculation

-Store Minimum Advisable Cycle Length

Figure C-3-2. Subroutine OFSE1.



Maximize Bandwidth With Brook's Algorithm
Also Called Progression Shift and Offset Subroutine
or Subroutine Progression

-Adjust Progression Speed
-Calculate Min. Progression Greens In "A" and "B" Directions

-Calculate Cumulative Travel Time W.R.T. "A" and "B" Directions

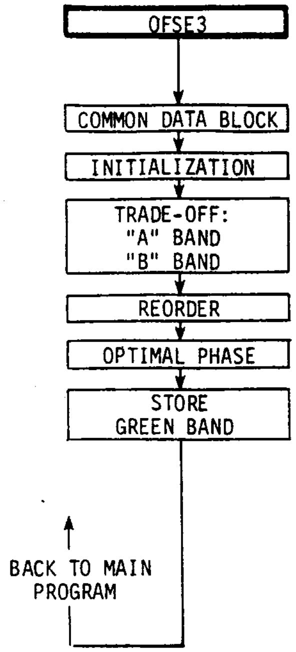
-Calculate Left and Right Interference For Each Intersection and Find Best For Each Side

-Reorder Left and Right Interference By Intersections

-Search For Minimum Total Interference

-Find The Best Combination Of Cycle Length and Progression Band Solution
-Save The Best Interference Solution

Figure C-3-3. Subroutine OFSE2.



Adjust The Band Between "A" and "B" Direction
Also Called Optimal Progression Subroutine
or Subroutine Bands

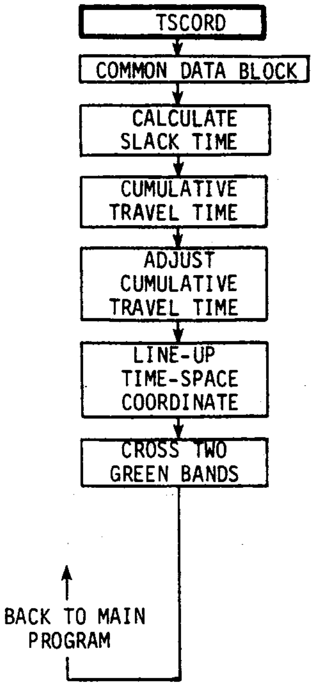
-Subtract Out "A" Band and Add To "B" Band By Adjusting "B" Interference
-Calculate Minimum and Maximum of "A" and "B" Bands

-Reorder MMLT and MMHT According To Intersections

-Store Optimal Phase Sequence

-Store and Save Green Bands In "A" and "B" Directions
-Calculate Progression Speed

Figure C-3-4. Subroutine OFSE3.



Calculates Coordinates For Time-Space Diagram

-Calculate The Difference Between Actual Green and Green Band

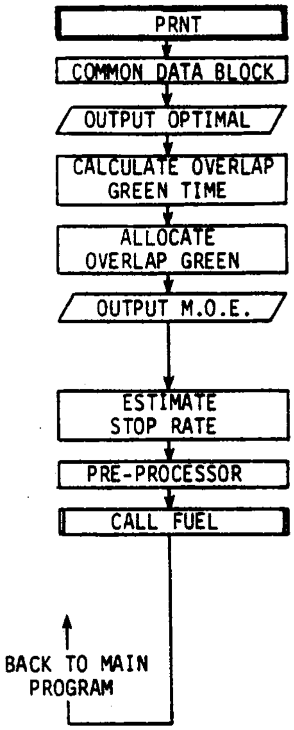
-Calculate The Cumulative Travel Time For Progression Band In "A" and "B" Directions

-Adjust Actual Travel Time For Lag Time Due To Signal Phase Sequence and Queue Clearance

-Adjust The Offset Of The First Signal To Zero

-Cross Two Green Bands To Save Space For Time-Space Diagram
-Adjust Offsets W.R.T. Cycle Length

Figure C-3-5. Subroutine TSCORD.



Print The "Best Solution" Of PASSER II-84

-Output Optimal Progression Solution

-Identify Optimal Phase Sequence, Phase Intervals, and Overlapped Green Time For Arterial and Cross Street

-Add Overlapped Green To Arterial Street Green

-Output Measures Of Effectiveness(M.O.E.'s) and Levels Of Service(L.O.S.'s) For Each Movement, Intersection, and Total Arterial System

-Calculate Estimate Stop Rate By Mod. AKCELIK(ARRB) Equ.

-Pre-Processor For Fuel Consumption Calculation

Figure C-3-6. Subroutine PRNT.

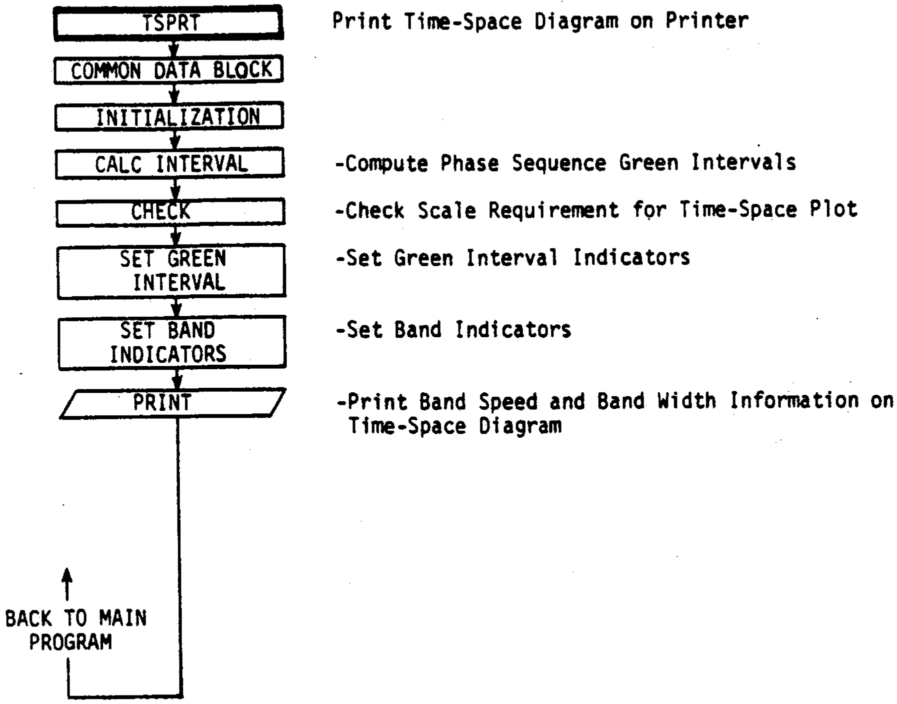
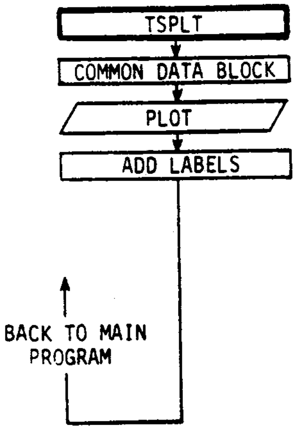


Figure C-3-7. Subroutine TSPRT.

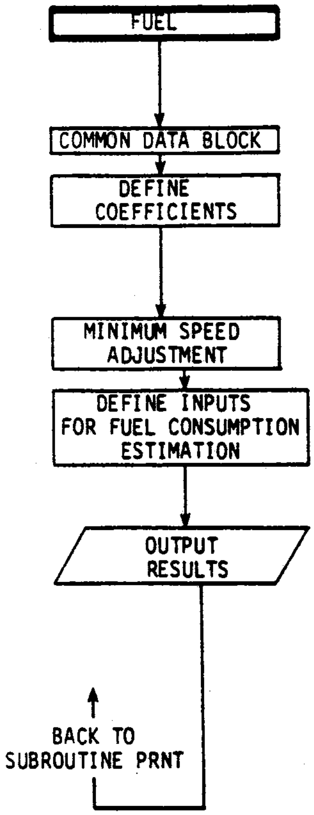


Print Time-Space Diagram on CALCOMP Plotter

-Plot Greens, Left Turn Greens, "A" Band, "B" Band

-Add Band Speed and Band Width Information on the Time-Space Diagram

Figure C-3-8. Subroutine TSPLT.



Estimate The Value Of Consumption Based Upon Step-Wise Multi-Regression Analysis From The Model Developed For TRANSYT-7F By TRC At University Of Florida.
This Model Has Been Modified For PASSER II-84

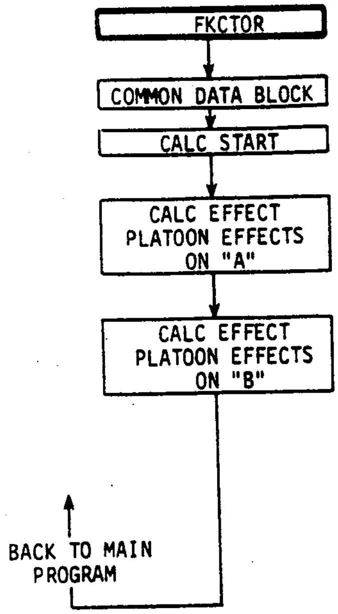
-Define Fuel Consumption Coefficients
1. The Speed In Miles Per Hour
2. Gallons Per Vehicle-Mile
3. Gallons Per Vehicle-Hour
4. Gallons Per Vehicle-Stop

-If Speed Is Too Slow, Assume Approach Speed = 20 mph For Calculating Fuel Consumption Due To Delays and Stops

-Accept Fuel Consumption Estimation Variables For PASSER
F = Fuel Consumed In Gallons Per Hour
S = Number Of Vehicle Stops Per Hour
D = Delay In Vehicle-Hours Per Hour
TT = Total Distance Traveled in Veh-Miles Per Hour

-Printout Fuel Consumption Calculation

Figure C-3-9. Subroutine FUEL.



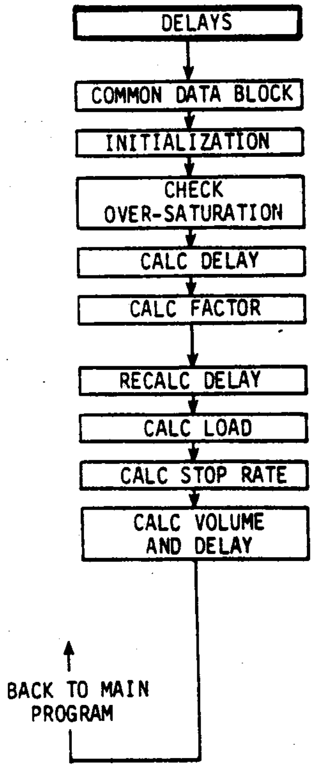
Calculate The Effect Of Progression When The Platoon Disperses Between Intersections

-Calculate Start Of Through Green In "A" and "B" Progression Bands

-Calculate Platoon Dispersion Effects On "A" Progression Direction; Calculate Variance In Arrival Time, Platoon Size, Platoon Projections, and Through Green Limits

-Calculate Platoon Dispersion Effects On "B" Progression Direction. Calculate Variance In Arrival Time, Platoon Size, Platoon Projections, and Through Green Limits At Downstream

Figure C-3-11. Subroutine FKCTOR.



Calculate Delays For Movement, Intersection, and Total Arterial System

-Initialization For Delay and Stop Calculation

-If Maximum Sat.Flow.Ratio Is Greater Than 0.95, Assume Level Of Service "F"

-Calculate Delay Per Movement Using Mod.Webster Delay Equ.

-Calculate Progression Factor For Increased Arrivals During Green Time

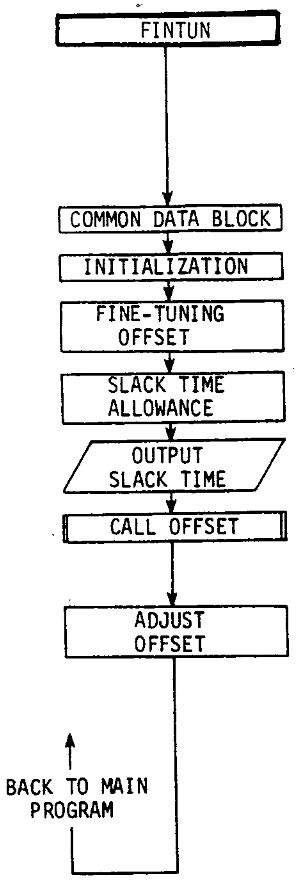
-Calculate Delay Using Mod. NCHRP Delay Equ.

-Calculate Load Factor and Prob. Of Clearing Queue

-Calculate Estimate Stop Rate By Mod.AKCELIK(ARRB) Equ.

-Calculate Volume and Delay For Each Movement, Intersection, and Total Arterial System

Figure C-3-10. Subroutine DELAYS.



Use The New Offset Finetuning Algorithm To Accept Output From TSCORD. Then Do:

1. Find Slack Time In The T-S Plot,
2. Check Thru_Band Vs Actual_Green,
3. Detect Plot_Thru_Red & Correct,
4. Indicate Avail Slack_Time Allowance, and
5. Optimize Offset & Adjust Accordingly.

-Initialize All Variables and Arrays

-Check Offset for Every Intersection and Search for Slack Time Allowance

-Find Acceptable Slack Time Allowance at A & B Dir. for Four Possible Phase Sequences

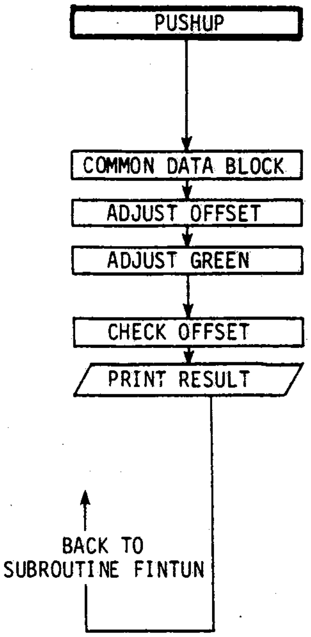
-Printout Available Slack Time Allowance

-Check Offsets and Time-Space Coordinate of Progression Band

-Start Reduced-Delay Offset Analysis

-Adjust Coordinate For the New Time-Space Diagram Recalculate Progression Speed in A & B Dir.

Figure C-3-12. Subroutine FINTUN.



Adjust Offset of the Time-Space Coordinate by Push UP or Push Down the Offset According to Slack Time (Positive-Up or Negative-Down).

To: 1. Correct the Plot_Through_The_Red Condition.
    2. Adjust the T-S Coordinate by the Opt.Offset.

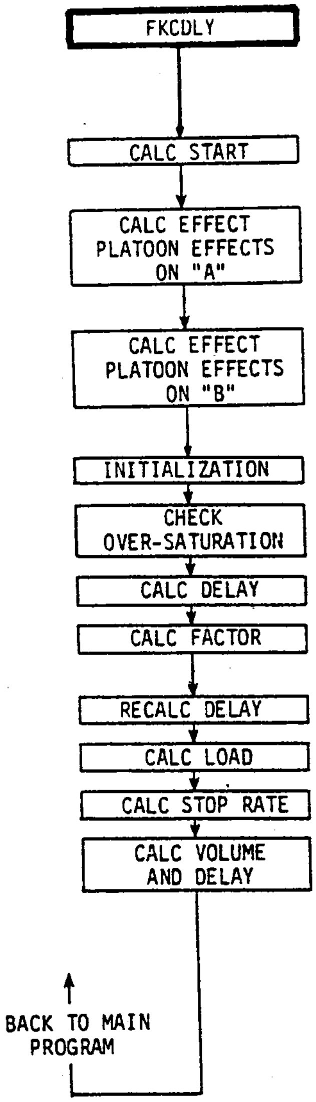
-Adjust Offset by Push Time-Space Coordinates

-Adjust Time-Space Coordinate of Progression Band in A & B Directions According to the Fine-Tuned Offsets.

-Adjust Intersection Offsets by the Cycle Length

-Print out Results of the Fine-Tuned Offsets and Time-Space Coordinates

Figure C-3-13. Subroutine PUSHUP.



Calculate The Effect Of Progression When The Platoon Disperses Between Intersections
Calculate Delays For Movement, Intersection, and Total Arterial System

-Calculate Start Of Through Green In "A" and "B" Progression Bands

-Calculate Platoon Dispersion Effects On "A" Progression Direction; Calculate Variance In Arrival Time, Platoon Size, Platoon Projections, and Through Green Limits

-Calculate Platoon Dispersion Effects On "B" Progression Direction. Calculate Variance In Arrival Time, Platoon Size, Platoon Projections, and Through Green Limits At Downstream

-Initialization For Delay and Stop Calculation

-If Maximum Sat.Flow.Ratio Is Less Than 0.95, Assume Level Of Service "F"

-Calculate Delay Per Movement Using Mod.Webster Delay Equ.

-Calculate Progression Factor For Increased Arrivals During Green Time

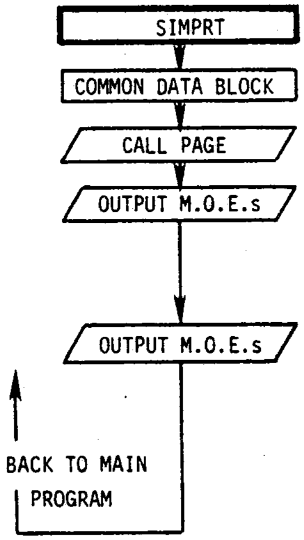
-Calculate Delay Using Mod. NCHRP Delay Equ.

-Calculate Load Factor and Prob. Of Clearing Queue

-Calculate Estimate Stop Rate By Mod.AKCELIK(ARRB) Equ.

-Calculate Volume and Delay For Each Movement, Intersection, and Total Arterial System

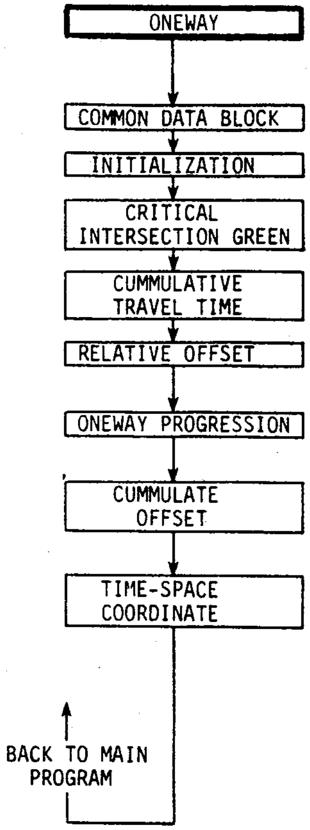
Figure C-3-14. Subroutine FKCDLY.



Print Out Summarized PASSER II-84 Output.

- Print Out PASSER II-84 Headings.
- Output Measures Of Effectiveness (M.O.E.s) for Each Movement and Intersection Including Saturation Flow Ratio, Delay, Percentage of Queue Clearance, and Total Stops.
- Output Measures Of Effectiveness (M.O.E.s) for Total Arterial System.

Figure C-3-15. Subroutine SIMPRT.



Calculate Offsets for Perfect One-way Progression in A & B Direction and Recompute Time-Space Coordinates with the Slack Time Allowance

-Identify Critical Intersection No. and Critical Green Time in A & B Direction

-Calculate Cummulative Travel Time in A & B Direction

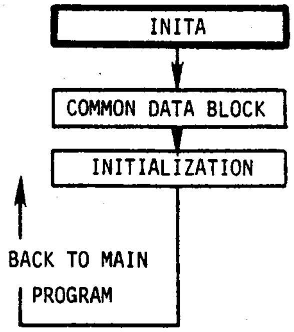
-Calculate Relative Offsets due to Different Signal Phase Sequences in A & B Direction

-Accumulate Travel Time from the Start of the Green Time in A & B Direction

-Calculate Offset for Perfect Oneway Progression
-Find Time Lag Between Progression Band in A & B Direction

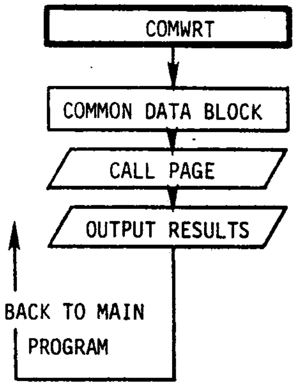
-Calculate Time-Space Coordinate for Perfect Progression Band

Figure C-3-16. Subroutine ONEWAY.



Initialize All Variable Arrays Used In the Common Data Block for Debugging.

Figure C-3-17. Subroutine INITA.



Output Value of All Variable Arrays Used In the Common Data Block for Debugging.

-Print Out PASSER II-84 Headings.

-Print Out All Variable Arrays.

Figure C-3-18. Subroutine COMWRT.

APPENDIX D

PASSER II-84 DATA INPUT CODING INSTRUCTIONS

Data entry for PASSER II-84 can be made on the same Texas SDHPT's PASSER II-80 coding form (Form 1444-1,2) as shown in Figures D-1, D-2, and D-3. The other alternative data entry method can be made on the interactive data entry form using RJEJCL 1.4 System supported by the Texas SDHPT's D-19 and D-18T. The front of the form (Figure D-2) contains the format for the ARTERIAL HEADER CARD, INTERSECTION HEADER CARD, and the INTERSECTION DETAIL CARDS. The back of the form (Figure D-3) contains coding notes.

Data are always entered right-justified as whole numbers without decimal points, fractions, or leading zeros. In all three types of input cards, the data to be entered may require only one- or two-card columns of a data field. If a field is left blank where the program expects a number, the blank is interpreted as a zero (0).

Each set of data for an arterial must begin with an **ARTERIAL HEADER CARD** followed by an **INTERSECTION HEADER CARD** for each intersection and a set of three **INTERSECTION DETAIL CARDS** for each intersection on the arterial. A maximum of 20 intersections may be analyzed in a single PASSER II-84 run.

Note that a "card" is equivalent to a record or a line of data input coding 80 field characters long.

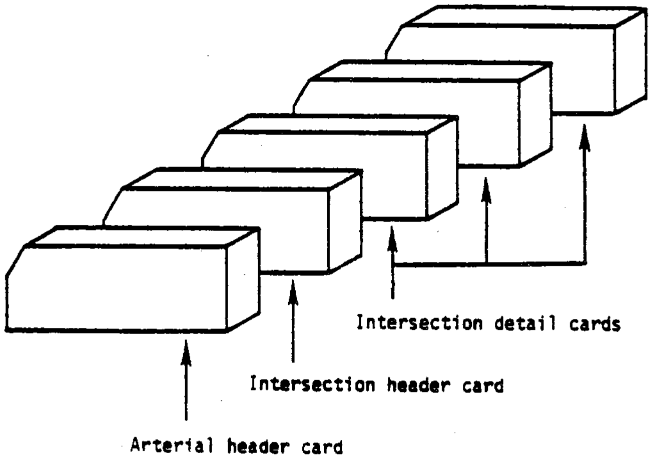
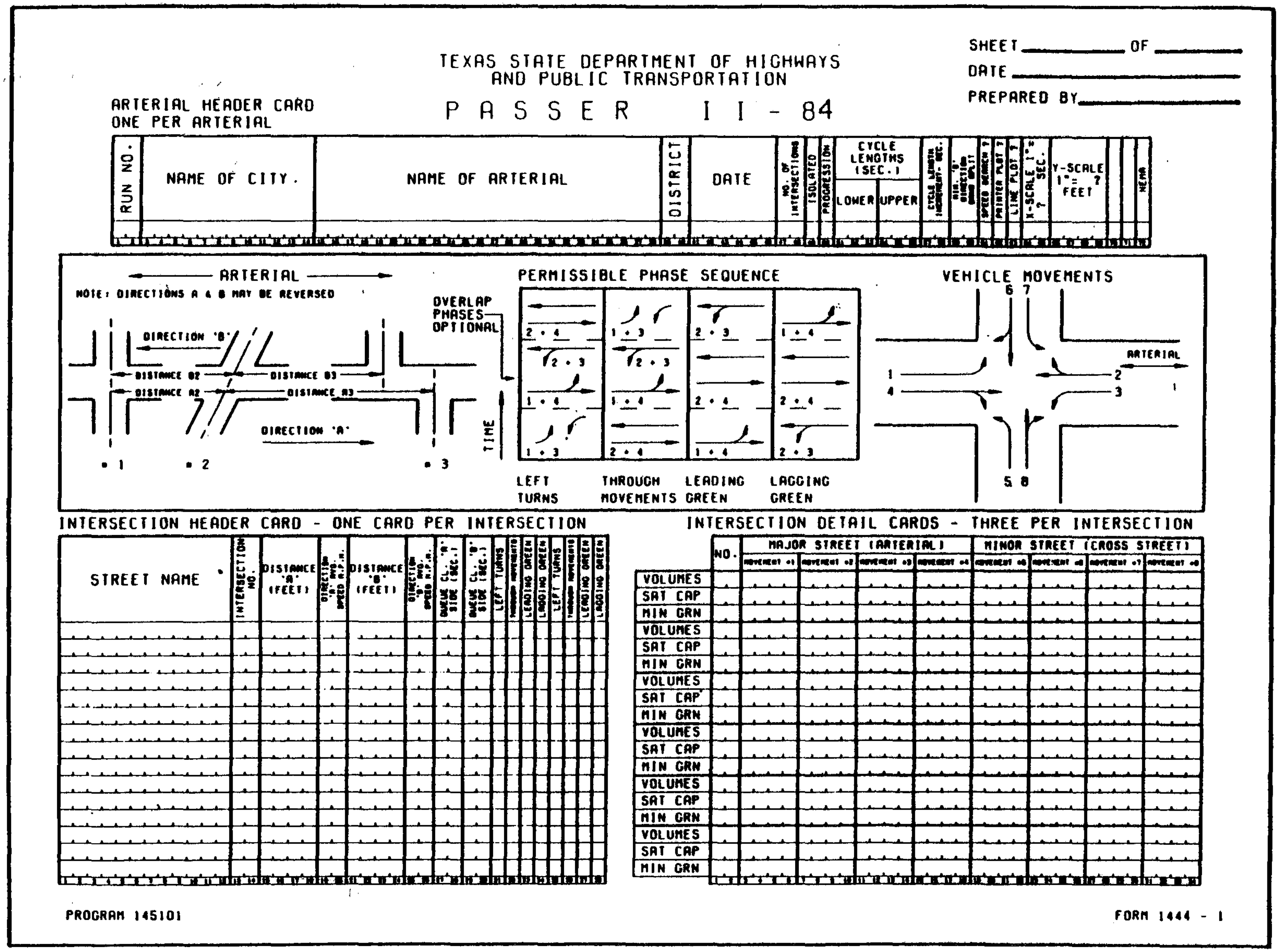


Figure D-1. PASSER II-84 Input Data Deck.



SHEET ________ OF ________
DATE ________
PREPARED BY ________

TEXAS STATE DEPARTMENT OF HIGHWAYS
AND PUBLIC TRANSPORTATION

PASSER II - 84

ARTERIAL HEADER CARD
ONE PER ARTERIAL

RUN NO.	NAME OF CITY.	NAME OF ARTERIAL	DISTRICT	DATE	NO. OF INTERSECTIONS	ISOLATED	PROGRESSION	CYCLE LENGTHS (SEC.) LOWER	CYCLE LENGTHS (SEC.) UPPER	CYCLE LENGTH INCREMENT- SEC.	MIN. 'B' DIRECTION GREEN SPLIT	SPEED SEARCH ?	PRINTER PLOT ?	LINE PLOT ?	X-SCALE 1"= ? SEC.	Y-SCALE 1"= ? FEET			NEMA

INTERSECTION HEADER CARD - ONE CARD PER INTERSECTION

STREET NAME	INTERSECTION NO.	DISTANCE 'A' (FEET)	DIRECTION 'A' AVG. SPEED M.P.H.	DISTANCE 'B' (FEET)	DIRECTION 'B' AVG. SPEED M.P.H.	QUEUE CL. 'A' SIDE (SEC.)	QUEUE CL. 'B' SIDE (SEC.)	LEFT TURNS	THROUGH MOVEMENTS	LEADING GREEN	LAGGING GREEN	LEFT TURNS	THROUGH MOVEMENTS	LEADING GREEN	LAGGING GREEN

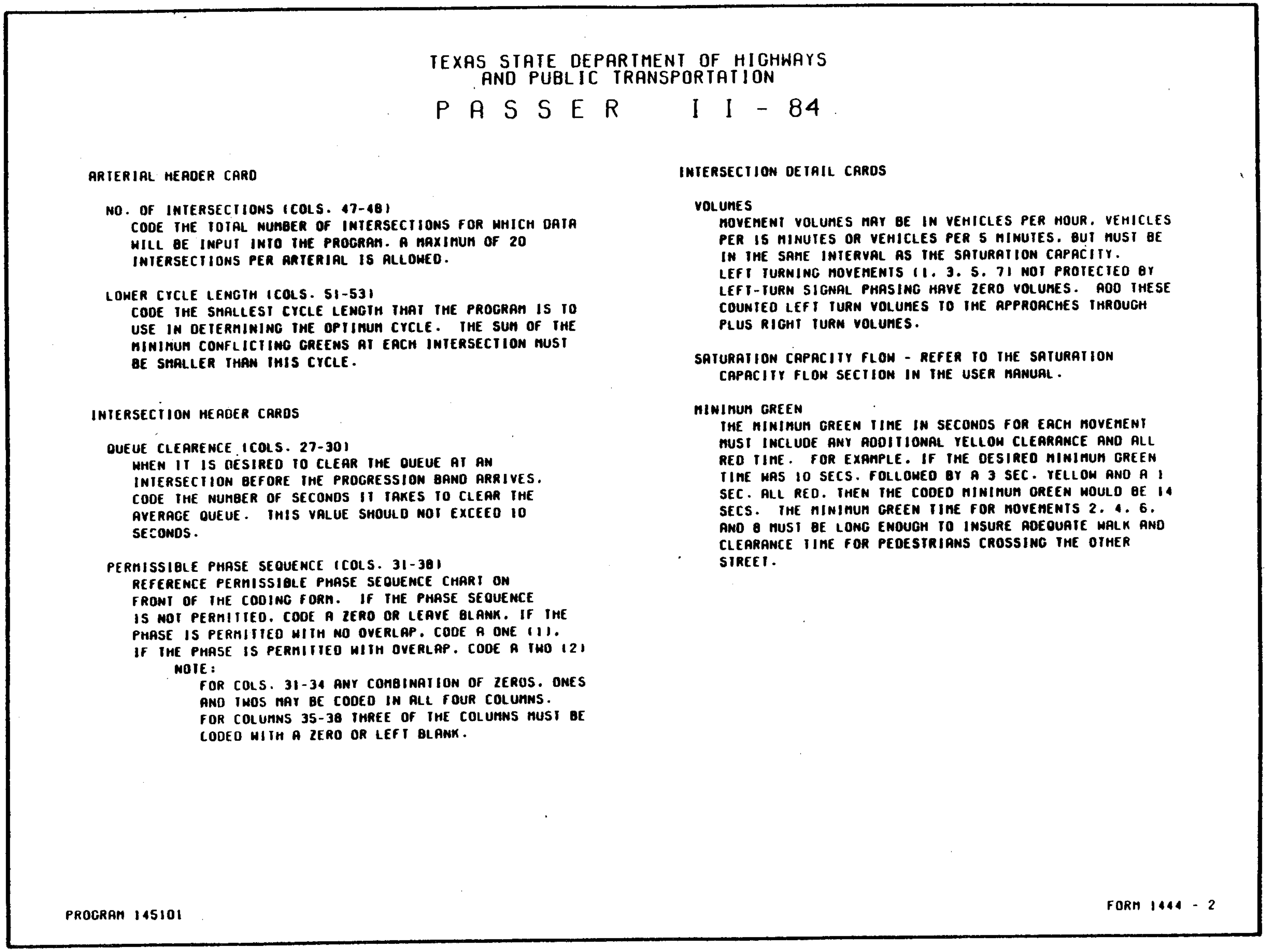
INTERSECTION DETAIL CARDS - THREE PER INTERSECTION

	NO.	MAJOR STREET (ARTERIAL)				MINOR STREET (CROSS STREET)			
		MOVEMENT #1	MOVEMENT #2	MOVEMENT #3	MOVEMENT #4	MOVEMENT #5	MOVEMENT #6	MOVEMENT #7	MOVEMENT #8
VOLUMES									
SAT CAP									
MIN GRN									
VOLUMES									
SAT CAP									
MIN GRN									
VOLUMES									
SAT CAP									
MIN GRN									
VOLUMES									
SAT CAP									
MIN GRN									
VOLUMES									
SAT CAP									
MIN GRN									
VOLUMES									
SAT CAP									
MIN GRN									

PROGRAM 145101

FORM 1444 - 1

Figure D-2. Example of Input Form 1444-1.



TEXAS STATE DEPARTMENT OF HIGHWAYS
AND PUBLIC TRANSPORTATION

P A S S E R I I - 84

ARTERIAL HEADER CARD

NO. OF INTERSECTIONS (COLS. 47-48)
CODE THE TOTAL NUMBER OF INTERSECTIONS FOR WHICH DATA WILL BE INPUT INTO THE PROGRAM. A MAXIMUM OF 20 INTERSECTIONS PER ARTERIAL IS ALLOWED.

LOWER CYCLE LENGTH (COLS. 51-53)
CODE THE SMALLEST CYCLE LENGTH THAT THE PROGRAM IS TO USE IN DETERMINING THE OPTIMUM CYCLE. THE SUM OF THE MINIMUM CONFLICTING GREENS AT EACH INTERSECTION MUST BE SMALLER THAN THIS CYCLE.

INTERSECTION HEADER CARDS

QUEUE CLEARENCE (COLS. 27-30)
WHEN IT IS DESIRED TO CLEAR THE QUEUE AT AN INTERSECTION BEFORE THE PROGRESSION BAND ARRIVES. CODE THE NUMBER OF SECONDS IT TAKES TO CLEAR THE AVERAGE QUEUE. THIS VALUE SHOULD NOT EXCEED 10 SECONDS.

PERMISSIBLE PHASE SEQUENCE (COLS. 31-38)
REFERENCE PERMISSIBLE PHASE SEQUENCE CHART ON FRONT OF THE CODING FORM. IF THE PHASE SEQUENCE IS NOT PERMITTED. CODE A ZERO OR LEAVE BLANK. IF THE PHASE IS PERMITTED WITH NO OVERLAP. CODE A ONE (1). IF THE PHASE IS PERMITTED WITH OVERLAP. CODE A TWO (2)

NOTE:
FOR COLS. 31-34 ANY COMBINATION OF ZEROS. ONES AND TWOS MAY BE CODED IN ALL FOUR COLUMNS.
FOR COLUMNS 35-38 THREE OF THE COLUMNS MUST BE CODED WITH A ZERO OR LEFT BLANK.

INTERSECTION DETAIL CARDS

VOLUMES
MOVEMENT VOLUMES MAY BE IN VEHICLES PER HOUR. VEHICLES PER 15 MINUTES OR VEHICLES PER 5 MINUTES. BUT MUST BE IN THE SAME INTERVAL AS THE SATURATION CAPACITY.
LEFT TURNING MOVEMENTS (1. 3. 5. 7) NOT PROTECTED BY LEFT-TURN SIGNAL PHASING HAVE ZERO VOLUMES. ADD THESE COUNTED LEFT TURN VOLUMES TO THE APPROACHES THROUGH PLUS RIGHT TURN VOLUMES.

SATURATION CAPACITY FLOW - REFER TO THE SATURATION CAPACITY FLOW SECTION IN THE USER MANUAL.

MINIMUM GREEN
THE MINIMUM GREEN TIME IN SECONDS FOR EACH MOVEMENT MUST INCLUDE ANY ADDITIONAL YELLOW CLEARRANCE AND ALL RED TIME. FOR EXAMPLE. IF THE DESIRED MINIMUM GREEN TIME WAS 10 SECS. FOLLOWED BY A 3 SEC. YELLOW AND A 1 SEC. ALL RED. THEN THE CODED MINIMUM GREEN WOULD BE 14 SECS. THE MINIMUM GREEN TIME FOR MOVEMENTS 2. 4. 6. AND 8 MUST BE LONG ENOUGH TO INSURE ADEQUATE WALK AND CLEARANCE TIME FOR PEDESTRIANS CROSSING THE OTHER STREET.

PROGRAM 145101

FORM 1444 - 2

Figure D-3. Example of Input Form 1444-2.

ARTERIAL HEADER CARD
ONE PER ARTERIAL

RUN NO.	NAME OF CITY	NAME OF ARTERIAL
1 2	3 4 5 6 7 8 9 10 11 12 13 14	15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38

DISTRICT	DATE	NO. OF INTERSECTIONS	ISOLATED	PROGRESSION	CYCLE LENGTHS (SEC.)		CYCLE LENGTH INCREMENT- SEC.	MIN. "B" DIRECTION BAND SPLIT	SPEED SEARCH ?	PRINTER PLOT ?	LINE PLOT ?	X-SCALE 1" = ? SEC.	Y-SCALE 1" = ? FEET			NEMA
					LOWER	UPPER										
39 40	41 42 43 44 45 46	47 48	49	50	51 52 53	54 55 56	57 58	59 60	61	62	63	64 65	66 67 68 69	70	71	72

Figure D-4. Example of Input Form 1444-2
(Arterial Hearder Card, One per Arterial).

ARTERIAL HEADER CARD

The ARTERIAL HEADER CARD supplies information to the program which is common to the arterial and also contains information concerning the identification and geometrics of the arterial street. There must be one and only one ARTERIAL HEADER CARD for each arterial. Multiple arterials may be analyzed in one run of the program where each arterial must begin with an ARTERIAL HEADER CARD followed by the INTERSECTION HEADER and DETAIL Cards.

RUN NO. (Columns 1-2). Any number from 01 to 99 can be used to identify a particular run in a series of runs made on the same arterial.

NAME OF CITY (Columns 3-14). This field is used only to identify the name of the city where the arterial is located and is printed on the output as it is entered on the coding form.

NAME OF ARTERIAL (Columns 15-38). This field is used to identify the name of the arterial under study and is printed on the output exactly as it is entered on the coding form.

DISTRICT (Columns 39-40). The District number is used for identification and is printed on the output as it is entered.

DATE (Columns 41-46). The date is entered as MMDDYY where MM is the number of the month, DD is the day, and YY is the last two digits of the year.

NO. OF INTERSECTIONS (Columns 47-48). The total number of signalized intersections along the arterial under study is entered. The maximum number of intersections that can be analyzed on one arterial is 20. This number must correspond to the number of INTERSECTION HEADER CARDS.

ISOLATED (Column 49). The number one (1) is entered if the signalized intersections are not coordinated but are isolated. If the isolated mode is used, both the LOWER and UPPER CYCLE LENGTHS (Columns 51-56) must be set to the same value. In the isolated mode, only one arterial phase sequence may be evaluated per intersection. Time-space diagrams are not printed when using the isolated mode.

PROGRESSION (Column 50). The number one (1) is entered if a progression solution is desired. Otherwise, the default option is to calculate under isolated operation (option zero - 0). Unlike the isolated mode, the progression optional mode will allow the user to evaluate a range of cycle lengths and four different phase sequences on the major streets, if requested, and one phase sequence on the minor street. Time-space diagrams can be printed when using the progression option.

CYCLE LENGTHS SEC. (Columns 51-56). Cycle lengths can be entered in two different ways. Both the lower and upper (range) can be entered when a progression solution is desired. They both should be set to the same value when the isolated option is used. A progression solution also can be obtained for the known cycle length by setting both lower and upper cycle lengths to that value.

LOWER (Columns 51-53). The smallest cycle length (in seconds) the program may consider for a solution is entered here. It should be at least four seconds greater than the sum of the minimum conflicting greens or equal to this sum if an evaluation of existing timings is being attempted. An example of determining the sum of the minimum greens is shown in Figure D-5.

The smallest permissible cycle length should be determined beforehand by using Webster's method, the Poisson method, or some other suitable method at the critical intersection. A review of the Webster method is given in Appendix A. The Poisson method is reviewed in the Traffic Engineer's Handbook by ITE. Also see p. 91.

Each intersection in an arterial system will generally have a different minimum delay cycle length from the other intersections. The smallest permissible cycle length for the arterial should not be less than 0.85 times the largest individual cycle length, nor greater than 1.25 times the smallest cycle length for an intersection. For example, assume the four minimum delay cycle lengths are 45, 50, 50, and 55 seconds based on Webster's formula. The permissible cycle length range of the arterial should not be less than (0.85 X 55) = 47 seconds nor greater than (1.25 X 45) = 56 seconds.

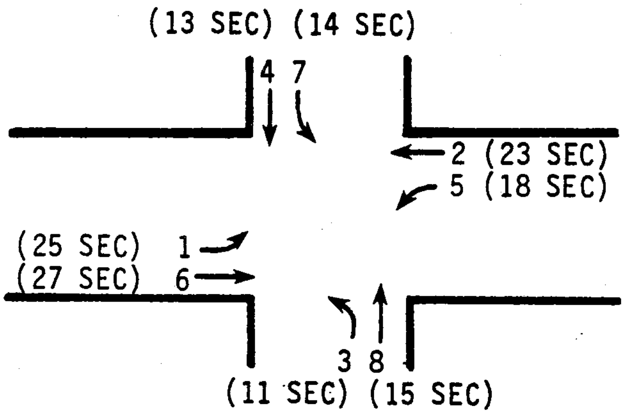
As stated earlier, an advisable cycle length for each intersection will be printed on the PASSER II-84 output, but the user will not have this until he has finished a run of the program.

UPPER (Columns 54-56). The largest cycle length (in seconds) the program may consider in obtaining the "best solution" is entered in this data field. The upper limit of the cycle length is usually no more than 10 seconds greater than the lower limit. If a progression solution is desired for one cycle length, then both the lower and upper cycle limits should be entered accordingly.

CYCLE LENGTH INCREMENT (SEC.) (Columns 57-58). The number of seconds the program will increase as a step between the lower and upper cycle length limits is coded. A 5-second increment is recommended for pretimed signal systems, but a different increment could be used for digital or analog traffic responsive systems.

MIN. "B" DIRECTION BAND SPLIT (Columns 59-60). The user may specify the percent of the total progression bandwidth to be provided in the "B" direction. If no percentage is entered, "A" and "B" direction bands will be split in proportion to the traffic volume distributed in "A" and "B" directions. If one direction is favored over the other, irrespective of volumes, the favored direction must be coded as it impacts the "B" direction.

SPEED SEARCH (Column 61). This field is optional but can be used to find a final speed that is within ± 2 M.P.H. of the desired speed. If the number one (1) is entered for searching the best solution, the program will vary the desired speed (Column 19-20 and 25-26) on each link uniformly in ± 1 M.P.H. increments and select a final speed that is within ± 2 M.P.H. of the desired speed.



NEMA Movement No.	1	2	5	6	3	4	7	8
Minimum Green Time	25	23	18	27	11	13	14	15
Conflicting Sums	48		45		24		29	
Larger Major Street Sum		48						
Larger Minor Street Sum		29						
Minimum Cycle Length		77 seconds						

Conclusions: With the above minimum greens coded, the lower cycle length value must equal or exceed 77 seconds.

Figure D-5. Example of determining the sum of the minimum greens for "over-lapped" multiphase signalization.

PRINTER PLOT? (Column 62). The number one (1) should be entered if it is desired to print the time-space diagram on the printer.

LINE PLOT? (Column 63). The number one (1) is entered if it is desired to plot the time-space diagram by a line plotter.

X-SCALE 1" = ? (SEC.) (Columns 64-65). The number of seconds to be used on the horizontal scale is entered. The default value of 1" = 30 seconds is used if this field is left blank.

Y-SCALE 1" = ? (FEET) (Columns 66-69). The number of feet to be used on the vertical scale is entered. The default value of 1" = 1000 feet is used if this field is left blank.

NEMA (COLUMN 72). A one (1) is entered if it is desired to utilize NEMA (National Electrical Manufacturers' Association) phase movement designations. If this option is used, the vehicle movements as shown on the coding form should be disregarded. Otherwise, the program will assume the default PASSER's phase definition--option zero (0). It is also possible now in PASSER II-84 to make a translation between PASSER's phase definition and the NEMA phase definition. If the user desires to use PASSER's phase definition as input but chooses the NEMA phase definition as output, then a two (2) should be entered. If the user prefers to use the NEMA phase as input but desires the output in PASSER's phase definition, a three (3) should be coded. NEMA and PASSER vehicle movement numbering are shown in Figure D-6. The designation of major and minor street movements on the **INTERSECTION DETAIL CARDS** is no longer valid when the NEMA option is used. Enter data according to the movement numbers in the diagram.

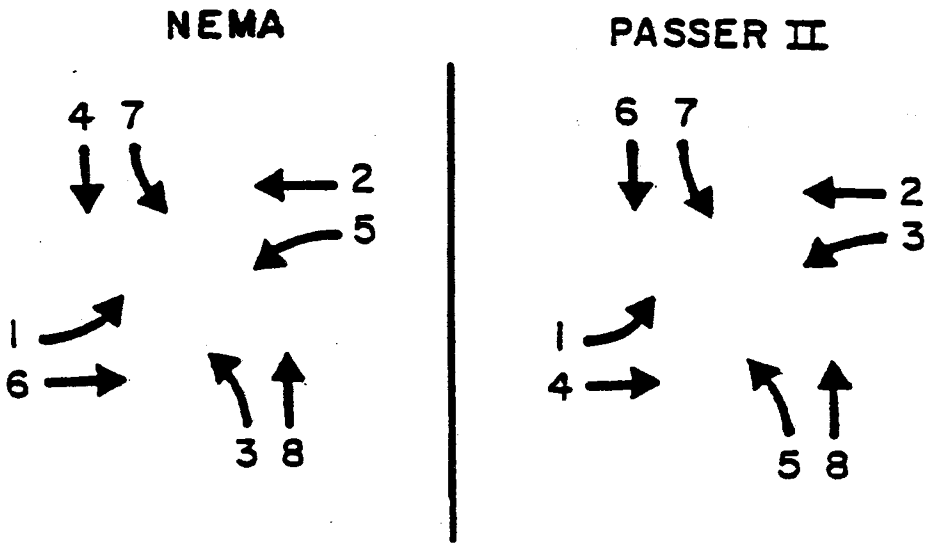


Figure D-6. NEMA & PASSER II's Phase Movement Definitions.

INTERSECTION HEADER CARD

The **INTERSECTION HEADER CARD** provides signal phasing information for each intersection. One card (one line of information) is required for each intersection. Descriptive information about the downstream link is also provided. A maximum of **20 INTERSECTION HEADER CARDS** can be input for one PASSER II-84 problem.

INTERSECTION HEADER CARD - ONE CARD PER INTERSECTION

STREET NAME	INTERSECTION NO.	DISTANCE 'A' (FEET)	DIRECTION 'A' AVG. SPEED M.P.H.	DISTANCE 'B' (FEET)	DIRECTION 'B' AVG. SPEED M.P.H.	QUEUE CL. 'A' SIDE (SEC.)	QUEUE CL. 'B' SIDE (SEC.)	LEFT TURNS	THROUGH MOVEMENTS	LEADING GREEN	LAGGING GREEN	LEFT TURNS	THROUGH MOVEMENTS	LEADING GREEN	LAGGING GREEN
1 2 3 4 5 6 7 8 9 10 11 12	13 14	15 16 17 18	19 20	21 22 23 24	25 26	27 28	29 30	31	32	33	34	35	36	37	38

Figure D-7. Intersection Header Card - One Card Per Intersection.

STREET NAME (Columns 1-12). The cross street name at the intersection is entered left-justified.

INTERSECTION NO. (Columns 13-14). The intersection sequence number in the "A" direction is entered for this intersection. Normally intersections are numbered 1,2,..,n down the arterial but can be numbered in any order the user desires. The "A" direction can be selected to be either direction along the arterial. However, all the calculations will be made with respect to the first signal in the "A" direction as user selected.

DISTANCE "A" (FEET) (Columns 15-18). The distance in feet from this signal to the previous signal in the "A" direction is entered. Normally, this distance is measured from centerline to centerline of the intersections.

The first intersection along the arterial will not have an upstream link. Therefore, distances "A" and "B" of the first intersection are always zero (0), and columns 15-26 on the first INTERSECTION HEADER CARD must also be left blank (or zero).

DIRECTION "A" AVG. SPEED (M.P.H.) (Columns 19-20). The desired speed in miles per hour is entered for the link whose distance was just coded in columns 15-18. The average speed (in MPH) between intersections should be based on the average speeds obtained from a floating car study or other similar study during peak and off-peak periods for each direction of travel. A floating car study could be used to find the average speed which exists between two points by driving the test vehicle within or following platoons of vehicles. The average speed is then calculated from five to ten trial runs during the off-peak travel conditions and five to ten trial runs during both the AM peak period and the PM peak period. The speeds obtained should be the free-flowing speeds of platoons between stop signs or stops at traffic signals. Trial runs during both off-peak and peak periods should be made if different average speeds occur during these two periods. If they do, two or three time-space diagrams should be prepared. If the average speeds change along an arterial, the change in average speed may be coded in the proper **INTERSECTION HEADER CARD.** For example, if the "A" direction average speed between intersections 1 and 2 is 30 M.P.H. and the "A" direction average speed between intersections 2 and 3 is 26 M.P.H., columns 19-20 for Intersection 2 would be coded as 30 and Intersection 3 would be coded as 26. A less accurate but an alternative method is to enter 28 M.P.H. in columns 19-20 for both Intersections 2 and 3.

DISTANCE "B" (FEET) (Columns 21-24). The distance in the "B" direction from the downstream intersection back to this one is entered in feet. Normally, this distance is the same as the one entered in columns 15-18. The first intersection along the arterial will not have an upstream link. Therefore, columns 15-26 on the first INTERSECTION HEADER CARD must be left blank (or zero).

DIRECTION "B" AVG. SPEED (M.P.H.) (Columns 25-26). The "B" direction desired speed in miles per hour is entered for the link just entered in columns 19-20. A complete description of the desired speed is given above for the "A" direction average speed.

QUEUE CL. "A" SIDE (SEC.) (Columns 27-28). This feature may be used when it is desired to insure that the progression band will arrive after the start of the "A" direction green (with a maximum of 10 seconds). Some lag time may result at a signal when the program attempts to balance slack time even if no queue clearance time is provided. Hand adjustments of the offsets from the time-space diagram can also provide some improvement to the progression band in the "B" direction for a given best solution. The queue clearance in the "A" direction at the first intersection must be left blank (or zero).

QUEUE CL. "B" SIDE (SEC.) (Columns 29-30). The "B" direction band lag in seconds (queue clearance time) of this signal is entered right justified. It must not exceed 10 seconds. Normally, columns 27-28 and 29-30 should be left blank. The queue clearance for the first intersection in the "B" direction must also be left blank (or zero).

PERMISSIBLE PHASE SEQUENCE (Columns 31-38). There are four possible phase sequences: **LEFT TURNS FIRST** (dual lead), **THROUGH MOVEMENTS FIRST** (dual lag), **LEADING GREEN,** and **LAGGING GREEN.** The first four columns are used for the phase sequence on the major street, and the last four are used for the minor street. These eight columns indicate the phase sequences that the program will evaluate in determining the best solution. Either a one (1) or two (2) entered in the column pertaining to the phase sequence(s) is used to differentiate whether a non-overlapped or overlapped phase is desired. A diagram in the center of the coding form shows the **PERMISSIBLE PHASE SEQUENCES.**

Each multiphase intersection must have at least one major street phase sequence and may have all four of them considered. Generally, the first run is made with all four of the phase sequences on the major street and the **THROUGH MOVEMENTS FIRST** phase sequence specified on the minor street.

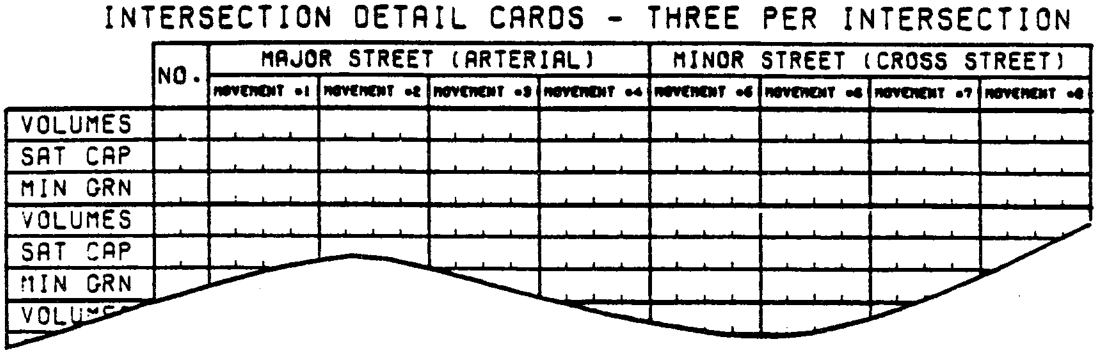
An intersection having a simple **two-phase operation** would have only one major street phase and one minor street phase. The appropriate phase sequence to select would be the THROUGH MOVEMENTS FIRST sequence without the overlap phase interval. The left turn phase interval in the sequence is deleted in the program by not coding left turn movement volumes or minimum green times.

For multiphase operation, the optional overlap phases may be/are desirable because they reduce the amount of lost time within the phase sequence and, thus, lessen the delay to the motorist. The advantage of overlap phasing is demonstrated in a later section. Since some controllers are inflexible and require the same phase order for each timing plan, care must be exercised to insure that the final patterns do not conflict with the order of the phase intervals at an intersection and violate implementation of the phase sequence in the controller. Lead-lag phasing may be required to implement AM and PM green splits. To allow a phase sequence to use the optional overlap feature, a two (2) is entered in the respective phase sequence column the program uses.

Note:
- If left blank (0), the phase sequence is not permitted.
- A one (1) is coded if the phase sequence is to be permitted without the overlap phase.
- A two (2) is coded if the phase sequence is to be permitted with the overlap phase.

INTERSECTION DETAIL CARDS

Three **INTERSECTION DETAIL CARDS** are required for each intersection on the major street. A maximum of **60 INTERSECTION DETAIL CARDS** can be input in one problem. All elements related to the **VEHICLE MOVEMENTS** should be numbered according to the diagram in the center of the coding form. All entries must be right justified.



INTERSECTION DETAIL CARDS - THREE PER INTERSECTION

	NO.	MAJOR STREET (ARTERIAL)				MINOR STREET (CROSS STREET)			
		MOVEMENT #1	MOVEMENT #2	MOVEMENT #3	MOVEMENT #4	MOVEMENT #5	MOVEMENT #6	MOVEMENT #7	MOVEMENT #8
VOLUMES									
SAT CAP									
MIN GRN									
VOLUMES									
SAT CAP									
MIN GRN									

Figure D-8. INTERSECTION DETAIL CARDS - THREE PER INTERSECTION.

VOLUMES. The first card of the set of three cards must be the vehicle volumes for each movement for each approach. The volumes entered can be in vehicles per hour, vehicles per 15 minutes, or vehicles per 5 minutes. Volumes entered for movements 2, 4, 6, and 8 are total volumes of the through movement plus the right turning vehicles. If the intersection is a T intersection, the non-existent movements should be left blank. If the user does not want a separate protected left-turn signal phase, the left turning movements (1, 3, 5 and 7) must be left blank. When the peak left-turn volume is not greater than three vehicles per cycle or its opposing through volume, there is no need to provide a protected left-turn phase.

SAT CAP (Saturation Flow Rate or "Capacities"). Reasonably accurate values should be established since the movement green time is calculated based on the movement's volume-to-saturation flow ratio. Thus, saturation flow units (e.g., vehicles per hour of green) must be of the same time interval as the movement volume units. The saturation flow rate in vehicles per hour of green could be obtained for each movement from the Highway Capacity Manual using a load factor of 1.0 and a P.H.F. of 1.00. Technically speaking, the saturation flow rate is not the capacity until it is multiplied by the phase's G/C value. The value used here assumes a G/C of 1.00.

An alternate approach to determining the movement's saturation flow is to assume that it is "n" times the saturation flow rate for one lane, where "n" is the number of lanes used by the movement. Approximate saturation flow rates per lane can be obtained from the following table:

Table D-1. Saturation Flow Rates.

SATURATION FLOW RATES

(Vehicles Per Hour of Green Per Lane)

	Estimated Maximum Saturation Flow Rate Per Lane		
Traffic Conditions	Protected Left (single lane)	Protected Left (double lane)	Protected Through (main lanes only)
Bay Length Adequate	1700	1600/lane	1750
Bay Not Adequate	1500	1350/lane	1650
No Bay	1400	Not Recommended	1450

NOTE: For unprotected movements, multiply the number of left turns by 1.6 and add to the accompanying through volume. Add the saturation flow rate of the protected left turn bay to that of the accompanying through movement, if it is present.

MIN GRN (Minimum Green Times). The minimum green time in seconds for each movement is the minimum time for the green, yellow, and all-red time, if any, for that particular movement. For example, if the desired minimum green interval was 10 seconds followed by a 3-second yellow interval and a 1-second all-red interval, the coded minimum green time would be 14 seconds. The minimum phase green times for movements 2, 4, 6, and 8 must be long enough to insure adequate walk and pedestrian clearance time for pedestrians crossing the other street.

It is important to note that the minimum cycle length coded in columns 37-39 of the ARTERIAL HEADER CARD must exceed the sum of the minimum green times of the conflicting movements. See the Cycle Lengths Section for an example of the sum of the minimum greens.

T Intersection

A T intersection requires special coding. An example, as shown on Figure D-9 on the next page, demonstrates the intersection and phase sequence. In this example, a protected left turn is desired for the left turning traffic from Main Street to Stem Street, which is movement 1 in the NEMA phase movement designations. Possible signal phasing for Main Street is either a leading left turn (phase codes 1 and 6) or through movements first (phase codes 2 and 6). Leading left turn refers to the left turn movements in the "A" direction along Main Street.

On Stem Street, only one signal phasing is possible. Both movements 4 and 7 can be handled in one phase, and, in essence, a protected left turn is provided. PASSER II-84 is capable of providing proper error-detection for incorrect side street sequence, but care must still be taken to check whether the actual movements occur in the field could be output by the program. The error messages and their suggested actions are indicated in Appendix E.

If Stem Street were on the opposite side of Main Street, the left turning traffic from Main Street would be movement 5. Possible signal phasings for Main Street with this configuration would be either a lagging left turn (phase codes 2 and 5) or through movements first (phase codes 2 and 6). "Lagging left turn" refers to left turn movements in the "B" direction along Main Street.

Only one signal phasing is possible on Stem Street with movements 4 and 7 proceeding simultaneously. A protected left turn is provided on Stem Street. Saturation flow rates must also reflect the field data measurements.

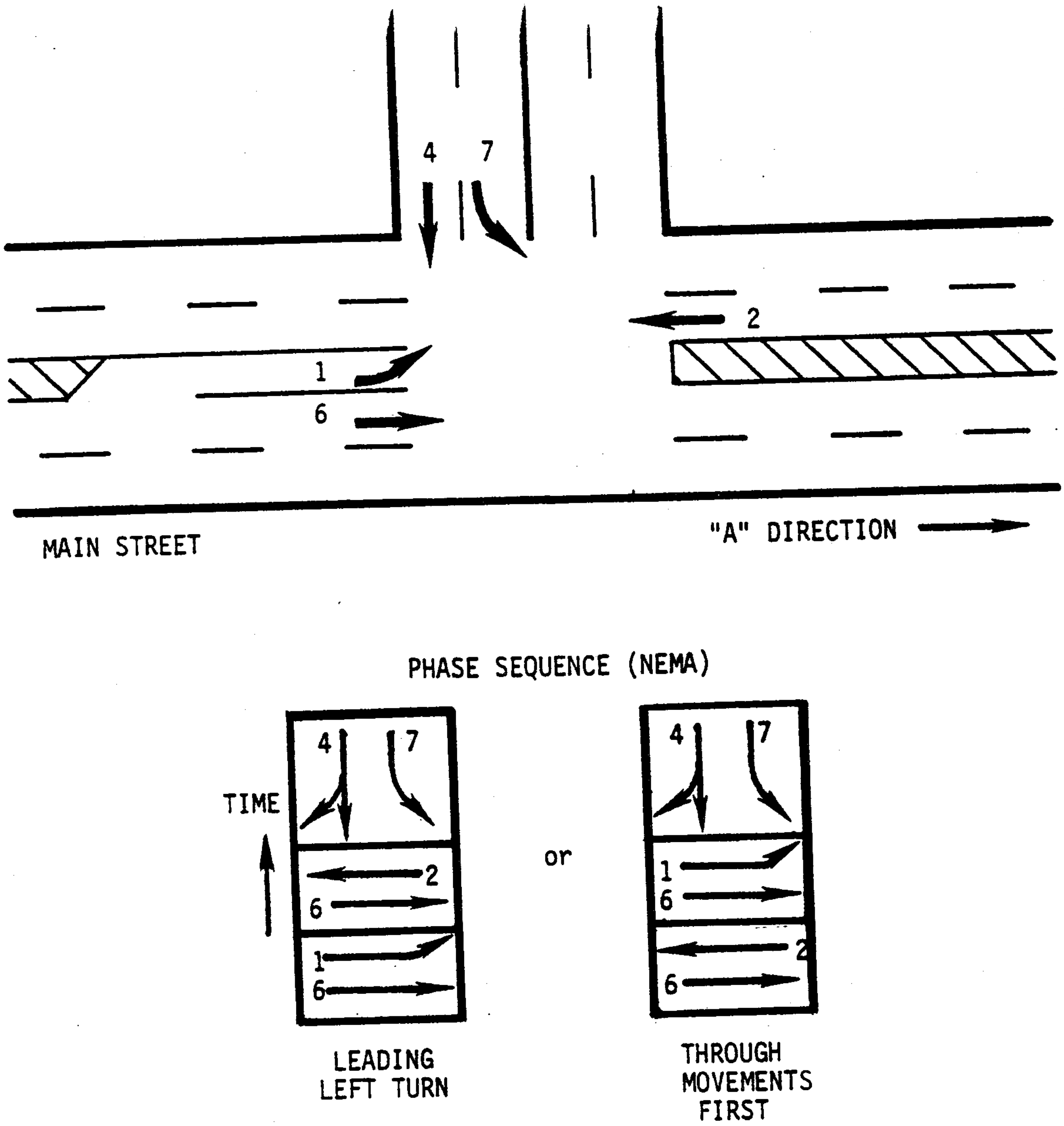


Figure D-9. Example of "T" - Intersection At Stem Street.

Splitting the Cross Street Green - Cross Street Phasing With No Overlap

PASSER II-84 can be used to develop a timing plan where all traffic on the approach in one direction precedes all traffic on the approach in the opposite direction. This condition has been given several names; in PASSER, it is called **"no overlap phasing"**. In order to maximize progression bandwidth, overlapping of the through phases is usually considered because it can also provide shorter cycle lengths.

An overlap phase is created when one of two paired movements requires more time than the other, and another compatible movement is also available. An example, as shown on Figure D-10 illustrates the case of "splitting the cross street green".

Movement	3	4	7	8
Min. green required to move actual demand,sec.	13	15	11	17

Overlap phasing would result in the following:

Phase	3+8	4+8	4+7
Phase min. green, sec.	13	4	11

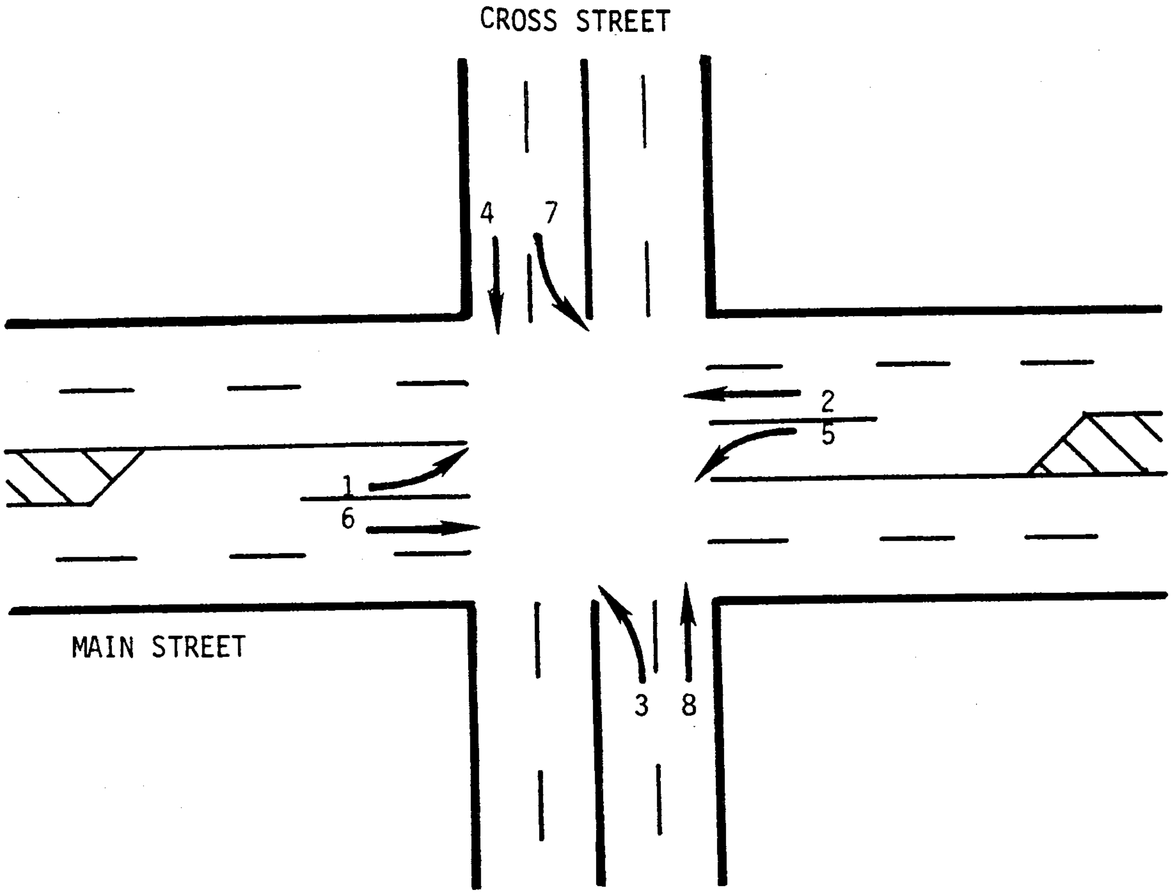
As above, the 4+8 phase is an overlap phase. If no overlap phasing is desired, the following occurs:

Phase	3+8	4+7
Phase min. green, sec.	17	15

The total time for the cross street with overlap phasing is 28 seconds. In order to move the same demand with no overlap phases, 32 seconds are required.

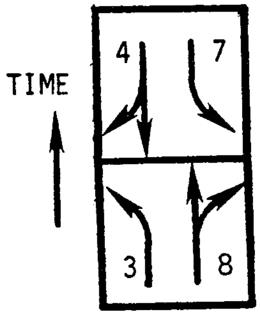
Safety considerations may warrant that no overlapping phases be provided on the cross street, even though a split phase is a less efficient method to utilize green time. The signal timing plan for no overlap phasing will be movements 3 and 8 followed by movements 4 and 7. Therefore, a one (1) must be coded in the cross street leading green and lagging green columns. (See the discussion of INTERSECTION HEADER CARD).

Because the program will seek to maximize utilization of green time, good progression will be more difficult to obtain with a no overlap solution. The user must code identical minimum green times for the paired movements in a split phase and consider all the possible slack time at that intersection. This special case is illustrated in Figure D-10.



PHASE SEQUENCE (NEMA) FOR MAIN STREET

It could be any one of the four (4) optional phase sequences.



Split phase
with no overlap

Figure D-10. Example of Cross Street Phasing "With No Overlap".

ONE-WAY PROGRESSION

Subroutine ONEWAY, similar to the one in PASSER III, calculates the offsets and overwrites the time-space coordinates providing "perfect" one-way progression along a two-way arterial street. The perfect one-way progression solution in either the "A" or "B" direction can be obtained by specifying a one (1) or a ninety-nine (99) in the optional **"MIN. 'B' Direction Band Split"** of the PASSER II-84 input data set. Code a one (1) for one-way progression in the "A" direction. Code a ninety-nine (99) for one-way progression in the "B" direction.

ONE-WAY STREETS

A one-way street may be assigned in PASSER II-84 as the "B" direction. "A" direction volumes should be coded as zeros (0). Code a ninety-eight (98) in the Min. "B" Direction Band Split field (Columns 59 and 60) of the ARTERIAL HEADER CARD. The phase sequences on the INTERSECTION HEADER CARDS must be either through movements first or lagging green. Non-zero speeds must be assigned to the "A" direction.

APPENDIX E

PASSER II-84 ERRROR MESSAGES

PASSER II-84 mainly has two types of error messages and codes to alert the user of any input data errors and/or potential problems in the output results. The first type of error messages occurs in the "CODING ERROR MESSAGE" section of the output, which follows immediately behind the ECHO printout of the input data deck. The program will terminate due to these errors. The second type of error messages, if any, will not terminate the program execution but merely produces a warning in the **"BEST SOLUTION"** output section after the **"NO APPARENT CODING ERRORS"** has been printed.

These error message codes and their suggested actions using PASSER's phase movement definition, are indicated as follows:

TYPE I. ERROR MESSAGES

NO ARTERIAL PHASE PATTERNS ARE SPECIFIED

At least one signal phase sequence option must be specified in the INTERSECTION HEADER CARD for all the intersections.

MAIN ST MIN GREENS OF LEFT TURNS DO NOT EQUAL THE MIN GREENS OF THEIR CORRESPONDING THROUGH MOVEMENTS AS REQUIRED FOR PHASE SEQUENCES WITH NO OVERLAP

When phase sequencing with no overlap has been specified, the left turn movements on the major street (1,3) must equal their corresponding through movements (4,2) minimum green. Please check the minimum green time intervals specified in the input data deck.

CROSS ST MIN GREENS OR LEFT TURNS DO NOT EQUAL THE MIN GREENS OF THEIR CORRESPONDING THROUGH MOVEMENTS AS REQUIRED FOR PHASE SEQUENCES WITH NO OVERLAP

When phase sequencing with no overlap has been specified, the left turning movements on the minor street (5,7) must equal the corresponding through movements (8,6) minimum green. Check your minimum green time and the necessity to use "NO OVERLAP PHASE" option.

THE SUM OF CRITICAL MINIMUM GREENS EXCEEDS THE LOWER CYCLE LENGTH
LOWERCYCLE = SEC. --- SUM MIN GREENS = SEC.

The largest sum of the minimum greens of the following movement combinations exceeds the lowest cycle length.

1 + 2, 5 + 6
3 + 4, 7 + 8

Recheck your minimum green time requirements or increase your lowest cycle length used in the ARTERIAL HEADER CARD.

NUMBER OF INTERSECTIONS REQUESTED DOES NOT MATCH NUMBER OF INTERSECTIONS FOUND

Please check the number of intersections specified in the ARTERIAL HEADER CARD against INTERSECTION HEADER CARD coded.

VOLUMES FOUND WITHOUT SAT. FLOW RATE ON MOVEMENT n

Saturation flow rate or saturation capacity must be specified for all the movements with traffic volume. The INTERSECTION DETAIL CARDS may be out of sequence or saturation capacities may have been omitted for movement n on the intersection.

TYPE II WARNINGS

X - RATIO EXCEEDS 1.20
OVER-SATURATED STATISTICS CANNOT BE ESTIMATED

When the movement is over-saturated, negative values may be presented in the measures of effectiveness section which indicate possibly incorrect solutions. Please attempt to increase the capacity of the movement in question and reprocess the problem.

OVERSATURATED CONDITION DOES NOT CHANGE THROUGHOUT THE STUDY PERIOD

When the movement is over-saturated, excess long queue of vehicles may exist and not be able to clear throughout the study period. The probability of queue clearance will remain zero due to the inability of signal operations. Please follow the same action as the warning message above.

PLOTTING LIMITS EXCEEDED

Errors may occur because of the improper scale coded in the ARTERIAL HEADER CARD for time-space plot. The plotting may not be completed. Please adjust the "Y-Scale" to a larger number.

APPENDIX F COMPARISONS OF THE NETSIM EVALUATION RESULTS FOR THE PASSER II-80 AND PASSER II-84 PROGRAMS -- SKILLMAN AVENUE, DALLAS, TEXAS.

PASSER II-84

```
                                  CUMULATIVE STATISTICS SINCE BEGINNING OF SIMULATION

                      PRESENT TIME IS  8  0  0,    ELAPSED SIMULATED TIME IS  15 MINUTES,  0 SECONDS

                                                    LINK STATISTICS

          VEH-    VEH   MOV.   DELAY        TOTAL   T-TIME   T-TIME/   D-TIME   D-TIME/    PCT    AVG.   AVG.  STOPS  AVG  CYCL
  LINK    MILES   TRP   TIME   TIME   M/T   TIME    / VEH.  VEH-MILE   / VEH   VEH-MILE   STOP   SPEED  OCC.  /VEH   SAT  FAIL
                        V-MIN  V-MIN        V-MIN    SEC    SEC/MILE    SEC    SEC/MILE  DELAY   MPH                PCT

( 10,  1) 53.4    94   96.2   42.9  0.69  139.1   88.8    156.3     27.4     48.2      73   23.0    9.2   0.71    3    0
( 11,  1) 58.0   153   99.7   84.1  0.54  183.8   72.1    190.3     33.0     87.1      77   18.9   12.2   0.78    4    0
( 19,  1)169.7   448  300.8  242.1  0.55  542.9   72.7    191.9     32.4     85.6      67   18.8   36.3   0.77   12    0
( 20,  1)155.7   274  244.3  182.9  0.57  427.2   93.5    164.6     40.1     70.5      69   21.9   28.6   0.77   10    0
(  1, 20) 62.9   111  109.2   11.8  0.90  121.0   65.4    115.5      6.4     11.2       2   31.2    8.0   0.07    3    0
( 12,  2) 10.6    28   18.7   12.0  0.61   30.7   65.8    173.6     25.6     67.6      71   20.7    2.0   0.64    2    0
( 18,  2) 30.3    80   54.9   37.0  0.60   91.9   68.9    182.0     27.8     73.3      71   19.8    6.1   0.82    4    0
(  3, 21) 32.4   428   55.0   40.5  0.58   95.5   13.4    177.0      5.7     75.0      20   20.3    6.4   0.54   14    0
( 21,  3)  9.0   119   16.8   18.9  0.47   35.6   18.0    237.2      9.5    125.6      69   15.2    2.4   0.36    4    0
( 13,  3) 30.7    81   55.3   40.8  0.58   96.0   71.1    187.8     30.2     79.7      75   19.2    6.4   0.80    2    0
( 17,  3) 88.3   233  153.7  134.4  0.53  288.1   74.2    195.8     34.6     91.4      77   18.4   19.2   0.80    7    0
( 22,  3)200.2   439  386.0  238.3  0.62  624.3   85.3    187.1     32.6     71.4      54   19.2   41.9   0.60   12    0
( 22,  4)  9.5   125   19.4   22.3  0.47   41.7   20.0    264.4     10.7    141.3      77   13.6    2.8   0.44    6    0
( 14,  4) 21.2    56   36.5   25.4  0.59   61.9   66.3    175.0     27.2     71.9      70   20.6    4.1   0.82    3    0
( 16,  4) 45.1   119   76.7   63.4  0.55  140.2   70.7    186.6     32.0     84.5      73   19.3    9.3   0.78    5    0
( 15,  4)196.6   346  343.6  179.2  0.66  522.8   90.7    159.6     31.1     54.7      50   22.6   34.8   0.64   12    0
(  1, 10)164.7   290  260.0   67.8  0.79  327.8   67.8    119.4     14.0     24.7       2   30.1   21.8   0.08    8    0
(  1, 11)160.0   423  284.3   72.2  0.80  356.5   50.6    133.7     10.2     27.1       0   26.9   23.7   0.01    8    0
(  2, 12) 58.3   155  104.6   16.8  0.86  121.5   47.0    125.1      6.5     17.3       6   28.8    8.0   0.19    5    0
(  3, 13)118.0   313  208.3   47.3  0.81  255.6   49.0    129.9      9.1     24.0       2   27.7   16.9   0.05    6    0
(  4, 14) 37.4    99   64.2   11.1  0.85   75.3   45.6    120.7      6.7     17.7       4   29.8    5.0   0.08    3    0
(  4, 15) 84.5   149  174.4   22.1  0.89  196.5   79.1    139.4      8.9     15.7       2   25.8   13.1   0.07    5    0
(  4, 16) 11.3    30   20.1    2.6  0.88   22.7   45.4    120.4      5.2     13.9       9   29.9    1.5   0.17    1    0
(  3, 17) 28.3    75   49.8    6.7  0.88   56.5   45.2    119.8      5.4     14.3       6   30.1    3.7   0.05    2    0

(  2, 18) 13.6    36   23.4    2.8  0.89   26.2   43.7    115.6      4.7     12.5       4   31.2    1.8   0.06    1    0
(  1, 19) 59.7   158  105.0   19.4  0.84  124.4   47.2    124.9      7.4     19.5       1   28.8    8.2   0.04    3    0
(  2, 20) 20.7   273   34.0    7.2  0.83   41.1    9.0    119.3      1.6     20.8       0   30.2    2.8   0.0     8    0
( 20,  2)  8.4   111   15.3   12.4  0.55   27.6   14.9    197.1      6.7     88.2      75   18.3    1.9   0.23    4    0
( 21,  2) 95.7   400  163.9   80.3  0.67  244.2   36.6    153.2     12.0     50.4      20   23.5   16.1   0.10   12    0
(  2, 21) 28.2   118   54.5    5.5  0.91   60.0   30.4    127.7      2.8     11.8       5   28.2    4.0   0.12    4    0
(  4, 22) 27.2   360   48.1   23.2  0.67   71.3   11.9    157.5      3.9     51.2       3   22.9    4.7   0.14    9    0
(  3, 22) 56.0   123  115.4   10.0  0.92  125.4   61.2    134.4      4.9     10.8       3   26.8    8.4   0.07    4    0

                                                  NETWORK STATISTICS

     VEHICLE-MILES=2145.44      VEHICLE-MINUTES=  5575.2      VEHICLE-TRIPS (EST.)= 1688      STOPS/VEHICLE= 1.35

   MOVING/TOTAL TRIP TIME=0.680    AVG. SPEED (MPH)=23.09    MEAN OCCUPANCY= 371.2 VEH.    AVG DELAY/VEHICLE= 63.39 SEC

     TOTAL DELAY= 1783.3 MIN.        DELAY/VEH-MILE= 0.83 MIN/V-MILE        TRAVEL TIME/VEH-MILE= 2.60 MIN/V-MILE

                                 STOPPED DELAY AS A PERCENTAGE OF TOTAL DELAY=50.8

                                  SEED FOR RANDOM NUMBER GENERATOR IS    22275803
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APPENDIX F COMPARISONS OF THE NETSIM EVALUATION RESULTS FOR THE PASSER II-80 AND PASSER II-84 PROGRAMS -- SKILLMAN AVENUE, DALLAS, TEXAS.

PASSER II-80

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                            CUMULATIVE STATISTICS SINCE BEGINNING OF SIMULATION

                PRESENT TIME IS  8  0  0,   ELAPSED SIMULATED TIME IS  15 MINUTES,  0 SECONDS

                                              LINK STATISTICS


              VEH-   VEH   MOV.  DELAY         TOTAL T-TIME  T-TIME/   D-TIME   D-TIME/    PCT   AVG.   AVG.  STOPS  AVG  CYCL
   LINK      MILES   TRP   TIME  TIME    M/T   TIME  / VEH.  VEH-MILE  / VEH   VEH-MILE   STOP  SPEED  OCC.   /VEH   SAT  FAIL
                          V-MIN V-MIN          V-MIN  SEC    SEC/MILE   SEC    SEC/MILE  DELAY   MPH                PCT


( 10,   1) 53.4    94   94.4  45.3  0.68  139.7   89.2    157.0     28.9      50.9      74   22.9    9.3   0.72    3    0
( 11,   1) 58.0   153  101.1  79.3  0.56  180.4   70.7    186.8     31.1      82.1      76   19.3   12.0   0.75    4    0
( 19,   1)171.2   452  296.7 237.1  0.56  533.8   70.9    187.1     31.5      83.1      67   19.2   35.8   0.72   12    0
( 20,   1)155.1   273  242.4 203.4  0.54  445.8   98.0    172.4     44.7      78.7      69   20.9   29.8   0.80   10    0
(  1,  20) 61.7   109  105.5  13.0  0.89  118.5   65.2    115.2      7.2      12.7       3   31.3    7.9   0.07    3    0
( 12,   2) 10.6    28   17.7  14.5  0.55   32.2   69.1    182.4     31.2      82.3      73   19.7    2.1   0.71    2    0
( 18,   2) 31.4    83   54.5  34.2  0.61   88.7   64.1    169.2     24.7      65.2      68   21.3    5.9   0.73    3    0
(  3,  21) 32.4   428   54.5  49.3  0.52  103.8   14.5    192.2      6.9      91.3      27   18.7    6.9   0.55   15    0
( 21,   3)  8.6   113   15.7  28.6  0.35   44.3   23.5    310.5     15.2     200.6      79   11.6    3.0   0.50    5    0
( 13,   3) 30.3    80   53.1  42.9  0.55   95.9   71.9    189.9     32.2      84.9      75   19.0    6.4   0.79    2    1
( 17,   3) 87.1   230  152.5 125.9  0.55  278.4   72.6    191.7     32.8      86.7      76   18.8   18.5   0.78    6    0
( 22,   3)201.6   442  394.2 266.2  0.60  660.5   89.7    196.6     36.1      79.2      61   18.3   44.3   0.71   12    0
( 22,   4)  8.8   116   17.6  17.1  0.51   34.8   18.0    237.3      8.9     117.0      71   15.2    2.3   0.44    5    0
( 14,   4) 22.0    58   37.0  25.9  0.59   62.9   65.1    171.8     26.8      70.6      73   21.0    4.2   0.74    3    0
( 16,   4) 45.8   121   79.2  65.5  0.55  144.6   71.7    189.3     32.5      85.7      74   19.0    9.6   0.79    5    0
( 15,   4)197.7   348  346.7 169.6  0.67  516.3   89.0    156.7     29.2      51.5      49   23.0   34.3   0.63   11    0
(  1,  10)157.9   278  258.3  72.8  0.78  331.1   71.5    125.8     15.7      27.7       1   28.6   22.0   0.06    8    0
(  1,  11)159.2   421  283.7  68.4  0.81  352.1   50.2    132.7      9.7      25.8       0   27.1   23.3   0.02    8    0
(  2,  12) 57.9   154  104.0  17.1  0.86  121.1   47.2    125.5      6.7      17.7       6   28.7    8.0   0.19    5    0
(  3,  13)118.0   313  207.7  44.1  0.82  251.8   48.3    128.0      8.5      22.4       2   28.1   16.7   0.05    6    0
(  4,  14) 37.0    98   65.4  12.2  0.84   77.5   47.5    125.6      7.4      19.7       2   28.7    5.2   0.05    3    0
(  4,  15) 80.6   142  164.6  16.5  0.91  181.1   76.5    134.9      7.0      12.3       3   26.7   12.0   0.04    4    0
(  4,  16) 11.7    31   21.3   2.1  0.91   23.4   45.3    120.2      4.2      11.0       8   29.9    1.6   0.10    1    0
(  3,  17) 29.1    77   49.4   7.3  0.87   56.7   44.2    117.1      5.7      15.1       4   30.7    3.7   0.06    2    0


(  2,  18) 14.0    37   23.3   3.5  0.87   26.8   43.5    115.0      5.7      15.1      12   31.3    1.8   0.19    1    0
(  1,  19) 59.7   158  106.6  20.3  0.84  126.9   48.2    127.5      7.7      20.4       0   28.2    8.4   0.02    3    0
(  2,  20) 20.8   274   33.6   8.1  0.81   41.7    9.1    120.4      1.8      23.4       2   29.9    2.8   0.03    8    0
( 20,   2)  8.3   109   14.2  13.1  0.52   27.4   15.1    199.0      7.2      95.5      77   18.1    1.8   0.21    4    0
( 21,   2) 95.7   400  162.2  81.2  0.67  243.4   36.5    152.6     12.2      50.9      18   23.6   16.1   0.11   12    0
(  2,  21) 27.2   114   51.9   6.3  0.89   58.2   30.5    128.2      3.3      13.9       3   28.1    3.9   0.07    4    0
(  4,  22) 27.7   367   49.6  23.1  0.68   72.7   11.9    157.5      3.8      50.1       4   22.9    4.8   0.10    9    0
(  3,  22) 53.3   117  107.3  11.0  0.91  118.3   60.7    133.3      5.6      12.4       3   27.0    7.9   0.06    4    0


                                             NETWORK STATISTICS


      VEHICLE-MILES=2133.71       VEHICLE-MINUTES=  5590.9       VEHICLE-TRIPS (EST.)= 1677       STOPS/VEHICLE= 1.37

   MOVING/TOTAL TRIP TIME=0.674    AVG. SPEED (MPH)=22.90   MEAN OCCUPANCY= 372.2 VEH.    AVG DELAY/VEHICLE= 65.30 SEC

      TOTAL DELAY= 1825.1 MIN.         DELAY/VEH-MILE= 0.86 MIN/V-MILE         TRAVEL TIME/VEH-MILE= 2.62 MIN/V-MILE

                              STOPPED DELAY AS A PERCENTAGE OF TOTAL DELAY=51.9

                               SEED FOR RANDOM NUMBER GENERATOR IS    18672443
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APPENDIX G COMPARISONS OF THE PASSER II-80, PASSER II-84, TRANSYT-7F AND MAXBAND COMPUTER PROGRAMS.

	PASSER II-84	PASSER II-80	MAXBAND (MITROP)	TRANSYT-7F
Control Variables	Cycle Offset ϕ-Sequence ϕ-Length	Cycle Offset ϕ-Sequence ϕ-Length	Cycle Offset ϕ-Sequence ϕ-Length	Cycle Offset ϕ-Length
Optimization	Max. Bandwidth Min. Interference Delay-Offset	Max. Bandwidth Min. Interference	Max. Bandwidth MPCODE	Min. Delay
Solution	Local Optimum	Local Optimum	Global Optimum	Local Optimum
Objective Function	Max. Efficiency Min. System Delay	Max. Efficiency	Min.(Flow x Cost) Offset Split Cycle	Min. PI =(Delay + k x stops)
Delay Measurement	Mod. Webster NCHRP-TTI-PINY	Mod. Webster	Link Performance Saturation Deterrence	Platoon Representation by Flow Profile
Delay Componet	1. Uniform Delay 2. Overflow Delay	1. Uniform Delay 2. Random Delay 3. Empirical Adj.	1. Deterministic Queue 2. Stochastic Overflow	1. Uniform Delay 2. Random Delay 3. Saturation Delay
Fuel Consumption	Yes	No	No	Yes
Data Input Base	Node	Node	Node	Link
Phase Selection	PASSER NEMA or Combinations	PASSER ($^{A}_{B}$ Dir.) NEMA	Inbound Outbound	Link Movements