TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
TTI-2-18-76-178-1		

4. Title and Subtitle A Report on The User's Manual For Diamond Interchange Signalization--PASSER III	5. Report Date August, 1977 6. Performing Organization Code
7. Author(s) Daniel B. Fambro, Donald L. Putman, Herman E. Haenel, Larry W. Cervenka, and Carroll J. Messer	8. Performing Organization Report No.
9. Performing Organization Name and Address Texas Transportation Institute Texas A&M University College Station, Texas 77843	10. Work Unit No. 11. Contract or Grant No. Research Study 2-18-76-178
12. Sponsoring Agency Name and Address State Department of Highways and Public Transportation P. O. Box 5051 Austin, Texas 78763	13. Type of Report and Period Covered Interim - September 1975 August 1976 14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with DOT, FHWA.
Research Study Title "Development of a Frontage Road Level of Service Evaluation Program - Passer III

16. Abstract

This report describes the user's manual for PASSER III, a practical computer program developed to assist the traffic engineer in determining optimal traffic signal timings for pretimed or traffic-responsive, fixed-sequence signalized diamond interchanges. The program is applicable to isolated interchanges as well as to a series of interchanges through which progression is desired along the frontage roads. In addition, design engineers may use PASSER III to evaluate the effectiveness of proposed interchange design alternatives.

PASSER III can evaluate any signal timing plan that might exist at a signalized diamond interchange. Four basic signal phasing sequences (phasing codes) can be analyzed. A fifth phasing code, phasing code 1A, has the same phasing sequence as code 1, but the green splits are calculated by a different procedure. However, both methods of calculating green splits are based on the approach movement volume to signal capacity ratios. The program also determines the level of service for each phase at the intersections which make up a diamond interchange. PASSER III provides all data required to implement the signal timing plan it calculates.

Two typical example programs, an isolated interchange and a frontage road progressive system, were coded and executed by PASSER III. The completed input data card coding forms and the program output, including time-space diagrams for the progression solution, are contained in this report.

17. Key Words	18. Distribution Statement
Diamond Interchanges, Signalization, Frontage Road Progression, Delay-Offset, Level of Service, PASSER III	No Restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22151.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	66	

Form DOT F 1700.7 (8-69)

A REPORT ON THE USER'S MANUAL FOR DIAMOND INTERCHANGE SIGNALIZATION--PASSER III

by

Daniel B. Fambro
Engineering Research Associate
Texas Transportation Institute

Donald L. Putman
ADP Programmer
File D-19
Texas State Department of Highways
and Public Transportation

Herman E. Haenel
Supervising Traffic Engineer
File D-18T
Texas State Department of Highways
and Public Transportation

Larry W. Cervenka
Traffic Engineer
File D-18T
Texas State Department of Highways
and Public Transportation

Carroll J. Messer
Associate Research Engineer
Study Supervisor
Texas Transportation Institute

Research Report Number 178-1

Development of a Frontage Road Level
of Service Evaluation Program - PASSER III

Research Study Number 2-18-76-178

Sponsored by the Texas
State Department of Highways and Public Transportation
In Cooperation with the
U.S. Department of Transportation
Federal Highway Administration

Texas Transportation Institute
Texas A&M University
College Station, Texas

August 1977

ABSTRACT

This report describes the user's manual for PASSER III, a practical computer program developed to assist the traffic engineer in determining optimal traffic signal timings for pretimed or traffic-responsive, fixed-sequence signalized diamond interchanges. The program is applicable to isolated interchanges as well as to a series of interchanges through which progression is desired along the frontage roads. In addition, design engineers may use PASSER III to evaluate the effectiveness of proposed interchange design alternatives.

PASSER III can evaluate any signal timing plan that might exist at a signalized diamond interchange. Four basic signal phasing sequences (phasing codes) can be analyzed. A fifth phasing code, phasing code 1A, has the same phasing sequence as code 1, but the green splits are calculated by a different procedure. However, both methods of calculating green splits are based on the approach movement volume to signal capacity ratios. The program also determines the level of service for each phase at the intersections which make up a diamond interchange. PASSER III provides all data required to implement the signal timing plan it calculates.

Two typical example programs, an isolated interchange and a frontage road progressive system, were coded and executed by PASSER III. The completed input data card coding forms and the program output, including time-space diagrams for the progression solution, are contained in this report.
Key Words: Diamond Interchanges, Signalization, Frontage Road Progression, Delay-Offset, Level of Service, PASSER III

SUMMARY

With increasing demands on urban freeways, frontage roads are becoming more important as a source of additional capacity for the main lanes. An alternate route in the freeway corridor is especially beneficial during rush hour or incident conditions. To make the best use of these existing facilities, it is essential that intersections along the frontage roads operate in the most efficient manner possible. Toward this goal, the Texas State Department of Highways and Public Transportation in cooperation with the U.S. Department of Transportation, Federal Highway Administration sponsored a cooperative research project with the Texas Transportation Institute entitled "Development of a Frontage Road Level of Service Evaluation Program -- PASSER III" which addressed several objectives related to improving frontage road-freeway design and operations. This report presents the user's manual for the diamond interchange signalization computer program, PASSER III, developed in this research project.

The program was developed to assist the traffic engineer in determining the optimal traffic signal timings for pretimed or traffic-responsive, fixed-sequence signalized diamond interchanges. It is applicable to isolated interchanges as well as to a series of interchanges through which progression is desired along the frontage roads. In addition, design engineers may use the program to evaluate the effectiveness of proposed interchange design alternatives. PASSER III provides all information required for the field implementation of the signal timing plan it calculates.

The program can evaluate any signal timing plan that might exist at a signalized diamond interchange. The four basic signal phasing sequences (phasing codes), lead-lead, lag-lead, lead-lag and lag-lag, can be analyzed. A fifth phasing code, phasing code 1A, has the same phasing sequence as code 1, but the green splits are calculated by a different procedure. However, both methods of calculating green splits are based on the approach movement volume to signal capacity ratios. All interchange signal timing plans can be analyzed by the delay-offset technique to determine which pattern provides the smallest overall interchange delay. Both interior and exterior movement delays are calculated by the program. Interior maximum queue lengths per cycle are compared to the queue storage provided by the design. Based on selected measures of effectiveness, the program determines the level of service for each phase at the intersections which make up the diamond interchange. The program is structured to evaluate either proposed designs

or existing facilities on an individual interchange basis.

Linked to the isolated diamond interchange program, to be used when desired on an optional basis, is the frontage road progression program. This program can analyze the diamond interchange frontage road network as if it were a signalized arterial. Optimal frontage road progression time-space diagrams can be developed and offsets calculated. A complete frontage road level of service analysis is provided including frontage road travel times.

The user's manual contains detailed, step-by-step instructions for filling out the two input data card forms that were developed to assist the engineer in the coding of data. Both forms are illustrated in the report. The options available to users of this program along with the parameters required for their execution are discussed. Two example problems, one isolated interchange and one frontage road progressive system, were coded by the authors and analyzed by PASSER III. The completed input data card coding forms and the program output, including the optimal time-space diagrams for the progression solution, are contained in the final section of the report.

Implementation

The results of this research, a practical and efficient computer program, have been directly implemented on the Department's computer system in Austin through the Division of Automation. The program will be available statewide to Texas State Department of Highways and Public Transportation engineers and may be accessed at the District remote terminal units. The results generated by this program should prove most helpful in preparing traffic signal timing plans for diamond interchanges and for evaluating existing and proposed design alternatives.

TABLE OF CONTENTS

INTRODUCTION TO PASSER III

Background

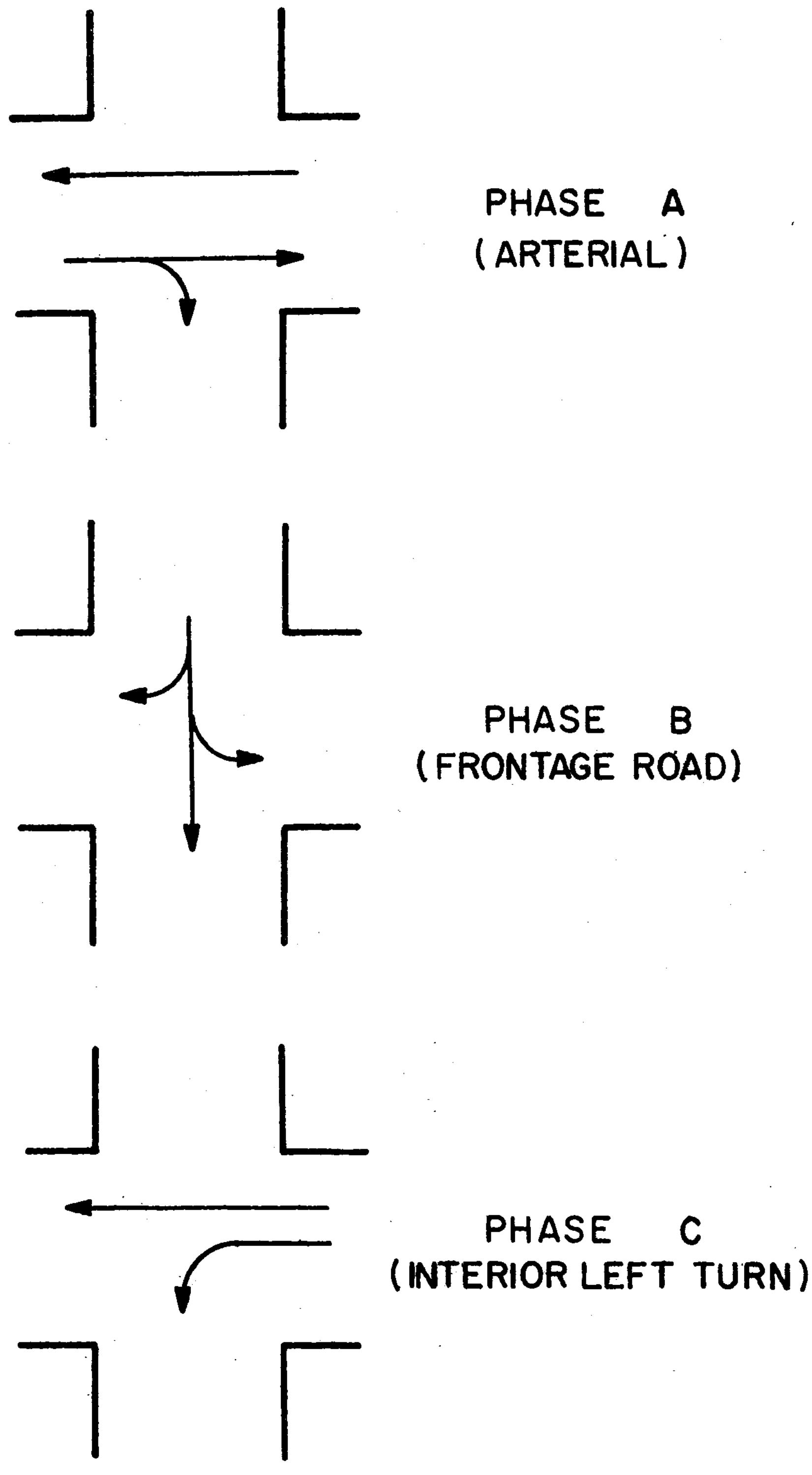
PASSER is an acronym for Progression Analysis and Signal System Evaluation Routine. PASSER III is a practical computer program developed to assist the traffic engineer in determining optimal traffic signal timings for pretimed or traffic-responsive, fixed-sequence signalized diamond interchanges. The program is applicable to isolated interchanges as well as to a series of interchanges through which progression is desired along the frontage roads. In addition, design engineers may use this program to evaluate the effectiveness of proposed interchange design alternatives.

The basic theory of the progression option of the program was developed and tested by the Texas Transportation Institute in the Dallas Corridor Project sponsored by the Federal Highway Administration and described in a previous publication (1). PASSER was adapted for off-line processing and analysis purposes in HPR Project 165, and a Level-of-Service determination for the approaches to an intersection was undertaken in HPR Project 203. Both projects were sponsored by the Texas State Department of Highways and Public Transportation, and the results of each have been documented in several reports (2, 3, 4).

The development of PASSER III was undertaken in HPR Project 178 which was also sponsored by the Texas State Department of Highways and Public Transportation. A more detailed discussion of the operational theory and field validation of this program is contained in a companion report (5). Program users should be familiar with all aspects of Chapter 2 in Reference 5 before using PASSER III.

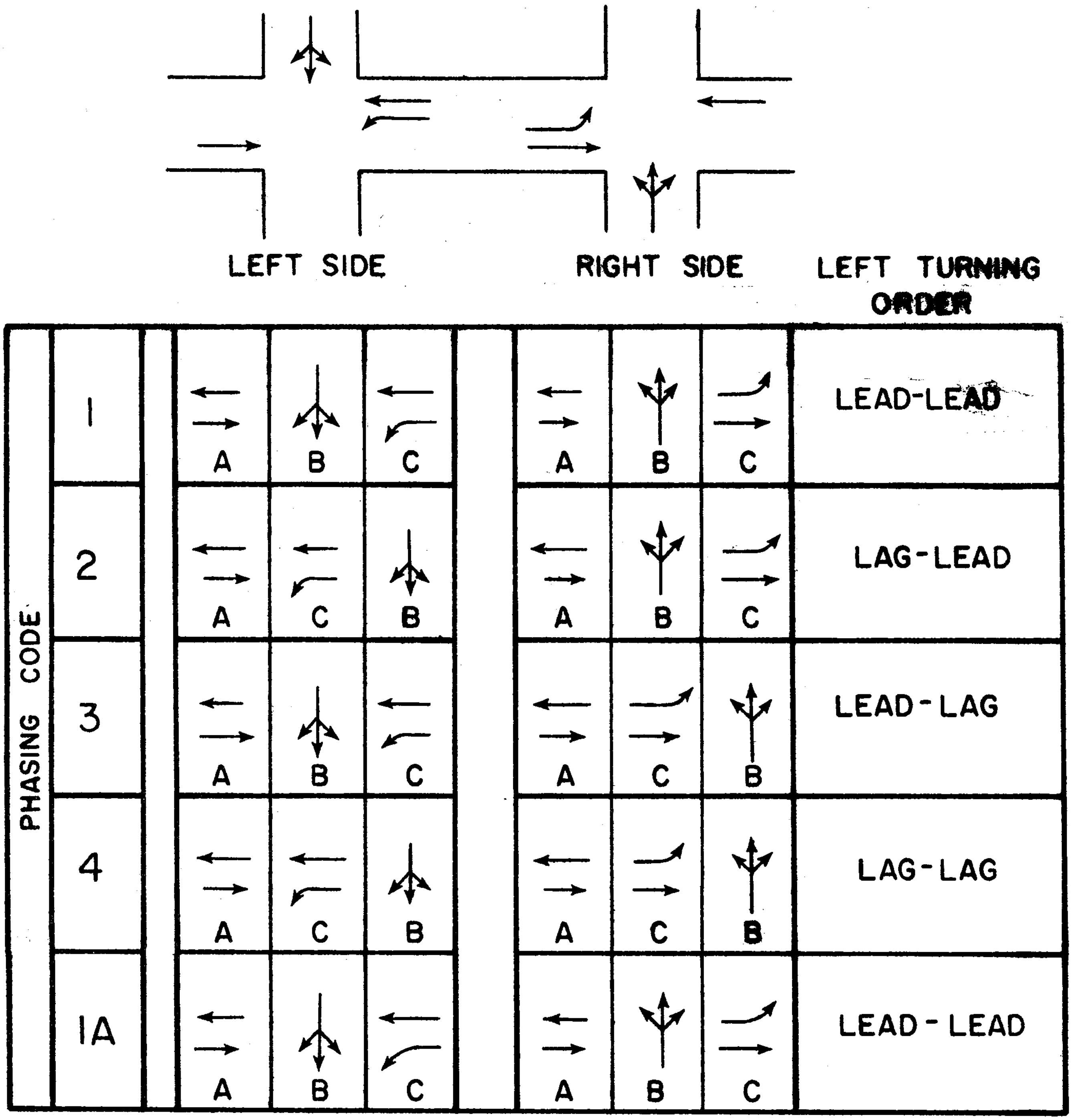
Diamond Interchange Signalization

The program determines the traffic signal timings (splits) and the level of service for each phase at the two intersections which make up a diamond interchange. The three basic protected signal phases (shown in Figure 1) that exist at one intersection of the interchange can be combined with the three basic phases that exist at the other intersection in four possible sequences (6). These four phase sequence combinations (shown in Figure 2) are called phasing codes in PASSER III. For phasing codes one (1) through four (4), traffic signal timings are calculated by the Webster



Three Basic Phases at Left-Side
Intersection of Interchange

Figure 1



Phase Sequences for Phasing
Codes Used by PASSER III

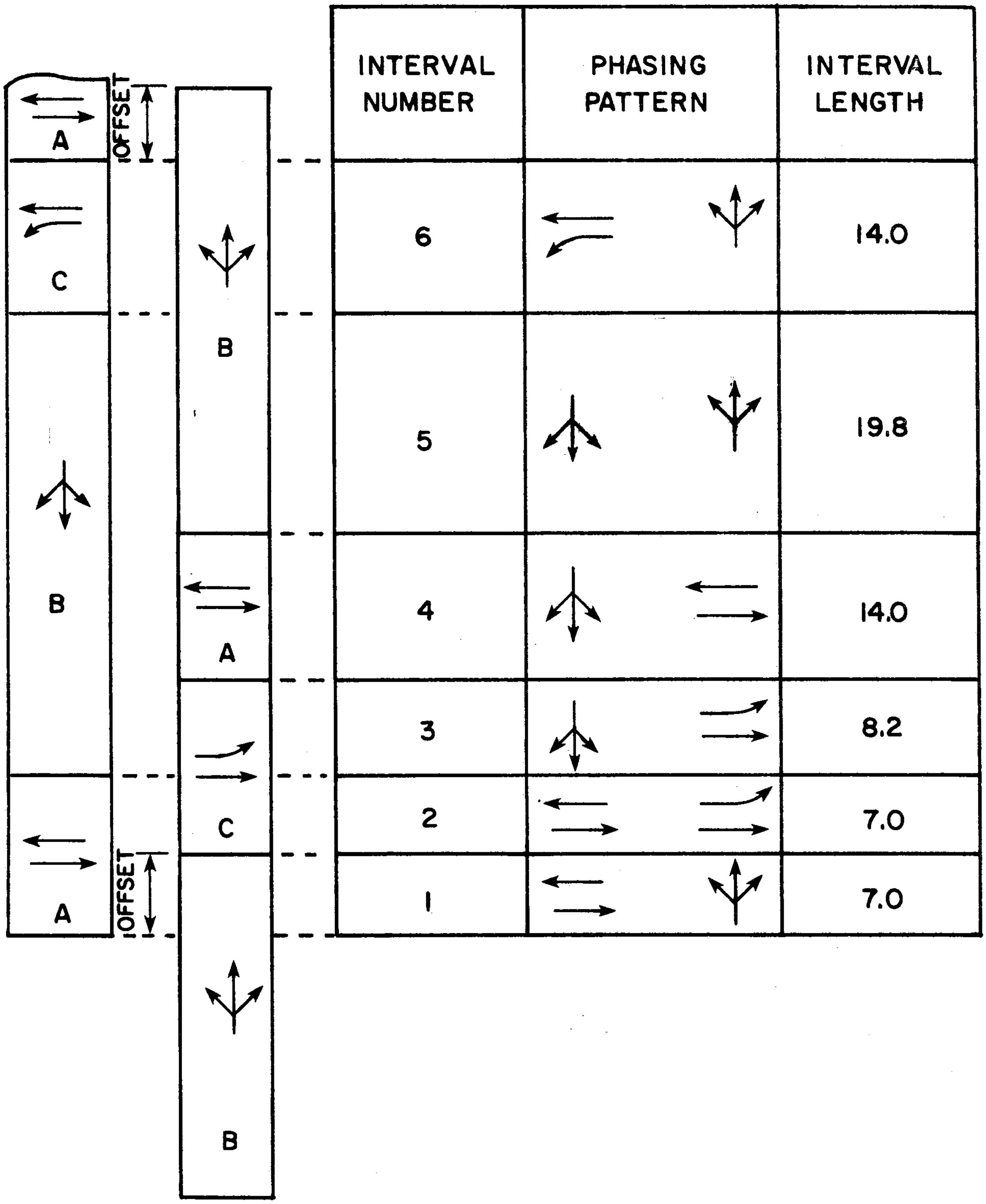
Figure 2

method (7). A modification of phasing code 1, phasing code 1A, uses the four-phase with overlap procedure (8) to calculate the green splits. Although the green splits computed by the two signal timing methods will usually be different, the phase sequence order for phasing codes 1 and 1A is the same. In both methods green splits are calculated based on approach movement volume to signal capacity ratios. Therefore, the effectiveness of either signal timing plan will depend on the quality of the volume and movement capacity (saturation flow) data provided to the program.

One optional output of the program determines a signal timing plan (green splits, phase sequence order and offset between the two signals) which minimizes average delay per vehicle experienced by all vehicles using the signalized diamond interchange. Delay to the exterior movements is calculated using Webster's delay equation (9), and delay to the interior movements is computed from a modification of the deterministic delay-offset technique (10, 11, 12). This feature of the program allows the traffic engineer to select the optimal signal timing plan or to evaluate the effectiveness of a specific timing plan at any interchange. A brief discussion of this feature follows.

As the internal offset (length of time from the start of the left side basic phase "A" to the end of right side basic "B") varies from zero to the cycle length in one second increments, different signal timing plans result. For a sixty second cycle, sixty timing plans would exist for each phasing code. One or more phasing codes can be analyzed during a single run with the average delay per vehicle being calculated for each signal timing plan. The objective of this feature of the program is to find the offset for each phasing code that minimizes the delay and from those minimums select the lowest possible delay value.

A second output of the program provides a phase interval chart which is simply the signal timing plan selected by the delay-offset analysis with the individual phase intervals defined according to the basic phase (Figure 1) that exists at each frontage road intersection during the phase interval and the time duration of that interval (Figure 3). Assume that phasing code number one shown in Figure 2 is found to provide the minimum delay solution when the internal offset between the two frontage road intersections is seven seconds. The signal timing plan that would result is illustrated in Figure 3.



Development of Diamond Interchange
Phasing Pattern and Phase Interval
Chart from Phasing ABC:ABC and
Offset

Figure 3

Isolated Interchange Operations

PASSER III was developed in part to calculate the signal timing information needed for the plan development and field implementation of a pretimed or traffic-responsive, fixed-sequence signalized diamond interchange. The program will calculate the optimal green times and will provide the following measures of effectiveness for each movement at the two intersections which make up the diamond interchange:

1. Demand to signal capacity ratio, X-ratio, for the critical lane.
2. Average vehicular delay, sec./veh.
3. Probability of clearing the queue for the critical lane.
4. Storage ratio on interior movements.

If the traffic engineer is concerned with minimizing individual vehicle delay at a particular diamond interchange, the program will determine the optimal signalization strategy for that interchange (delay-offset analysis). This can be done by selecting the best solution from all signal timing plans (Figure 3) that can be generated from each phasing code (Figure 2) the user wants to consider. The program varies the internal offset in one second increments throughout the cycle length (sixty signal timing plans for a sixty second cycle) for each phasing code. PASSER provides a plot of individual vehicle delay as a function of the internal offset for each phasing code that is analyzed (Figure 11).

Frontage Road Progression Operations

Another PASSER III output will provide a frontage road progression solution. This solution can either be one-way progression along either of the two frontage roads or maximum possible two-way progression along both frontage roads. The user may select either option as desired. All standard output and options applicable to isolated interchange operation apply to a progressive system as well. Green times, operational measures of effectiveness and phase interval charts will be provided for each interchange in the frontage road system. A delay-offset analysis is still optional for each interchange, but is generally not recommended in combination with the progression output (due to run cost).

Several progression options are also available to program users. These include searching for the cycle length and progression speed (between specified bounds) which provide the optimal progression solution, specifying the percent of the total progression bandwidth to be provided in the "B" direction and requesting a printer and/or line plot of the optimal progression solution. Standard output of the progression feature of the program includes several system measures of effectiveness (bandwidths, progression speeds and travel times in both directions and the efficiency and attainability of the solution) together with all information needed to implement the optimal solution in the field (phase interval charts and offsets for each interchange).

Data Requirements

Much of the input data required by the program is similar to that needed by the PASSER II signal timing program. Allowable cycle lengths, turning movement volumes, number of effective lanes and minimum green times are required to analyze an isolated interchange. The Webster method described in Appendix A can be used in developing the cycle lengths to be analyzed by the program. If progression is desired, interchange distances and progression speeds are needed to arrive at an optimal solution. In addition, the traffic engineer can specify a particular signal timing plan at an interchange or a set of allowable timing plans. Each allowable timing plan for the interchange is analyzed to determine the pattern which gives the best frontage road progression. If a delay-offset analysis is desired, additional information such as the travel times and queue storages for interior movements is required as input data as well as the specific types of signalization to be evaluated. Sample input coding sheets are shown in Figures 4 and 5, and two example programs are shown in another section of this report.

Results generated by this program may not necessarily represent the optimal solution for a particular interchange and/or progressive system. However, the user can approach the optimal solution by supplying the most accurate values for data such as the average speed, the queue clearances, the intersection traffic volumes, the number of effective lanes and suitable minimum green times. If the "floating car" study, calculated system cycle length or other similar studies as well as traffic and pedestrian counts are used as a basis for determining the values supplied to the program, the probability of approaching an optimal solution will be greatly increased.

TEXAS STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION Form 1405-1

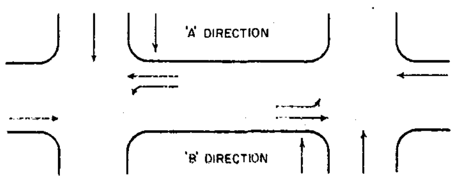
PROGRESSION ANALYSIS AND SIGNAL SYSTEM EVALUATION ROUTINE FOR DIAMOND INTERCHANGES-'PASSER III'

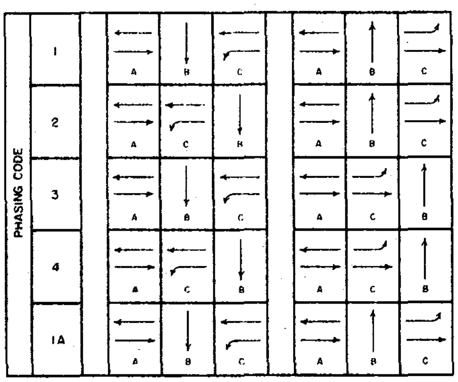
FREEWAY HEADER CARD FORM (One card per freeway)

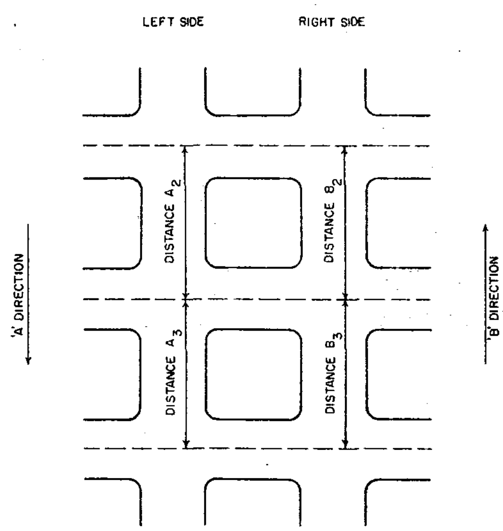
CODE 0 IF NO
CODE 1 IF YES

NAME OF CITY	NAME OF FREEWAY	DIST.	DATE			RUN NO.	Number of Interchanges	Isolated?	[illegible]
			MO.	DATE	YEAR				
1 – 12	36	38	40	42	44	46	48	49	

INTERCHANGE HEADER CARD FORM (One card per interchange)







CODE 0 IF NO
CODE 1 IF YES

CROSS STREET NAME	INTERCHANGE NUMBER	CYCLE LENGTH (SEC)	DELAY-OFFSET ANALYSIS ?					PERMISSIVE LEFT TURNS?		INTERIOR TRAVEL TIME (SEC.)		INTERIOR QUEUE STORAGE (VEHICLES)				[illegible]	PRIORITY PHASING ? (INTERNAL OFFSET, SEC.)				
												RIGHT SIDE		LEFT SIDE							
			CODE 1	CODE 2	CODE 3	CODE 4	CODE 1A	LEFT SIDE	RIGHT SIDE	LEFT TO RIGHT	RIGHT TO LEFT	THROUGH	LEFT TURN	THROUGH	LEFT TURN		CODE 1	CODE 2	CODE 3	CODE 4	CODE 1A
1 – 12	14	17	18	19	20	21	22	23	24	26	28	30	32	34	36		54	56	58	60	62

Figure 4

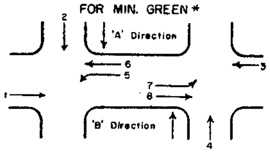
TEXAS STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

Form 1405-2

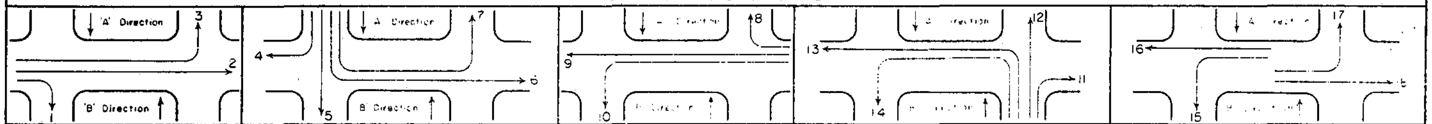
PROGRESSION ANALYSIS AND SIGNAL SYSTEM EVALUATION ROUTINE FOR DIAMOND INTERCHANGES - 'PASSER III'

INTERCHANGE DETAIL CARD FORM (Three cards per interchange)

VEHICLE MOVEMENTS FOR MIN. GREEN *



VEHICLE MOVEMENTS



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		

Figure 5

PROGRAM CODING INSTRUCTIONS

Freeway and Interchange Card Forms

Two input data card coding forms provided to assist the user in coding the necessary data required by the program are shown in Figures 4 and 5. These two coding forms contain the following data inputs:

1. FREEWAY HEADER (one card per freeway) and INTERCHANGE HEADER (one card per interchange).
2. INTERCHANGE DETAIL (Three cards per interchange).

Freeway Header Card - This first card identifies the freeway along which the diamond interchange(s) to be analyzed is (are) located. It also defines some general analysis parameters and options.

Columns 1-12:	Name of City - Enter the name of the city, beginning in Column 1.
Columns 13-36.	Name of Freeway - Enter the name of the freeway, beginning in Column 13.
Columns 37-38:	Dist. - Enter the district number, ending in Column 38.
Columns 39-44:	Date - Enter the date.
Columns 45-46:	Run No. - Enter an arbitrary number to aid in identifying different sets of input data.
Columns 47-48:	Number of Interchanges - Enter the number of signalized interchanges to be analyzed, ending in Column 48. The maximum number is 15.
Column 49:	Isolated? - If a one (1) is entered in Column 49, isolated interchange operations are desired, and the program will calculate green splits for each interchange in the data set for which volume data are provided. The program will not search for an optimal frontage road progression solution. If an optimal frontage road progression solution is desired, Column 49 should be skipped (left blank).

If a frontage road progression solution is desired, Columns 50 through 69 on the Freeway Header Card must be coded. Do not code columns 50-69 if isolated operations are desired.

Column 50:	Progression? - If a one (1) is entered in Column 50, the program will calculate green splits for each interchange in the data set and also search for an optimal frontage road progression solution.
Columns 51-53:	Lower Cycle Length - Enter the smallest cycle length (in seconds) that the program may consider in finding the optimal progression solution, ending in Column 53.

It must be as large as the sum of the minimum conflicting greens. To permit program flexibility, a value of at least four seconds greater than the sum of the minimum conflicting greens is suggested.

The smallest permissible cycle length should be calculated beforehand by using some suitable method for optimal cycle length determination at individual intersections. A review of one such method, the Webster method, is given in Appendix A.

Each interchange along a frontage road will generally have a different optimal cycle length from the other interchanges. The smallest permissible cycle length should not be less than 0.85 times the largest optimal cycle length. A value closer to the largest interchange optimal cycle length is preferred from an operational standpoint. Also, it should not normally be greater than 1.25 times the smallest individual optimal cycle length although a value of 1.5 is permissible when the minimum cycle length is small.

Columns 54-56: Upper Cycle Length - Enter the largest cycle length (in seconds) that the program may consider in finding the optimal progression solution, ending in Column 56. This upper bound on the cycle length is usually no more than 10 seconds greater than the lower bound value. If a progression solution for only one cycle length is desired, the same cycle length should be entered for the lower and upper cycle length limits.

Columns 57-58: Cycle Length Increment - Enter the increment (in seconds) used by the program to evaluate between the lower and upper cycle length limits, ending in Column 58. A five-second increment is recommended for pretimed signal systems, but a different increment could be used for digital or analog traffic-responsive systems.

Columns 59-60: Min. 'B' Direction Band Split - <u>Option 1</u>. The user may specify the percent of the total progression bandwidth to be provided in the "B" direction, ending in Column 60. The optimal progression solution determined by the program will be limited to one which provides a bandwidth at least equal to this coded value. However, if conditions allow, a larger "B" direction band will be provided, resulting in different band splits than those input. If no percentage is entered, the "A" and "B" direction bands will be split generally in proportion to the traffic volume distribution in the "A" and "B" directions.

Min. 'B' Direction Band Split - <u>Option 2</u>. If a one (1) is coded in column 60, perfect one-way progression will be provided in the "A" direction. If a ninety-nine (99) is coded in columns 59-60, one-way progression will be provided in the "B" direction.

Column 61: Link Speed Search? - If a one (1) is entered in this column, the program will search for an optimal solution by varying all link speeds within ± 2 MPH increments of the link speeds coded in Columns 41-42 and 47-48 of the Interchange Header Cards. If Column 61 is skipped (left blank), no link speed search is conducted.

Column 62: Printer Plot? - Enter a one (1) if it is desired to have the optimal time-space progression diagram printed on the district terminal printer. If it is not desired to have the optimal time-space diagram printed on the district terminal printer, Column 62 must be skipped (left blank).

Column 63: Line Plot? - Enter a one (1) if it is desired to have the optimal time-space diagram plotted by a D-19 line plotter. If it is not desired to have the optimal time-space diagram plotted by the D-19 line plotter, Column 63 must be skipped (left blank).

If a D-19 line plot was not requested, Columns 64-69 should be skipped (left blank).

Columns 64-65: If a D-19 line plot has been requested, code the number of seconds that are equal to one inch for scaling the plot.

Columns 66-69: If a D-19 line plot has been requested, code the number of feet that are equal to one inch for scaling the plot.

Interchange Header Card - The Interchange Header Card provides signalization and geometric information for each signalized interchange in the data set. One card (one line of information) is required for each interchange to be analyzed. If a frontage road progression solution is desired, additional information about the link to the next interchange along the frontage road also must be provided.

Columns 1-12: Cross-Street Name - Enter the name of the arterial cross-street at this interchange, beginning in Column 1.

Columns 13-14: Interchange Number - Enter the interchange sequence number in the "A" direction, ending in Column 14. The maximum number is 15. As noted in the figure of the Interchange Header Card (Figure 4), the "A" direction can be selected to be either direction along the frontage road. However, all signal progression offsets will be calculated with respect to the start of basic phase "A" at the first interchange in the "A" direction.

If an optimal frontage road progression solution has been requested, Columns 15-17 of the Interchange Header Card shall be skipped (left blank).

Columns 15-17: Cycle Length - If an optimal frontage road progression solution was not requested, enter the desired cycle length for the interchange(s), ending in Column 17. It must be as large as the sum of the minimum conflicting greens. To permit program flexibility, a value of at least four seconds greater than the sum of minimum conflicting greens is recommended.

As many as 15 interchanges with the same cycle length can be analyzed during one computer run.

The cycle length should be calculated beforehand by using some suitable method for cycle length determination at individual intersections. A review of one such method, the Webster method, is given in Appendix A.

When an optimal frontage road progression solution has been requested by the user, Columns 18-36 shall be skipped (left blank) in most cases. Evaluating more than one cycle length by the delay-offset technique when the progression option is in effect would generate a staggering amount of output, and use computer time which would be of considerable expense to the user.

Columns 18-22: Delay-Offset Analysis? - These five columns correspond to the five phasing codes shown in the figure of the Interchange Header Card (Figure 4). A delay-offset analysis can be requested for any or all five phasing codes. Enter a one (1) in the appropriate column to request a delay-offset analysis for that phasing code. If a delay-offset analysis is not desired for a particular phasing code, the corresponding column must be skipped (left blank).

Columns 23-24: Permissive Left Turns? - Enter a one (1) in Column 23 if a combination protected and unprotected left turns [circular green with green arrow followed by circular green (or vice versa) for left turn movements onto the frontage road] onto the frontage road are permitted at the left side intersection shown in the figure of the Interchange Header Card (Figure 4). Enter a one (1) in Column 24 if a combination protected and unprotected left turns are allowed at the right side intersection. If the protected and unprotected left turns are not permitted, the appropriate column must be skipped (left blank).

Columns 25-28: Interior Travel Time - Enter the travel time (in seconds) from the left side intersection to the right side intersection as shown in the figure of the Interchange Header Card, (Figure 4), ending in Column 26. Enter the travel time (in seconds) from the right side intersection to the left side intersection ending in Column 28.

The travel time is the time required for a queue of vehicles stopped at one intersection to start up and travel to the adjacent intersection. To assist users of this program, recommended travel times for interchanges with various internal spacings between the intersections are shown in Table 1.

TABLE 1. INTERCHANGE INTERIOR TRAVEL TIME AND OVERLAP AS A FUNCTION OF SEPARATION DISTANCE BETWEEN INTERSECTION STOP LINES

Distance (feet)	Travel Time[a] (seconds)	Overlap[b] (seconds)
67	6	4
94	7	5
125	8	6
160	9	7
200	10	8
244	11	9
288	12	10
322	13	11
376	14	12
420	15	13

[a] Travel time of through vehicle from stop line on exterior approach to interior stop line at downstream intersection. Calculated from $T = 0.5 + (0.45 \cdot d)^{0.5}$; 30 m.p.h. maximum speed. Coded in columns 25-28 of the Interchange Header Card.

[b] Used primarily with Phase Code 1A; four-phase overlap signalization. Provides a two second advance green. Coded in columns 61-62 of the Interchange Header Card.

Columns 29-30: Interior Queue Storage - Enter the queue storage in number of vehicles for vehicles traveling from left to right and proceeding straight through the right intersection, ending in Column 30.

An estimate of queue storage can be obtained by assuming that one vehicle occupies 25 feet of lane space. Multiple through lane storage must be added. A lane may share storage between left turn and through movements.

Columns 31-32: Interior Queue Storage - Enter the queue storage in number of vehicles for vehicles traveling from left to right and turning left at the right intersection, ending in Column 32.

Columns 33-34: Interior Queue Storage - Enter the queue storage in number of vehicles for vehicles traveling from right to left and proceeding straight through the left intersection, ending in Column 34.

Columns 35-36: Interior Queue Storage - Enter the queue storage in number of vehicles for vehicles traveling from right to left and turning left at the left intersection, ending in Column 36.

If a frontage road progression solution has been requested, Columns 37-52 of the Interchange Header Card must be completed.

Columns 37-40: "A" Direction Distance - Enter the distance in feet along the frontage road from this interchange to the next interchange in the "A" direction, ending in Column 40. See the figure of the Interchange Header Card (Figure 4) for illustration.

Columns 41-42: "A" Direction Speed - Enter the desired average progression speed in miles per hour for the link whose distance was just coded in Columns 37-40.

The "average speed" (in MPH) between interchanges for each direction of travel should be the average speeds during peak and off-peak volume conditions. The "floating car" or some similar study can be used to determine these average speeds. The "floating car" study is based on the average speed (between two points) found by traveling within or following platoons of vehicles. This average speed is determined from five to ten trial runs made during off-peak volume conditions, five to ten trial runs made during AM peak period conditions, or five to ten trial runs made during PM peak period conditions. The speeds obtained should be free-flowing speeds of platoons between stop signs and stops at traffic signals. If there are only a few vehicles on the frontage road (not enough to constitute a platoon), the observer should travel at a comfortable speed keeping in mind the few vehicles on the frontage road so as to obtain a reasonable average speed. In such an instance, 10 runs should be made along each frontage road. Trial runs during both off-peak and peak periods should be made to determine if different average speeds occur. If they do, two or three time-space diagrams should be prepared. The "average speed" shown in columns 41-42 and 47-48 should normally be 2 to 4 miles per hour below the average speed obtained from the "floating car" study.

The user may not wish to enter a different average progression speed for each link along a frontage road even though the speeds vary. For example, if the "A" direction average speed between interchanges 1 and 2 is 30 MPH and the "A" direction average speed between interchanges 2 and 3 is 26 MPH, Columns 41-42 for both Interchanges 1 and 2 could show "28."

Columns 43-46: "B" Direction Distance - Enter the frontage road distance in feet in the "B" direction from the next interchange back to this one, ending in Column 46. (See the figure of the Interchange Header Card, Figure 4.) Usually this distance is the same as that coded in Columns 37-40.

Columns 47-48: "B" Direction Speed - Enter the desired average progression speed in miles per hour for the link whose distance was just coded in Columns 43-46.

The last interchange along the frontage road will not have a downstream link to code. Therefore, the last Interchange Header Card would have Columns 37-48 blank (i.e., no link distance and speed information).

Columns 49-50: "A" Direction Queue Clearance - If it is desired to insure that the progression band will lag the start of the "A" direction progressive green by a certain amount at the interchange, enter this amount of lag time in seconds, ending in Column 50. This lag time (queue clearance time) should not exceed five seconds. If an insured lag time is not desired, these columns must be skipped (left blank).

PASSER attempts to balance out "slack" time and, as a consequence, some progression lag time may occur at a signal even if no assured time is provided. Hand adjustments of the offsets from the time-space diagram normally can also provide some progression lagging for a given optimal progression solution.

Columns 51-52: "B" Direction Queue Clearance - If an insured lag time is desired for the "B" direction at this signal, enter this progression band lag in seconds, ending in Column 51. This lag time should not exceed five seconds. Normally, columns 49-50 and 51-52 will be skipped (left blank).

<u>Columns 53-62 must be coded.</u>

Columns 53-62: Priority Phasing? - Internal offset values are entered into these ten columns, two columns for each of the five phasing codes shown in the figure of the Interchange Header Card (Figure 4). The internal

offset is defined as the time in seconds from the beginning of basic phase "A" at the left side frontage road intersection to the end of basic phase "B" at the right side frontage road intersection.

If a delay-offset analysis was not requested, internal offsets must be selected by the user and must be coded into the columns corresponding to all phasing patterns which are being evaluated. Internal offset values can range from zero to the cycle length. Since an internal offset of zero is possible, a minus one (-1) must be entered into the columns corresponding to all phasing patterns which are not being evaluated by the program.

If a delay-offset analysis has been requested to calculate optimal internal offsets, a minus one (-1) must be coded into the columns corresponding to each of the five phasing patterns. The optimal internal offset values calculated by the program will then be used to find the best progression solution. However, the user can override the optimal offset by substituting other internal offset values ranging from zero to the cycle length into the appropriate columns.

Interchange Detail Card Forms

There are three interchange detail cards (or three lines of information) to be coded per signalized interchange. These cards (lines) relate to the vehicle movements at each interchange as shown in Figure 5 (page 9). All data entered must be right-justified, i.e., ended in the right most field column. Only card descriptions will be given in the following discussion.

Line 1. The equivalent straight through movement passenger car volumes illustrated in Figure 5 must be entered on this card in vehicles per hour. Flow rates for other increments of time must be converted to an hourly volume. It is suggested that the equivalent straight through movement passenger car volumes be determined by the methods described in, "A Guide for Designing and Operating Signalized Intersections in Texas," by Messer and Fambro (13). Right turning movements (1, 4, 8, 11) for which a free right turn lane is provided should have zero coded volumes. Arterial straight through movements (2 and 9) pertain to those vehicles traveling on the arterial street which proceed straight through the interchange. Arterial left turning movements (3 and 10) are those vehicles traveling on the arterial street which turn left onto the frontage road at the downstream intersection of the interchange. Frontage road straight through movements (5 and 12) contain those vehicles traveling on the frontage road which proceed straight through their respective intersection of the interchange. Frontage road left turning movements (6 and 13) are those vehicles traveling on the frontage road which turn left and proceed straight through the downstream intersection of the interchange. Frontage road U-turning movements (7 and 14) pertain to those vehicles traveling on the frontage road which turn left and also turn left at the downstream intersection of the interchange. U-turning movements (7 and 14) for which a U-turn lane is provided should have zero coded volumes. The interior left turning movements (15 and 17) are the total number of vehicles turning left, (Movement 15 = Movement 10 + Movement 14 and Movement 17 = Movement 3 + Movement 7) and the interior straight through movements (16 and 18) are the total number of vehicles traveling straight through the corresponding intersections of the interchange (Movement 16 = Movement 9 + Movement 13 and Movement 18 = Movement 2 + Movement 6).

Line 2. The number of effective lanes which serve the respective movement volumes shown in Figure 5 must be entered on this card. The program assumes the saturation capacity flow of each movement to be 1800 vehicles per hour green per effective lane. A movement's saturation capacity flow can be adjusted by multiplying the number of effective lanes which serve that movement by an appropriate factor as shown in Table 2. If both through and turning movements occur in the same lane, a fraction of that lane should be assigned to each movement. This assignment is usually the same as the fraction of the total traffic in the lane which performs each maneuver. For example, assume that a three lane frontage road exists at the left side intersection shown in Figure 5, and that the demand on each of the three lanes is 200 vehicles per hour. Of this, 50 vehicles per hour turn right from the rightmost lane, and all 200 vehicles in the leftmost lane turn left. Additionally, 50 of the 200 vehicles which turn left at the left intersection also turn left when they reach the right intersection (U-turn). Accordingly, the number of effective lanes which serve movements 4, 5, 6 and 7 are 0.25 (50/200), 1.75 (150/200 + 200/200), 0.75 (150/200) and 0.25 (50/200). Observation of the interchange being analyzed may indicate that an adjustment is needed in the effective number of lanes which serve some of the movement volumes. Reasonably accurate estimates of the number of effective lanes which serve a movement should be established since green times are calculated based on movement volume to saturation capacity flow rates.

Line 3. The minimum green time in seconds for each movement shown in the diagram of vehicle movements for minimum greens (Figure 5) is, in effect, the minimum time for the green, yellow and all-red, if any, for the movement. For

TABLE 2 - ADJUSTMENT FACTORS TO ACCOUNT FOR VARIOUS SATURATION CAPACITY FLOW RATES*

Desired Saturation Capacity Flow Rate (Veh./Hr./Lane)	Multiply the Total Number of Effective Lanes By
1500	0.83
1600	0.89
1700	0.94
1800	1.00
1900	1.06
2000	1.11
2100	1.17

* Different adjustment factors can be used for different movements.

example, if the desired minimum green interval was ten seconds followed by a three second yellow interval and a one second all-red interval, the coded minimum green time would be 14 seconds. The minimum phase green times for movements 1, 2, 3, 4, 5 and 7 must be long enough to insure adequate pedestrian crossing times or adequate "Walk" and "Don't Walk" time when pedestrian signals exist.

Note: For the isolated interchange option, the sum of the minimum greens of the conflicting phases at each intersection of the interchange must not exceed the cycle length coded in columns 15-17 of the Interchange Header Card (Figure 4). If the progression option was specified, the sum of the minimum greens must not exceed the minimum cycle length coded in columns 51-53 of the Freeway Header Card (Figure 4).

APPLICATIONS

PASSER III was designed (1) to calculate the signal timing information needed for the plan development and field implementation of pretimed or traffic-responsive, fixed-sequence signalized diamond interchanges and (2) to determine the optimal progression solution along the frontage roads through a series of signalized diamond interchanges for the given set of traffic flow conditions. Users of this program, as when using any other computer program, should remember that the program only calculates - it does not engineer. Sometimes several program runs may be needed before the final solution is calculated.

Isolated Interchange Option

To analyze a diamond interchange independently of its adjacent interchanges and/or intersections, if any exist, a one (1) should be coded in column 49 of the Freeway Header Card. Columns 50 through 69 of this card should be left blank as they refer to the frontage road progression option. For the isolated interchange option, the two input card coding forms would be filled out as shown in Figures 6 and 7 (pages 28 and 29). Based on example input data the program would provide the information shown in Figures 8 through 12 (pages 30 through 34) and described in the following sections.

Input Data. As shown in Figure 8, the first sheet of output from any program run contains a summary of the information punched on the Freeway Header Card. In this example, the user requested that the program calculate the green splits and several measures of effectiveness for an interchange on Interstate Highway 35 in Austin. A delay-offset evaluation of this interchange also has been requested . No progression options or parameters were input to the program.

Data contained on the Interchange Header Card and the Interchange Detail Cards are output by the program as shown in Figure 9. In the example, a delay-offset analysis was requested for phasing codes 1 and 4 (a one was entered in columns 18 and 21 of the Interchange Header Card). Interior travel times along with the interior queue storages were coded and input to the program as they are required in the execution of the delay-offset option. For each of the 18 vehicle movements, the volumes and the number of lanes which correspond to them are coded as shown in Figure 7. They are output by the program at the bottom of the Interchange Input Data Sheet (Figure 9). The eight minimum green values are coded on the same form (Figure 7) and output on the same sheet (Figure 9).

Signal Timing. The program in this mode does not search for the best cycle length to use; therefore, the cycle length to be analyzed must be determined beforehand. A review of one method of determining optimal cycle lengths at individual intersections, the Webster method, is given in Appendix A. For the isolated interchange option the desired cycle length must be entered in columns 15 through 17 of the first Interchange Header Card. In the example, a cycle length of 70 seconds was chosen for analysis as shown in Figure 6 (columns 16 and 17). After a run has been made, the measures of effectiveness calculated by the program indicate whether there may be a need to increase the cycle length to provide better green splits and increase the general capacity of the interchange. However, excessively long cycle lengths are more prone to overload the interior left turn lanes, which could promote through lane blockages and reduce capacity. Under normal peak-hour operating conditions, it is recommended that cycle lengths above 80 seconds in length be avoided if at all possible.

As shown in Figure 10, the program calculates the length of each of the three basic unprotected phases (green plus yellow plus all-red) which exist at each intersection of the interchange. In addition, the length of the "D" phase (time available for the interior straight through traffic, i.e., the sum of the "A" and "C" phases) is also output by the program.

Measures of Effectiveness. The program calculates several operational measures of effectiveness for each movement (phase) of the two signalized intersections of the diamond interchange along with a corresponding level of service. This output from the example is shown in Figure 10. Previously published criteria for three of the measures (13) upon which the level of service evaluations are based are presented in Table 3. Different measures may yield slightly different levels of service when evaluated for the same phase, particularly when comparing delay with the other measures. The fourth measure of effectiveness calculated by the program is the interchange interior storage ratio which is simply the ratio of the length of the maximum queue per cycle for the "C" and "D" phases to the available interior storage capacities for those phases. Storage ratios should not exceed 0.8 with 0.6 being a more desirable maximum. It should be noted that storage ratios are calculated only when a delay-offset analysis has been requested.

TABLE 3. LEVEL OF SERVICE CRITERIA FOR OPERATIONAL MEASURES OF EFFECTIVENESS ON SIGNALIZED MOVEMENTS (13)

OPERATIONAL MEASURES	LEVEL OF SERVICE A	B	C	D	E	F
Saturation Ratio, X	$\leq .6$	$\leq .7$	$\leq .8$	$\leq .85$	≤ 1.0	>1.0
Probability of Clearing Queues, P_c	$\geq .95$	$\geq .90$	$\geq .75$	$\geq .50$	$<.50$	
Average Approach Delay, d, sec./veh.	≤ 15	≤ 30	≤ 45	≤ 60	>60	

The methods by which the program calculates these operational measures of effectiveness are illustrated in Appendix B.

The engineer also can use the general signalization information shown in Figure 10 and the isolated interchange option to evaluate the effectiveness of a predetermined interchange signal timing plan. To accomplish this objective, the user must code the minimum green for each phase to be the same length as the actual green (green plus yellow plus all-red) provided for that phase by the timing plan being evaluated. The sum of the length of the minimum green phases at each intersection of the interchange should equal the cycle length coded in columns 15 through 17 of the Interchange Header Card.

Delay-Offset Plot. The delay-difference of offset option of the program can be utilized by the engineer to assist in the selection of an optimal signal timing plan at an individual diamond interchange. This option calculates the average delay per vehicle for all signal timing plans that are being analyzed. For each phasing code considered, the internal offset is varied in one second increments from zero to the length of the cycle. This allows the program to look at all possible signal timing plans for that phasing code. A delay-offset analysis of a particular phasing code is undertaken whenever a one (1) is entered in the column corresponding to that code (columns 18-22) on the Interchange Header Card. In the example, ones were coded in columns 18 and 21 of the Interchange Header Card (Figure 6). This is reflected by the program output shown in Figures 9 and 10.

The objective of the delay-offset option is to find the internal offset for each phasing code analyzed which minimizes delay and from those minimums select the lowest possible delay value. The phasing code and internal offset from which this minimum delay results is retained by the program and used to construct a phase interval chart. The phasing code and the internal offset also appear at the bottom of the General Signalization Sheet (Figure 10) and the Phase Interval Sheet (Figure 12). In addition, for each phasing code that is analyzed, a plot of the average delay per vehicle as a function of offset is provided by the program. The plot for the example program run is shown in Figure 11.

Phase Interval Chart. A phase interval chart is provided for each interchange at which either the delay-offset option was requested or a priority phasing was input to the program. Figure 12 illustrates the phase interval chart that resulted from the execution of the isolated interchange example program. This chart reflects phasing code 1 (ABC:ABC) with an internal offset of 7 seconds. The delay-offset option determined that this signal timing plan produced the minimum delay per vehicle for the interchange. Each phase interval chart contains the number of intervals that exist at the interchange, the basic phases that exist at each intersection of the interchange during each of the intervals and the length of each interval.

Interchange Analysis. Although PASSER III was designed primarily to analyze fixed-time and traffic-responsive fixed-sequence type control operations, the delay-offset analysis also can be used to study various full traffic actuated phasings and to determine the effects of different interchange approach lane configurations (number of approach lanes), left turn configurations between the frontage roads, and U-turn lane provisions. Thus the delay-offset analysis is quite flexible in its application to analyzing diamond interchanges.

A simple analysis of the interchange operation for all phasing codes can be made by permitting the delay-offset analysis to be run on all phasing codes (by inputing a one (1) in each of Columns 18-22 and by inputting a minus one (-1) for each Code shown in Columns 54-62). In making an analysis of an interchange, the traffic conditions which would occur during at least two peak periods (usually the AM and PM peak periods) should be analyzed. It also would be desirable to study the off-peak period operation since the off-peak period generally occurs during 20 to 22 hours of the day. If the delay-offset solution provides different optimal signal timing plans (different phase patterns) during the two (or more) peak periods and/or during the offpeak period, the engineer will need to decide (from a review of all delay-offset solutions) which phasing code will provide the best overall operation throughout the day.

There are occasions when the optimal operation of two or more phasing codes should be compared. These include the difference in operation obtained from different minimum green times associated with different phasing codes. For example, at a particular interchange a minimum green time of 12 seconds could be used for each movement when phasing code 4 is analyzed, and a minimum green time of 18 seconds could be coded for each movement when phasing code 1 and/or 1A is analyzed (a minimum of 18 seconds would ensure that the interior left turn movements between the frontage roads are cleared before oncoming cross street movements begin). Also, a shorter cycle length may be calculated by Webster for phasing code 4 than for phasing code 1A. The combination of the shorter cycle length and shorter minimum green times for phasing code 4 may result in code 4 providing the optimal practical signal timing plan for the interchange.

It is desirable to evaluate interchange operations resulting from the anticipated future traffic volumes as well as the present traffic volumes. This can be done by increasing the traffic volume to reflect the anticipated volumes in seven to ten years. A factor of 1.4 could be used to increase the current yearly volume for each movement if more reliable values are not available. The result of such an evaluation could show that phasing code 4 is more efficient at present, but that phasing code 1A will be more efficient and provide a better level of service in seven (or ten) years. A decision could be made based on engineering judgment (taking into consideration the difference in average delay per vehicle and the level of service measures for the two candidate solutions) to determine which phasing code operation to install at present.

The results of the research project have shown that the permissive left turn from the cross street onto the frontage road (left turns permitted during the circular green alone and during the circular green with the green left turn arrow) generally provides a more efficient operation than the non-permissive left turn (left turn only on green arrow indication) movement. There are occasions, however, where a protected (non-permissive) left turn phase will provide a more efficient operation than a permissive left turn operation. An example is discussed below.

In the example, there is a 325-foot distance between the two intersections of the diamond interchange. The analysis is for the PM peak period. Minimum green times for each movement are input for phasing code 1A with and without permissible left turns and phasing code 4 with permissible left turns only. The cycle lengths are based on Webster, the minimum green times, and the requirement that a level of service C or better be obtained for each movement.

As in shown in Table 4, phasing code 1A with protected left turns only provides a more efficient operation at the interchange than phasing code 1A with permissive left turns. This is due to the traffic pattern at the particular interchange and the long distance between the intersections of the interchange. It should be noted that in this instance phasing code 4 is more efficient than phasing code 1A. It also should be noted that phasing code 4 was found to be the most efficient for the AM peak period as well as for the PM peak period and was again found to be the most efficient after a factor of 1.4 was applied to each movement. Based on the study results, a controller providing phasing code 4 operation was chosen for installation.

Interchange Design. As previously mentioned, PASSER III can be used for interchange design analysis. To evaluate the effect of adding an additional lane to an approach, the effective number of lanes for the approach can be changed on the Interchange Detail Card. All other input data would remain the same. When left turn lane configurations are being studied, the interior queue storage values on the Interchange Detail Card can be changed. Again, all other input data would remain the same. The operational effect of adding a U-turn or free right turn lane can be evaluated by coding a zero (0) value for both volume and number of effective lanes for the movement where the lane was added. If a U-turn lane is added, the corresponding interior left turn movement volumes will be decreased. Also, the effective number of lanes serving the remaining movement volumes on the approach will usually change. By inputting different values of interior travel time on the Interchange Header Card, the operational effect of various spacings of the two intersections of the interchange can be evaluated.

TABLE 4. COMPARISON OF THREE ALTERNATIVE SIGNAL TIMING PLANS AT A DIAMOND INTERCHANGE

	Cycle Length (Based on Webster)	Average Delay per Vehicle (Sec.)	Minimum Green for Movements 1 & 3	Minimum Green for Movements 2 & 4	Minimum Green for Movements 5 - 8
Phase Code 4 (ACB;ACB) w/Permissive Left Turns (Left Turns on Circular Green During Phase A and on Circular Green with Left Turn Arrow During Phase C)	50 sec.	12.80	17	12	10
Phase Code 1A (ABC:ABC) w/Non-Permissive Left Turns (Protected Left Turns Only for Phase C)	60 sec.	15.02	17	12	10
Phase Code 1A (ABC:ABC) w/Permissive Left Turns	70 sec.	19.37	21*	21*	20*

* The 21 second minimum provides 10 seconds for clearing the appropriate vehicles through the far frontage road before the next movement begins (i.e., Phasing Interval B + C = 10 sec. which is then followed by Phasing Interval B + A). For movement 2 to be a minimum of 21 seconds, Phasing Interval B + C is 10 seconds, and Phasing Interval B + A is 11 seconds.

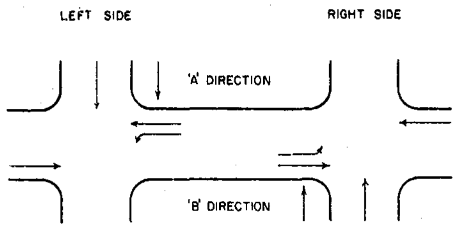
PROGRESSION ANALYSIS AND SIGNAL SYSTEM EVALUATION ROUTINE FOR DIAMOND INTERCHANGES-'PASSER III'

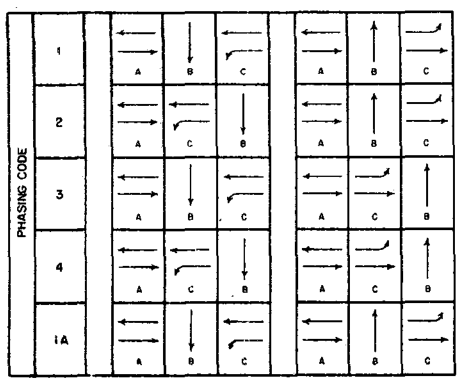
FREEWAY HEADER CARD FORM (One card per freeway)

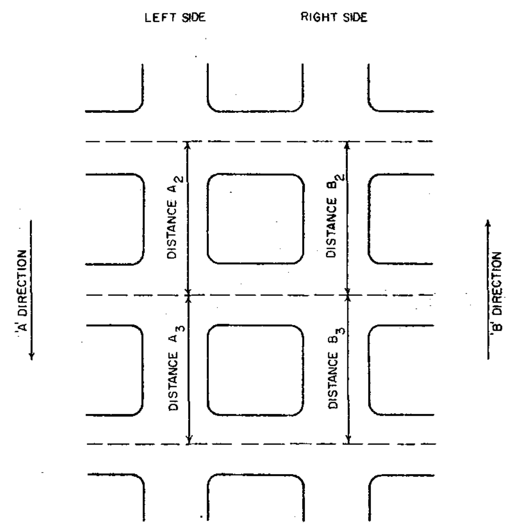
CODE 0 IF NO
CODE 1 IF YES

NAME OF CITY (1)	NAME OF FREEWAY (12)	DIST. (36)	DATE MO. (38, 40)	DATE DATE (42)	DATE YEAR (44)	RUN NO. (46)	Number of Interchanges (48)	Isolated? (49)	[illegible]
AUSTIN	INTERSTATE HIGHWAY 35	14	3	4	77	2	1	1	[illegible]

INTERCHANGE HEADER CARD FORM (One card per interchange)







CODE 0 IF NO
CODE 1 IF YES

CROSS-STREET NAME (1–12)	INTERCHANGE NUMBER (14)	CYCLE LENGTH (SEC) (17)	DELAY-OFFSET ANALYSIS ? CODE 1 (18)	CODE 2 (19)	CODE 3 (20)	CODE 4 (21)	CODE 1A (22)	PERMISSIVE LEFT TURNS? LEFT SIDE (23)	RIGHT SIDE (24)	INTERIOR TRAVEL TIME (SEC.) LEFT TO RIGHT (26)	RIGHT TO LEFT (28)	INTERIOR QUEUE STORAGE (VEHICLES) RIGHT SIDE THROUGH (30)	RIGHT SIDE LEFT TURN (32)	LEFT SIDE THROUGH (34)	LEFT SIDE LEFT TURN (36)	PROGRESSION INFORMATION [illegible]	PRIORITY PHASING ? (INTERNAL OFFSET, SEC.) CODE 1 (54)	CODE 2 (56)	CODE 3 (58)	CODE 4 (60)	CODE 1A (62)
HOUSTON AVE	1	70	1			1				10	10	8	8	8	8	[illegible]	-1	-1	-1	-1	-1

Figure 6

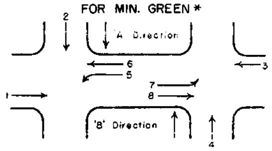
TEXAS STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

Form 1405-2

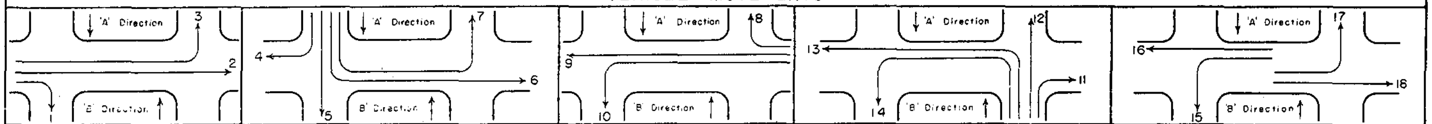
PROGRESSION ANALYSIS AND SIGNAL SYSTEM EVALUATION ROUTINE FOR DIAMOND INTERCHANGES - 'PASSER III'

INTERCHANGE DETAIL CARD FORM (Three cards per interchange)

VEHICLE MOVEMENTS FOR MIN. GREEN *



VEHICLE MOVEMENTS



	1 (4)	2 (8)	3 (12)	4 (16)	5 (20)	6 (24)	7 (28)	8 (32)	9 (36)	10 (40)	11 (44)	12 (48)	13 (52)	14 (56)	15 (60)	16 (64)	17 (68)	18 (72)
VOLUMES (VPH)	50	140	50	40	900	160		70	10	30	220	900	30		30	40	40	300
NO. OF LANES	.40	1.20	.40	.09	2.46	.45		1.28	.18	.54	.45	2.49	.06		.86	1.14	.24	1.76
MIN. GREEN (SEC.)*	14	25	14	26	14	14	14	14										
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		

Figure 7

```
PPPPPPPPP    AAAAAAAA    SSSSSSSS    SSSSSSSS   EEEEEEEEEE  RRRRRRRRR          IIIIIIIIIIIIIIIIIIIIIIII
PPPPPPPPPP  AAAAAAAAAA  SSSSSSSSSS  SSSSSSSSSS  EEEEEEEEEE  RRRRRRRRRR         IIIIIIIIIIIIIIIIIIIIIIII
PP      PP  AA      AA  SS      SS  SS      SS  EE          RR      RR            II        II        II
PP      PP  AA      AA  SS          SS          EE          RR      RR            II        II        II
PP      PP  AA      AA  SS          SS          EE          RR      RR            II        II        II
PPPPPPPPPP  AAAAAAAAAA   SSSSSSS     SSSSSSS    EEEEEEE     RRRRRRRRRR            II        II        II
PPPPPPPPP   AAAAAAAAAA    SSSSSSS     SSSSSSS   EEEEEEE     RRRRRRRRR             II        II        II
PP          AA      AA          SS          SS  EE          RR  RR                II        II        II
PP          AA      AA          SS          SS  EE          RR   RR               II        II        II
PP          AA      AA  SS      SS  SS      SS  EE          RR    RR              II        II        II
PP          AA      AA  SSSSSSSSSS  SSSSSSSSSS  EEEEEEEEEE  RR     RR          IIIIIIIIIIIIIIIIIIIIIIII
PP          AA      AA   SSSSSSSS    SSSSSSSS   EEEEEEEEEE  RR      RR         IIIIIIIIIIIIIIIIIIIIIIII
```

```
****************************************************************************************
*                                                                                      *
*  RUN NUMBER  1                                                     DATE  3/ 4/77     *
*                                                                                      *
*  INTERSTATE HIGHWAY 35               AUSTIN                        DISTRICT 14       *
*                                                                                      *
****************************************************************************************
*                                                                                      *
*  OPTIONS -                                                                           *
*                                                                                      *
*     CALCULATE GREEN SPLITS AND MEASURES OF EFFECTIVENESS --------         YES        *
*                                                                                      *
*     USE DELAY-OFFSET EVALUATION TECHNIQUE ----------------------         YES        *
*                                                                                      *
*     DETERMINE OPTIMAL PROGRESSION SOLUTION ---------------------          NO        *
*                                                                                      *
*     SEARCH FOR OPTIMAL SOLUTION BY VARYING LINK SPEEDS ----------          NO        *
*                                                                                      *
*     PRINT OPTIMAL TIME-SPACE PROGRESSION DIAGRAM ----------------          NO        *
*                                                                                      *
*     PLOT OPTIMAL TIME-SPACE PROGRESSION DIAGRAM -----------------          NO        *
*                                                                                      *
*  PARAMETERS - (ISOLATED INTERCHANGE ANALYSIS)                                        *
*                                                                                      *
*     DESIRED CYCLE LENGTH ---------------------------------------     70 SECONDS     *
*                                                                                      *
*  PARAMETERS - (FRONTAGE ROAD PROGRESSION ANALYSIS)                                   *
*                                                                                      *
*     NUMBER OF INTERCHANGES -------------------------------------      1             *
*                                                                                      *
*     LOWER CYCLE LENGTH LIMIT -----------------------------------      0 SECONDS     *
*                                                                                      *
*     UPPER CYCLE LENGTH LIMIT -----------------------------------      0 SECONDS     *
*                                                                                      *
*     CYCLE LENGTH INCREMENT -------------------------------------      1 SECONDS     *
*                                                                                      *
*     MINIMUM 'B' DIRECTION BAND SPLIT ---------------------------     NONE           *
*                                                                                      *
****************************************************************************************
```

Figure 8

INTERCHANGE INPUT DATA

INTERCHANGE 1 HOUSTON AVE	DISTANCE	PROGRESSION SPEED	QUEUE CLEARANCE
	FROM 1 TO 2 --- 0 FT,	FROM 1 TO 2 ---- 0 MPH,	'A' DIRECTION ----- 0 SEC,
	FROM 2 TO 1 --- 0 FT,	FROM 2 TO 1 ---- 0 MPH,	'B' DIRECTION ----- 0 SEC,

RUN DELAY-OFFSET ANALYSIS?

- CODE 1 OR LEAD-LEAD --------------------- YES
- CODE 2 OR LAG-LEAD ---------------------- NO
- CODE 3 OR LEAD-LAG ---------------------- NO
- CODE 4 OR LAG-LAG ----------------------- YES
- CODE 1A OR TTI 4-PHASE ------------------ NO

PERMISSIVE LEFT TURNS ALLOWED?

- AT LEFT SIDE INTERSECTION --------------------------- YES
- AT RIGHT SIDE INTERSECTION -------------------------- YES

INTERIOR TRAVEL TIME

- FROM LEFT TO RIGHT ACROSS THE INTERCHANGE ------- 10 SEC,
- FROM RIGHT TO LEFT ACROSS THE INTERCHANGE ------- 10 SEC,

PRIORITY PHASINGS / INTERNAL OFFSET

- CODE 4 OR LAG-LAG ------------ NONE
- CODE 3 OR LEAD-LAG ----------- NONE
- CODE 2 OR LAG-LEAD ----------- NONE
- CODE 1 OR LEAD-LEAD ---------- NONE

INTERIOR QUEUF STORAGE

- THROUGH MOVEMENT AT RIGHT SIDE INTERSECTION ----- 8 VEH,
- LEFT TURN MOVEMENT AT RIGHT SIDE INTERSECTION --- 8 VEH,
- THROUGH MOVEMENT AT LEFT SIDE INTERSECTION ------ 8 VEH,
- LEFT TURN MOVEMENT AT LEFT SIDE INTERSECTION ---- 8 VEH,

MOVEMENTS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
VOLUMES	50	140	50	40	900	160	0	70	10	30	220	900	30	0	30	40	40	300
NUMBER OF LANES	0,40	1,20	0,40	0,09	2,46	0,45	0,0	1,28	0,18	0,54	0,45	2,49	0,06	0,0	0,86	1,14	0,24	1,76
MINIMUM GREEN	14	25	14	26	14	14	14	14										

Figure 9

GENERAL SIGNALIZATION INFORMATION

INTERSTATE HIGHWAY 35 AT HOUSTON RUN NO. 2 3/ 4/77

MEASURES OF EFFECTIVENESS	LEFT SIDE				RIGHT SIDE			
	A	B	C	D	A	B	C	D
GREEN TIME (SEC.)	14.0	42.0	14.0	28.0	14.0	42.0	14.0	28.0
VOLUME/CAPACITY RATIO, X	0.49	0.45	0.14	0.06	0.22	0.51	0.65	0.28
LEVEL OF SERVICE	A	A	A	A	A	A	B	A
DELAY (SEC./VEH.)	28.55	9.50	27.21	15.57	27.06	9.62	65.49	17.21
LEVEL OF SERVICE	B	A	B	B	B	A	E	B
PROBABILITY OF CLEARING QUEUE	0.98	1.00			1.00	1.00		
LEVEL OF SERVICE	A	A			A	A		
STORAGE RATIO			0.09	0.07			0.05	0.11

PHASE ORDER = ABC/ABC
INTERNAL OFFSET = 7 SECONDS
TOTAL INTERCHANGE DELAY = 8.69 VEHICLE-HOURS PER HOUR

Figure 10

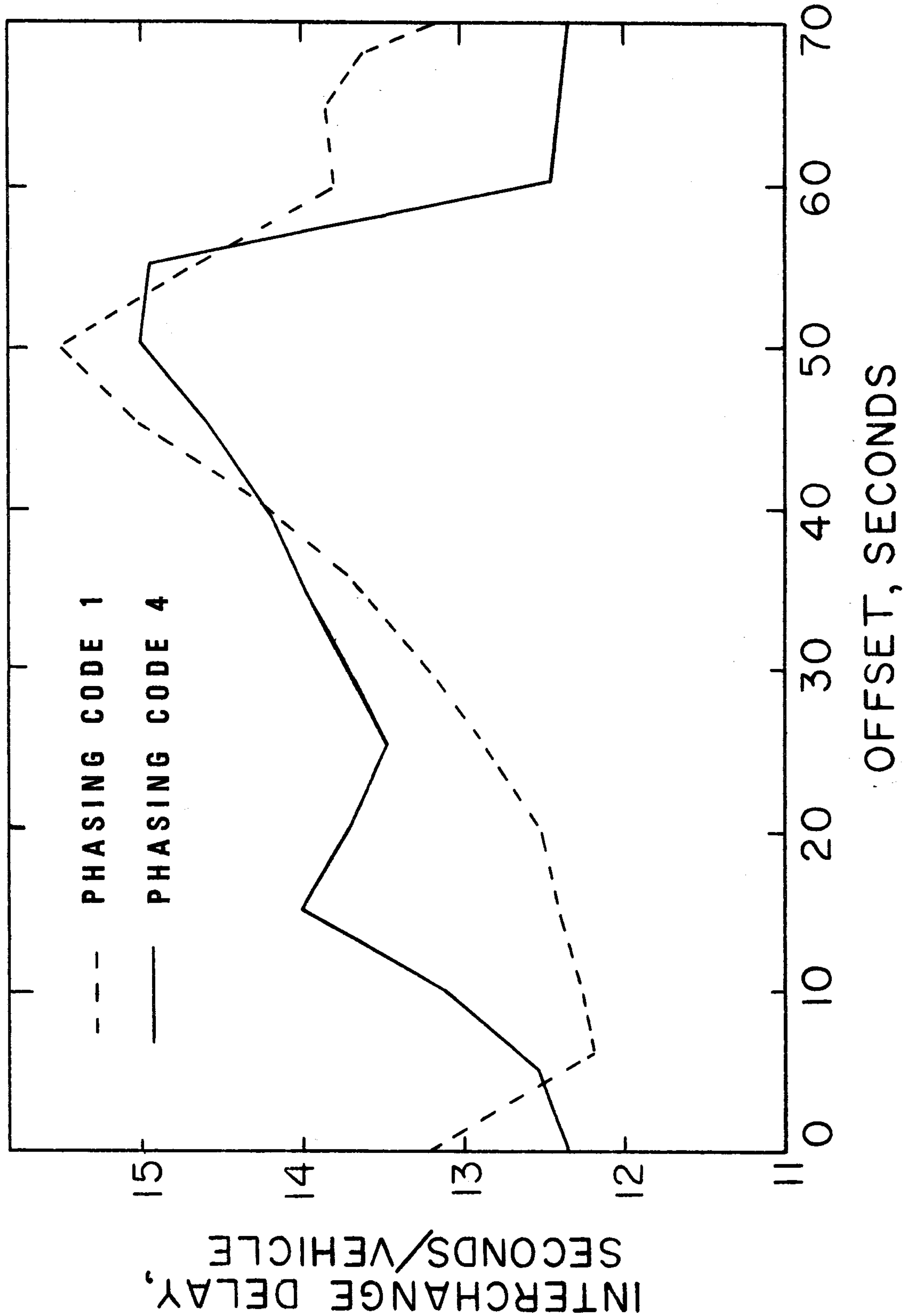

PHASING CODE 1
PHASING CODE 4
OFFSET, SECONDS
INTERCHANGE DELAY, SECONDS/VEHICLE
0
10
20
30
40
50
60
70
11
12
13
14
15

Figure 11

PHASE INTERVALS

INTERSTATE HIGHWAY 35 AT HOUSTON RUN NO. 2 3/ 4/77

PHASE INTERVAL NUMBER	LEFT SIDE STATUS	RIGHT SIDE STATUS	PHASE INTERVAL LENGTH(SEC.)
1	A	B	7.0
2	A	C	7.0
3	B	C	7.0
4	B	A	14.0
5	B	B	21.0
6	C	B	14.0

PHASE ORDER = ABC/ABC
INTERNAL OFFSET = 7 SECONDS

Figure 12

Frontage Road Progression

In order for the program to search for an optimal frontage road progression solution, a one (1) must be coded in column 50 of the Freeway Header Card. Column 49 on this same card must be left blank. The previous discussion concerning the program options available for the analysis of isolated interchanges is also applicable to the individual interchanges in the progressive system. Signal timing information, measures of effectiveness and phase interval charts will be provided as output by the program for each interchange in the system. When a frontage road progression solution was requested through a series of interchanges along Interstate Highway 35 in Austin, the two input card forms were filled out as shown in Figures 13 and 14 (pages 39 and 40). Figures 15 through 35 (pages 41 through 61) illustrate the output that was provided as a result of this data being punched on cards and executed by the PASSER III computer program. The following section of the report discusses the progression options available, the ways in which these options can be used and the output provided by the program when a frontage road progression solution has been requested.

Input Data. The first page of output, Figure 15, is a summary of the input data contained on the Freeway Header Card. Green splits and measures of effectiveness are calculated when a progression solution has been requested. As shown in Figure 15, several progression options were requested. These include varying the link speeds while searching for the optimal progression solution, printing the optimal time-space progression diagram on the district terminal printer and plotting the optimal time-space progression diagram on the D-19 line plotter. Notice that the parameters required for a frontage road progression analysis were input to the program. Progression options and parameters are entered in columns 50 through 69 of the Freeway Header Card.

The Interchange Input Data Sheets, Figures 16 through 20 summarize the data contained on the Interchange Header Cards and the Interchange Detail Cards. The information required for a progression solution (distances, progression speeds and queue clearance intervals) were coded and input to the program. No delay-offset analyses were requested; therefore, the parameters required for a delay-offset analysis, interior travel times and interior queue storages were not coded (Figure 13). Priority phasings (internal offsets) were input to the program because in order for the program to construct a signal timing plan for an interchange, the internal offset must be known.

Signal Timing. The length of the basic phases at each of the intersections in the system is output on the General Signalization Information Sheets, Figures 21 through 25. The information presented on these sheets is the same as would be presented if each interchange had been analyzed using the isolated interchange option. The one exception to this similarity is the addition of the external offset as output. The external offset is defined as the time the start of basic phase "A" at the left side intersection of the interchange lags the start of basic phase "A" at the left side intersection of interchange number one.

Measures of Effectiveness. The measures of effectiveness shown in Figures 21 through 25 are calculated by the same procedures used by the isolated interchange option. As no delay-offset analyses were output by the program, no interior storage ratios were output by the program, i.e., they are not applicable (N.A.) to this problem. These measures should be examined closely to insure that all intersections in the system are operating in a satisfactory manner.

When a frontage road progression option has been requested, several system measures of effectiveness are output by the program as shown in Figures 26 and 27. The program found the optimal cycle length for progression to be 75 seconds. The progression speed and bandwidth in both directions along with the efficiency and attainability of the progression solution are shown on the Optimal Progression Solution Sheet (Figure 26). The efficiency of the solution is the fraction of the cycle in the average progression band. The attainability is the fraction of the average of the minimum frontage road green time in each direction used for progression. On the Frontage Road Progression Information Sheet, Figure 27, the phase order for each intersection, the internal offset, the external offset and the cumulative travel time in both directions for each intersection in the system are provided as output by the program.

Phase Interval Charts. When a progression option has been requested, a phase interval chart will be provided for each interchange in the system. Figures 28 through 32 show the Phase Interval Sheets provided by the program for the example problem. The information provided by these charts is identical to the output provided by the isolated option with the exception of the external offset. It should be noted that the program must have both a phase order and an internal offset in order to construct these charts. The only way in which this information can be furnished to the program is by the request of a delay-offset analysis or the coding of a priority phasing (internal offset) for each phasing code to be considered. In the example illustrated in this report, the priority phasing method was used. Note: It is strongly recommended that the delay-offset option not be used in conjunction with any frontage road progression option until the users of this program are throughly familiar with its operation due to the computer time and expense involved.

Time-Space Plots. As indicated on the first input data sheet, a printer plot of the time-space diagram for the optimal solution was requested by coding a one (1) in column 62 of the Freeway Header Card. The simulated printer plot can be used to determine the most logical 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 can be requested from File D-19 by coding a one (1) in column 63 of the Freeway Header Card.

Figures 33 and 34 are a simulated printer plotted time-space diagram of the optimal progression solution for the example problem with "+++" indicating basic phase "A", blanks indicating basic phase "B" and "===" indicating basic phase "C". The bottom line at each interchange represents the left side intersection, whereas the top line represents the right side intersection. The "···" show the location of the progression bands. Figure 35 is the D-19 digital line plot of the time-space diagram of the optimal progression solution for the example problem.

Frontage Road Analysis. With increased freeway mainlane volumes, frontage roads are becoming more important as arterial streets. The frontage roads can serve partly as a freeway corridor alternate route to mainlane traffic. Short trip traffic should also be encouraged to use the frontage roads in lieu of moving onto and off the freeway mainlanes in a short distance. Improved level of service can be provided along a frontage road by interconnecting the frontage road signals. Frontage road signals of a mile spacing or less can be interconnected so as to obtain suitable progression. With PASSER III it is possible to design interconnected frontage road systems which will assure operating at suitable levels of service on both the frontage roads and cross street approaches.

It is also possible to determine an approximation of the level of service for an interchange and for the frontage road system. By determining the level of service based on each phase and based on each measure of effectiveness as shown in Figures 21-25, it is possible to determine an approximate level of service for each interchange (level of service A-C for the interchanges in Figures 21-25). By then analyzing the level of service for all interchanges as a group, it is possible to determine an approximate level of service for the frontage road system. Since each interchange (Figures 21-25) appears to be operating at a level of service between A and C, it is possible to conclude that the level of service for the frontage road system is between A and C. The highest value of attainability for progression should be obtained while also obtaining the chosen level of service (or better) for all phases. If it is desired to increase the values of efficiency and attainability for progression, a calculated phase time could be inserted in the Interchange Detail Cards for each phase after the initial computer run so that the "Minimum Green" for "Vehicle Movements for Minimum Green" 1, 2 and 5 and for "Vehicle Movements for Minimum Green" 3, 4 and 7 shown in Figure 5 would total to the cycle length (75 seconds in the example problem). The phase green time for the cross street movements could be decreased at the selected interchange(s) and the problem run again. A level of service C should be obtained for the "Phase A and Phase C" movements at the selected interchange(s) with the additional time given to the frontage road movements. The program would then show whether the values of efficiency and attainability have been increased. Several computer runs may be needed to obtain the desired optimal progression solution.

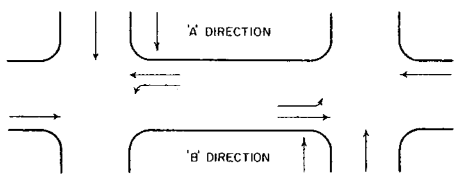
PROGRESSION ANALYSIS AND SIGNAL SYSTEM EVALUATION ROUTINE FOR DIAMOND INTERCHANGES-'PASSER III'

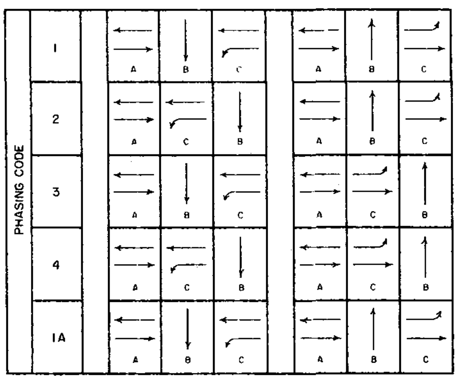
FREEWAY HEADER CARD FORM (One card per freeway)

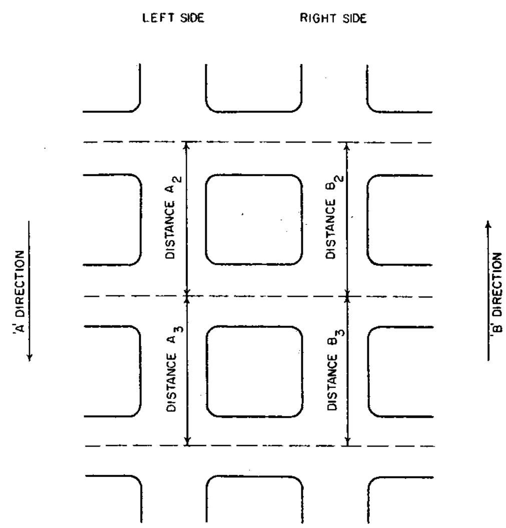
CODE 0 IF NO
CODE 1 IF YES

NAME OF CITY (1–12)	NAME OF FREEWAY (–36)	DIST. (38)	DATE MO. (40)	DATE DATE (42)	DATE YEAR (44)	RUN NO. (46)	Number of Interchanges (48)	Isolated? (49)	Progression? (50)	Lower Cycle Length (Sec) (53)	Upper Cycle Length (Sec) (56)	Cycle Length Increment (Sec) (58)	Min. 'B' Direction Band Split (60)	Link Speed Search? (61)	Printer Plot? (62)	Line Plot? (63)	X-Scale 1" = ___ Sec. (65)	Y-Scale 1" = ___ Sec. (69)
AUSTIN	INTERSTATE HIGHWAY 35	14	3	28	77	1	5		1	65	75	5		1	1	1	20	400

INTERCHANGE HEADER CARD FORM (One card per interchange)







CODE 0 IF NO
CODE 1 IF YES

CROSS-STREET NAME (1–12)	INTERCHANGE NUMBER (14)	CYCLE LENGTH (SEC.) (17)	DELAY-OFFSET ANALYSIS? CODE 1 (18)	CODE 2 (19)	CODE 3 (20)	CODE 4 (21)	CODE 1A (22)	PERMISSIVE LEFT TURNS? LEFT SIDE (23)	RIGHT SIDE (24)	INTERIOR TRAVEL TIME (SEC.) LEFT TO RIGHT (26)	RIGHT TO LEFT (28)	INTERIOR QUEUE STORAGE (VEHICLES) RIGHT SIDE THROUGH (30)	RIGHT SIDE LEFT TURN (32)	LEFT SIDE THROUGH (34)	LEFT SIDE LEFT TURN (36)	[illegible]	PRIORITY PHASING? (INTERNAL OFFSET, SEC.) CODE 1 (54)	CODE 2 (56)	CODE 3 (58)	CODE 4 (60)	CODE 1A (62)
HOUSTON AVE	1																10	10	10	10	10
DALLAS AVE	2																10	10	10	10	10
SAN MARCOS	3																10	10	10	10	10
EL PASO ST	4																10	10	10	10	10
ELGIN BLVD	5																10	10	10	10	10

Figure 13

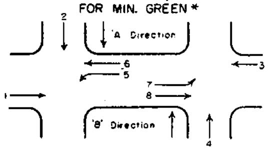
TEXAS STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

Form 1405-2

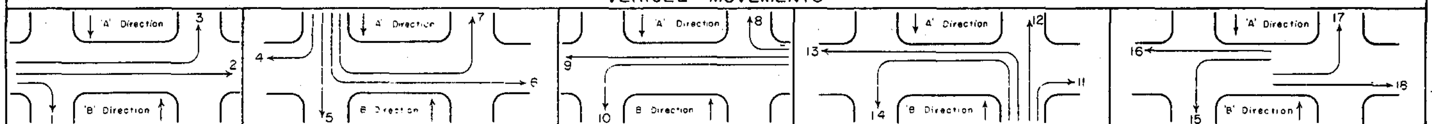
PROGRESSION ANALYSIS AND SIGNAL SYSTEM EVALUATION ROUTINE FOR DIAMOND INTERCHANGES - 'PASSER III'

INTERCHANGE DETAIL CARD FORM (Three cards per interchange)

VEHICLE MOVEMENTS FOR MIN. GREEN *



VEHICLE MOVEMENTS



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72
VOLUMES (VPH)	50	140	50	40	900	160		70	10	30	220	900	30		30	40	40	300
NO. OF LANES	.40	1.20	.40	.09	2.46	.45		1.28	.18	.54	.45	2.49	.06		.86	1.14	.24	1.76
MIN. GREEN (SEC.)*	14	25	14	26	14	14	14	14										
VOLUMES (VPH)	350	150	350	40	900	130		20	100	10	40	870	80		10	180	350	280
NO. OF LANES	.82	.36	.82	.09	2.58	.33		.30	1.54	.16	.12	2.64	.24		1.00	2.00	1.00	2.00
MIN. GREEN (SEC.)*	22	19	14	18	14	14	20	16										
VOLUMES (VPH)	60	300	50	100	900	90		50	200	40	20	800	70		40	270	50	390
NO. OF LANES	.16	1.64	.20	.27	2.49	.24		.20	1.64	.16	.06	2.70	.24		1.00	2.00	1.00	2.00
MIN. GREEN (SEC.)*	18	19	16	17	14	16	14	16										
VOLUMES (VPH)	70	200	120	20	900	120		20	150	60	100	800	100		60	250	120	320
NO. OF LANES	.36	1.02	.62	.06	2.61	.33		.18	1.30	.52	.30	2.40	.30		.38	1.62	.54	1.46
MIN. GREEN (SEC.)*	14	19	14	19	14	16	14	18										
VOLUMES (VPH)	80	220	200	15	900	110		5	200	120	10	920	60		120	260	200	330
NO. OF LANES	.32	.88	.80	.03	2.67	.30		.04	1.22	.74	.03	2.79	.18		.64	1.36	.76	1.24
MIN. GREEN (SEC.)*	16	19	14	19	14	14	14	16										
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		
VOLUMES (VPH)																		
NO. OF LANES																		
MIN. GREEN (SEC.)*																		

Figure 14

```
PPPPPPPPP    AAAAAAAA    SSSSSSSS    SSSSSSSS   EEEEEEEEEE  RRRRRRRRR         IIIIIIIIIIIIIIIIIIIIIIII
PPPPPPPPPP  AAAAAAAAAA  SSSSSSSSSS  SSSSSSSSSS  EEEEEEEEEE  RRRRRRRRRR        IIIIIIIIIIIIIIIIIIIIIIII
PP      PP  AA      AA  SS      SS  SS      SS  EE          RR      RR           II       II       II
PP      PP  AA      AA  SS          SS          EE          RR      RR           II       II       II
PP      PP  AA      AA  SS          SS          EE          RR      RR           II       II       II
PPPPPPPPPP  AAAAAAAAAA   SSSSSSS     SSSSSSS    EEEEEEE     RRRRRRRRRR           II       II       II
PPPPPPPPP   AAAAAAAAAA    SSSSSSS     SSSSSSS   EEEEEEE     RRRRRRRRR            II       II       II
PP          AA      AA          SS          SS  EE          RR  RR               II       II       II
PP          AA      AA          SS          SS  EE          RR   RR              II       II       II
PP          AA      AA  SS      SS  SS      SS  EE          RR    RR             II       II       II
PP          AA      AA  SSSSSSSSSS  SSSSSSSSSS  EEEEEEEEEE  RR     RR         IIIIIIIIIIIIIIIIIIIIIIII
PP          AA      AA   SSSSSSSS    SSSSSSSS   EEEEEEEEEE  RR      RR        IIIIIIIIIIIIIIIIIIIIIIII
```

```
*************************************************************************************
*                                                                                   *
*  RUN NUMBER  1                                                  DATE  6/17/77    *
*                                                                                   *
*  INTERSTATE HIGHWAY 35            AUSTIN                        DISTRICT 14      *
*                                                                                   *
*************************************************************************************
*                                                                                   *
*  OPTIONS -                                                                        *
*                                                                                   *
*     CALCULATE GREEN SPLITS AND MEASURES OF EFFECTIVENESS --------     YES        *
*                                                                                   *
*     USE DELAY-OFFSET EVALUATION TECHNIQUE ----------------------      NO         *
*                                                                                   *
*     DETERMINE OPTIMAL PROGRESSION SOLUTION ---------------------      YES        *
*                                                                                   *
*     SEARCH FOR OPTIMAL SOLUTION BY VARYING LINK SPEEDS ----------     YES        *
*                                                                                   *
*     PRINT OPTIMAL TIME-SPACE PROGRESSION DIAGRAM ---------------      YES        *
*                                                                                   *
*     PLOT OPTIMAL TIME-SPACE PROGRESSION DIAGRAM ----------------      YES        *
*                                                                                   *
*  PARAMETERS - (ISOLATED INTERCHANGE ANALYSIS)                                     *
*                                                                                   *
*     DESIRED CYCLE LENGTH ---------------------------------------    0 SECONDS    *
*                                                                                   *
*  PARAMETERS - (FRONTAGE ROAD PROGRESSION ANALYSIS)                                *
*                                                                                   *
*     NUMBER OF INTERCHANGES -------------------------------------    5            *
*                                                                                   *
*     LOWER CYCLE LENGTH LIMIT -----------------------------------   65 SECONDS    *
*                                                                                   *
*     UPPER CYCLE LENGTH LIMIT -----------------------------------   75 SECONDS    *
*                                                                                   *
*     CYCLE LENGTH INCREMENT -------------------------------------    5 SECONDS    *
*                                                                                   *
*     MINIMUM 'B' DIRECTION BAND SPLIT ---------------------------     NONE        *
*                                                                                   *
*************************************************************************************
```

Figure 15

INTERCHANGE INPUT DATA

INTERCHANGE 1 HOUSTON AVE	DISTANCE	PROGRESSION SPEED	QUEUE CLEARANCE
	FROM 1 TO 2 --- 1900 FT.	FROM 1 TO 2 ---- 35 MPH.	'A' DIRECTION ----- 0 SEC.
	FROM 2 TO 1 --- 1900 FT.	FROM 2 TO 1 ---- 35 MPH.	'B' DIRECTION ----- 0 SEC.

RUN DELAY-OFFSET ANALYSIS?

CODE 1 OR LEAD-LEAD --------------------- NO
CODE 2 OR LAG-LEAD ---------------------- NO
CODE 3 OR LEAD-LAG ---------------------- NO
CODE 4 OR LAG-LAG ----------------------- NO
CODE 1A OR TTI 4-PHASE ------------------ NO

PERMISSIVE LEFT TURNS ALLOWED?

AT LEFT SIDE INTERSECTION ------------------------- NO
AT RIGHT SIDE INTERSECTION ------------------------ NO

INTERIOR TRAVEL TIME

FROM LEFT TO RIGHT ACROSS THE INTERCHANGE ------- 0 SEC.
FROM RIGHT TO LEFT ACROSS THE INTERCHANGE ------- 0 SEC.

PRIORITY PHASINGS / INTERNAL OFFSET

CODE 1A OR TTI 4-PHASE -------- 10 SEC. OFFSET
CODE 4 OR LAG-LAG ------------ 10 SEC. OFFSET
CODE 3 OR LEAD-LAG ----------- 10 SEC. OFFSET
CODE 2 OR LAG-LEAD ----------- 10 SEC. OFFSET

INTERIOR QUEUE STORAGE

THROUGH MOVEMENT AT RIGHT SIDE INTERSECTION ----- 0 VEH.
LEFT TURN MOVEMENT AT RIGHT SIDE INTERSECTION --- 0 VEH.
THROUGH MOVEMENT AT LEFT SIDE INTERSECTION ------ 0 VEH.
LEFT TURN MOVEMENT AT LEFT SIDE INTERSECTION ---- 0 VEH.

MOVEMENTS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
VOLUMES	50	140	50	40	900	160	0	70	10	30	220	900	30	0	30	40	40	300
NUMBER OF LANES	0.40	1.20	0.40	0.09	2.46	0.45	0.0	1.28	0.18	0.54	0.45	2.49	0.06	0.0	0.86	1.14	0.24	1.76
MINIMUM GREEN	14	25	14	26	14	14	14	14										

Figure 16

INTERCHANGE INPUT DATA (CONTINUED)

INTERCHANGE 2 DALLAS AVE	DISTANCE	PROGRESSION SPEED	QUEUE CLEARANCE
	FROM 2 TO 3 --- 720 FT.	FROM 2 TO 3 ---- 35 MPH.	'A' DIRECTION ----- 0 SEC.
	FROM 3 TO 2 --- 720 FT.	FROM 3 TO 2 ---- 35 MPH.	'B' DIRECTION ----- 0 SEC.

RUN DELAY-OFFSET ANALYSIS?

CODE 1 OR LEAD-LEAD --------------------- NO

CODE 2 OR LAG-LEAD ---------------------- NO

CODE 3 OR LEAD-LAG ---------------------- NO

CODE 4 OR LAG-LAG ----------------------- NO

CODE 1A OR TTI 4-PHASE ------------------ NO

PERMISSIVE LEFT TURNS ALLOWED?

AT LEFT SIDE INTERSECTION --------------------------- NO

AT RIGHT SIDE INTERSECTION -------------------------- NO

INTERIOR TRAVEL TIME

FROM LEFT TO RIGHT ACROSS THE INTERCHANGE ------- 0 SEC.

FROM RIGHT TO LEFT ACROSS THE INTERCHANGE ------- 0 SEC.

PRIORITY PHASINGS / INTERNAL OFFSET

CODE 1A OR TTI 4-PHASE -------- 10 SEC. OFFSET

CODE 4 OR LAG-LAG ----------- 10 SEC. OFFSET

CODE 3 OR LEAD-LAG ---------- 10 SEC. OFFSET

CODE 2 OR LAG-LEAD ---------- 10 SEC. OFFSET

INTERIOR QUEUE STORAGE

THROUGH MOVEMENT AT RIGHT SIDE INTERSECTION ----- 0 VEH.

LEFT TURN MOVEMENT AT RIGHT SIDE INTERSECTION --- 0 VEH.

THROUGH MOVEMENT AT LEFT SIDE INTERSECTION ------ 0 VEH.

LEFT TURN MOVEMENT AT LEFT SIDE INTERSECTION ---- 0 VEH.

MOVEMENTS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
VOLUMES	350	150	350	40	900	130	0	20	100	10	40	870	80	0	10	180	350	280
NUMBER OF LANES	0.82	0.36	0.82	0.09	2.58	0.33	0.0	0.30	1.54	0.16	0.12	2.64	0.24	0.0	1.00	2.00	1.00	2.00
MINIMUM GREEN	22	19	14	18	14	14	20	16										

Figure 17

INTERCHANGE INPUT DATA (CONTINUED)

INTERCHANGE 3
SAN MARCOS

	DISTANCE	PROGRESSION SPEED	QUEUE CLEARANCE
INTERCHANGE 3 SAN MARCOS	FROM 3 TO 4 --- 2650 FT.	FROM 3 TO 4 ---- 30 MPH.	'A' DIRECTION ----- 0 SEC.
	FROM 4 TO 3 --- 2650 FT.	FROM 4 TO 3 ---- 30 MPH.	'B' DIRECTION ----- 0 SEC.

RUN DELAY-OFFSET ANALYSIS?

CODE 1 OR LEAD-LEAD --------------------- NO
CODE 2 OR LAG-LEAD --------------------- NO
CODE 3 OR LEAD-LAG --------------------- NO
CODE 4 OR LAG-LAG --------------------- NO
CODE 1A OR TTI 4-PHASE ------------------ NO

PERMISSIVE LEFT TURNS ALLOWED?

AT LEFT SIDE INTERSECTION -------------------------- NO
AT RIGHT SIDE INTERSECTION ------------------------- NO

INTERIOR TRAVEL TIME

FROM LEFT TO RIGHT ACROSS THE INTERCHANGE ------- 0 SEC.
FROM RIGHT TO LEFT ACROSS THE INTERCHANGE ------- 0 SEC.

PRIORITY PHASINGS / INTERNAL OFFSET

CODE 1A OR TTI 4-PHASE -------- 10 SEC. OFFSET
CODE 4 OR LAG-LAG ----------- 10 SEC. OFFSET
CODE 3 OR LEAD-LAG ----------- 10 SEC. OFFSET
CODE 2 OR LAG-LEAD ----------- 10 SEC. OFFSET

INTERIOR QUEUE STORAGE

THROUGH MOVEMENT AT RIGHT SIDE INTERSECTION ----- 0 VEH.
LEFT TURN MOVEMENT AT RIGHT SIDE INTERSECTION --- 0 VEH.
THROUGH MOVEMENT AT LEFT SIDE INTERSECTION ------ 0 VEH.
LEFT TURN MOVEMENT AT LEFT SIDE INTERSECTION ---- 0 VEH.

MOVEMENTS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
VOLUMES	60	300	50	100	900	90	0	50	200	40	20	800	70	0	40	270	50	390
NUMBER OF LANES	0.16	1.64	0.20	0.27	2.49	0.24	0.0	0.20	1.64	0.16	0.06	2.70	0.24	0.0	1.00	2.00	1.00	2.00
MINIMUM GREEN	18	19	16	17	14	16	14	16										

Figure 18

INTERCHANGE INPUT DATA (CONTINUED)

INTERCHANGE 4 EL PASO ST	DISTANCE	PROGRESSION SPEED	QUEUE CLEARANCE
	FROM 4 TO 5 --- 2220 FT.	FROM 4 TO 5 ---- 38 MPH.	'A' DIRECTION ----- 0 SEC.
	FROM 5 TO 4 --- 2200 FT.	FROM 5 TO 4 ---- 38 MPH.	'B' DIRECTION ----- 0 SEC.

RUN DELAY-OFFSET ANALYSIS?

CODE 1 OR LEAD-LEAD --------------------- NO

CODE 2 OR LAG-LEAD ---------------------- NO

CODE 3 OR LEAD-LAG ---------------------- NO

CODE 4 OR LAG-LAG ----------------------- NO

CODE 1A OR TTI 4-PHASE ------------------ NO

PERMISSIVE LEFT TURNS ALLOWED?

AT LEFT SIDE INTERSECTION --------------------------- NO

AT RIGHT SIDE INTERSECTION ------------------------- NO

INTERIOR TRAVEL TIME

FROM LEFT TO RIGHT ACROSS THE INTERCHANGE ------- 0 SEC.

FROM RIGHT TO LEFT ACROSS THE INTERCHANGE ------- 0 SEC.

PRIORITY PHASINGS / INTERNAL OFFSET

CODE 1A OR TTI 4-PHASE -------- 10 SEC. OFFSET

CODE 4 OR LAG-LAG ----------- 10 SEC. OFFSET

CODE 3 OR LEAD-LAG ----------- 10 SEC. OFFSET

CODE 2 OR LAG-LEAD ----------- 10 SEC. OFFSET

INTERIOR QUEUE STORAGE

THROUGH MOVEMENT AT RIGHT SIDE INTERSECTION ----- 0 VEH.

LEFT TURN MOVEMENT AT RIGHT SIDE INTERSECTION --- 0 VEH.

THROUGH MOVEMENT AT LEFT SIDE INTERSECTION ------ 0 VEH.

LEFT TURN MOVEMENT AT LEFT SIDE INTERSECTION ---- 0 VEH.

MOVEMENTS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
VOLUMES	70	200	120	20	900	120	0	20	150	60	100	800	100	0	60	250	120	320
NUMBER OF LANES	0.36	1.02	0.62	0.06	2.61	0.33	0.0	0.18	1.30	0.52	0.30	2.40	0.30	0.0	0.38	1.62	0.54	1.46
MINIMUM GREEN	14	19	14	19	14	16	14	18										

Figure 19

INTERCHANGE INPUT DATA (CONTINUED)

INTERCHANGE 5
ELGIN BLVD

	DISTANCE	PROGRESSION SPEED	QUEUE CLEARANCE
INTERCHANGE 5 ELGIN BLVD	FROM 5 TO 6 --- 0 FT.	FROM 5 TO 6 ---- 0 MPH.	'A' DIRECTION ----- 0 SEC.
	FROM 6 TO 5 --- 0 FT.	FROM 6 TO 5 ---- 0 MPH.	'B' DIRECTION ----- 0 SEC.

RUN DELAY-OFFSET ANALYSIS?

CODE 1 OR LEAD-LEAD --------------------- NO
CODE 2 OR LAG-LEAD ---------------------- NO
CODE 3 OR LEAD-LAG ---------------------- NO
CODE 4 OR LAG-LAG ----------------------- NO
CODE 1A OR TTI 4-PHASE ------------------ NO

PERMISSIVE LEFT TURNS ALLOWED?

AT LEFT SIDE INTERSECTION --------------------------- NO
AT RIGHT SIDE INTERSECTION -------------------------- NO

INTERIOR TRAVEL TIME

FROM LEFT TO RIGHT ACROSS THE INTERCHANGE ------- 0 SEC.
FROM RIGHT TO LEFT ACROSS THE INTERCHANGE ------- 0 SEC.

PRIORITY PHASINGS / INTERNAL OFFSET

CODE 1A OR TTI 4-PHASE -------- 10 SEC. OFFSET
CODE 4 OR LAG-LAG ------------ 10 SEC. OFFSET
CODE 3 OR LEAD-LAG ----------- 10 SEC. OFFSET
CODE 2 OR LAG-LEAD ----------- 10 SEC. OFFSET

INTERIOR QUEUE STORAGE

THROUGH MOVEMENT AT RIGHT SIDE INTERSECTION ----- 0 VEH.
LEFT TURN MOVEMENT AT RIGHT SIDE INTERSECTION --- 0 VEH.
THROUGH MOVEMENT AT LEFT SIDE INTERSECTION ------ 0 VEH.
LEFT TURN MOVEMENT AT LEFT SIDE INTERSECTION ---- 0 VEH.

MOVEMENTS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
VOLUMES	80	220	200	15	900	110	0	5	200	120	10	920	60	0	120	260	200	330
NUMBER OF LANES	0.32	0.88	0.80	0.03	2.67	0.30	0.0	0.04	1.22	0.74	0.03	2.79	0.18	0.0	0.64	1.36	0.76	1.24
MINIMUM GREEN	16	19	14	19	14	14	14	16										

Figure 20

GENERAL SIGNALIZATION INFORMATION

INTERSTATE HIGHWAY 35 AT HOUSTON AVE					RUN NO. 1			6/17/77
MEASURES OF EFFECTIVENESS	LEFT SIDE				RIGHT SIDE			
	A	B	C	D	A	B	C	D
GREEN TIME (SEC.)	14.0	34.1	26.9	40.9	14.0	32.9	28.1	42.1
VOLUME/CAPACITY RATIO, X	0.52	0.62	0.06	0.04	0.23	0.72	0.29	0.19
LEVEL OF SERVICE	A	B	A	A	A	C	A	A
DELAY (SEC./VEH.)	31.30	14.36	18.71	9.94	29.62	13.94	23.66	10.28
LEVEL OF SERVICE	C	A	B	A	B	A	B	A
PROBABILITY OF CLEARING QUEUE	0.96	0.98			1.00	0.90		
LEVEL OF SERVICE	A	A			A	B		
STORAGE RATIO			N.A.	N.A.			N.A.	N.A.

PHASE ORDER - ABC/ABC
INTERNAL OFFSET - 10 SECONDS
EXTERNAL OFFSET - 0.0 SECONDS

Figure 21

GENERAL SIGNALIZATION INFORMATION

INTERSTATE HIGHWAY 35 AT DALLAS AVE | RUN NO. 1 | 6/17/77

MEASURES OF EFFECTIVENESS	LEFT SIDE				RIGHT SIDE			
	A	B	C	D	A	B	C	D
GREEN TIME (SEC.)	28.1	28.9	18.0	46.1	14.0	24.0	37.0	51.0
VOLUME/CAPACITY RATIO, X	0.74	0.74	0.03	0.09	0.28	0.69	0.44	0.12
LEVEL OF SERVICE	C	C	A	A	A	B	A	A
DELAY (SEC./VEH.)	24.56	11.20	25.10	7.68	29.84	9.82	15.98	5.78
LEVEL OF SERVICE	B	A	B	A	B	A	B	A
PROBABILITY OF CLEARING QUEUE	0.86	0.85			1.00	0.89		
LEVEL OF SERVICE	C	C			A	C		
STORAGE RATIO			N.A.	N.A.			N.A.	N.A.

PHASE ORDER - ABC/ABC
INTERNAL OFFSET - 10 SECONDS
EXTERNAL OFFSET - 30.8 SECONDS

Figure 22

GENERAL SIGNALIZATION INFORMATION

INTERSTATE HIGHWAY 35 AT SAN MARCOS — RUN NO. 1 — 6/17/77

MEASURES OF EFFECTIVENESS	LEFT SIDE				RIGHT SIDE			
	A	B	C	D	A	B	C	D
GREEN TIME (SEC.)	27.1	33.9	14.0	41.1	23.8	37.2	14.0	37.8
VOLUME/CAPACITY RATIO, X	0.68	0.52	0.17	0.15	0.53	0.42	0.21	0.24
LEVEL OF SERVICE	B	A	A	A	A	A	A	A
DELAY (SEC./VEH.)	20.87	21.49	29.84	10.53	22.64	10.17	30.22	13.01
LEVEL OF SERVICE	B	B	B	A	B	A	C	A
PROBABILITY OF CLEARING QUEUE	0.92	1.00			0.99	1.00		
LEVEL OF SERVICE	B	A			A	A		
STORAGE RATIO			N.A.	N.A.			N.A.	N.A.

PHASE ORDER - ACB/ACB
INTERNAL OFFSET - 10 SECONDS
EXTERNAL OFFSET - 24.3 SECONDS

Figure 23

GENERAL SIGNALIZATION INFORMATION

INTERSTATE HIGHWAY 35 AT EL PASO ST RUN NO. 1 6/17/77

MEASURES OF EFFECTIVENESS	LEFT SIDE				RIGHT SIDE			
	A	B	C	D	A	B	C	D
GREEN TIME (SEC.)	19.3	32.6	23.1	42.4	14.0	29.1	31.9	45.9
VOLUME/CAPACITY RATIO, X	0.53	0.53	0.34	0.17	0.48	0.55	0.33	0.22
LEVEL OF SERVICE	A	A	A	A	A	A	A	A
DELAY (SEC./VEH.)	27.64	22.33	26.98	10.01	31.13	6.66	18.97	8.65
LEVEL OF SERVICE	B	B	B	A	C	A	B	A
PROBABILITY OF CLEARING QUEUE	0.98	1.00			0.98	0.99		
LEVEL OF SERVICE	A	A			A	A		
STORAGE RATIO			N.A.	N.A.			N.A.	N.A.

PHASE ORDER - ABC/ABC
INTERNAL OFFSET - 10 SECONDS
EXTERNAL OFFSET - 34.4 SECONDS

Figure 24

GENERAL SIGNALIZATION INFORMATION

INTERSTATE HIGHWAY 35 AT ELGIN BLVD RUN NO. 1 6/17/77

MEASURES OF EFFECTIVENESS	LEFT SIDE A	LEFT SIDE B	LEFT SIDE C	LEFT SIDE D	RIGHT SIDE A	RIGHT SIDE B	RIGHT SIDE C	RIGHT SIDE D
GREEN TIME (SEC.)	20.8	37.6	16.6	37.4	17.6	31.6	25.8	43.4
VOLUME/CAPACITY RATIO, X	0.62	0.62	0.62	0.24	0.50	0.50	0.50	0.28
LEVEL OF SERVICE	B	B	B	A	A	A	A	A
DELAY (SEC./VEH.)	27.57	6.73	37.34	13.39	28.57	17.45	24.93	10.48
LEVEL OF SERVICE	B	A	C	A	B	B	B	A
PROBABILITY OF CLEARING QUEUE	0.94	0.98			0.98	1.00		
LEVEL OF SERVICE	B	A			A	A		
STORAGE RATIO			N.A.	N.A.			N.A.	N.A.

PHASE ORDER - ABC/ACB
INTERNAL OFFSET - 10 SECONDS
EXTERNAL OFFSET - 70.0 SECONDS

Figure 25

OPTIMAL PROGRESSION SOLUTION

```
**********************************************************
*                                                        *
*                                                        *
*  INTERSTATE HIGHWAY 35      RUN NO.  1     6/17/77     *
*                                                        *
*                                                        *
**********************************************************
*                                                        *
*                                                        *
*  CYCLE LENGTH                          75     SEC.     *
*                                                        *
*                                                        *
*  'A' DIRECTION                                         *
*                                                        *
*      PROGRESSION SPEED                 34.8   MPH.     *
*                                                        *
*      BAND WIDTH                        25.0   SEC.     *
*                                                        *
*                                                        *
*  'B' DIRECTION                                         *
*                                                        *
*      PROGRESSION SPEED                 34.8   MPH.     *
*                                                        *
*      BAND WIDTH                        23.9   SEC.     *
*                                                        *
*                                                        *
*  EFFICIENCY                            0.33            *
*                                                        *
*                                                        *
*  ATTAINABILITY                         0.93            *
*                                                        *
*                                                        *
**********************************************************
```

Figure 26

FRONTAGE ROAD PROGRESSION INFORMATION

INTERSTATE HIGHWAY 35 RUN NO. 1 6/17/77

INTERCHANGE	LEFT SIDE PHASE ORDER	RIGHT SIDE PHASE ORDER	INTERNAL OFFSET(SEC.)	EXTERNAL OFFSET(SEC.)	'A' DIRECTION TRAVEL TIME(SEC.)	'B' DIRECTION TRAVEL TIME(SEC.)
HOUSTON AVE	ABC	ABC	10	0.0	14.4	208.8
DALLAS AVE	ABC	ABC	10	30.8	62.6	157.8
SAN MARCOS	ACB	ACB	10	24.3	98.1	134.0
EL PASO ST	ABC	ABC	10	34.4	180.6	63.6
ELGIN BLVD	ABC	ACB	10	70.0	227.2	17.5

Figure 27

PHASE INTERVALS

INTERSTATE HIGHWAY 35 AT HOUSTON AVE RUN NO. 1 6/17/77

PHASE INTERVAL NUMBER	LEFT SIDE STATUS	RIGHT SIDE STATUS	PHASE INTERVAL LENGTH(SEC.)
1	A	B	10.0
2	A	C	4.0
3	B	C	24.1
4	B	A	10.0
5	C	A	4.0
6	C	B	22.9

PHASE ORDER = ABC/ABC
INTERNAL OFFSET = 10 SECONDS
EXTERNAL OFFSET = 0.0 SECONDS

Figure 28

PHASE INTERVALS

INTERSTATE HIGHWAY 35 AT DALLAS AVE RUN NO. 1 6/17/77

PHASE INTERVAL NUMBER	LEFT SIDE STATUS	RIGHT SIDE STATUS	PHASE INTERVAL LENGTH(SEC.)
1	A	B	10.0
2	A	C	18.1
3	B	C	18.9
4	B	A	10.0
5	C	A	4.0
6	C	B	14.0

PHASE ORDER - ABC/ABC
INTERNAL OFFSET - 10 SECONDS
EXTERNAL OFFSET - 30.8 SECONDS

Figure 29

PHASE INTERVALS

INTERSTATE HIGHWAY 35 AT SAN MARCOS RUN NO. 1 6/17/77

PHASE INTERVAL NUMBER	LEFT SIDE STATUS	RIGHT SIDE STATUS	PHASE INTERVAL LENGTH(SEC.)
1	A	B	10.0
2	A	A	17.1
3	C	A	6.7
4	C	C	7.3
5	B	C	6.7
6	B	B	27.2

PHASE ORDER = ACB/ACB
INTERNAL OFFSET = 10 SECONDS
EXTERNAL OFFSET = 24.3 SECONDS

Figure 30

PHASE INTERVALS

INTERSTATE HIGHWAY 35 AT EL PASO ST RUN NO. 1 6/17/77

PHASE INTERVAL NUMBER	LEFT SIDE STATUS	RIGHT SIDE STATUS	PHASE INTERVAL LENGTH(SEC.)
1	A	B	10.0
2	A	C	9.3
3	B	C	22.6
4	B	A	10.0
5	C	A	4.0
6	C	B	19.1

PHASE ORDER = ABC/ABC
INTERNAL OFFSET = 10 SECONDS
EXTERNAL OFFSET = 34.4 SECONDS

Figure 31

PHASF INTERVALS

INTERSTATE HIGHWAY 35 AT ELGIN BLVD RUN NO, 1 6/17/77

PHASE INTERVAL NUMBER	LEFT SIDE STATUS	RIGHT SIDE STATUS	PHASE INTERVAL LENGTH(SEC.)
1	A	B	10.0
2	A	A	10.8
3	B	A	6.8
4	B	C	25.8
5	B	B	5.0
6	C	B	16.6

PHASE ORDER = ABC/ACB
INTERNAL OFFSET = 10 SECONDS
EXTERNAL OFFSET = 70.0 SECONDS

Figure 32

PASSER III
RUN NO. 1
6/17/77

TIME-SPACE DIAGRAM FOR INTERSTATE HIGHWAY 35

CYCLE LENGTH = 75 SECONDS

HORIZONTAL SCALE 1 INCH = 20 SECONDS
VERTICAL SCALE 1 INCH = 400 FEET

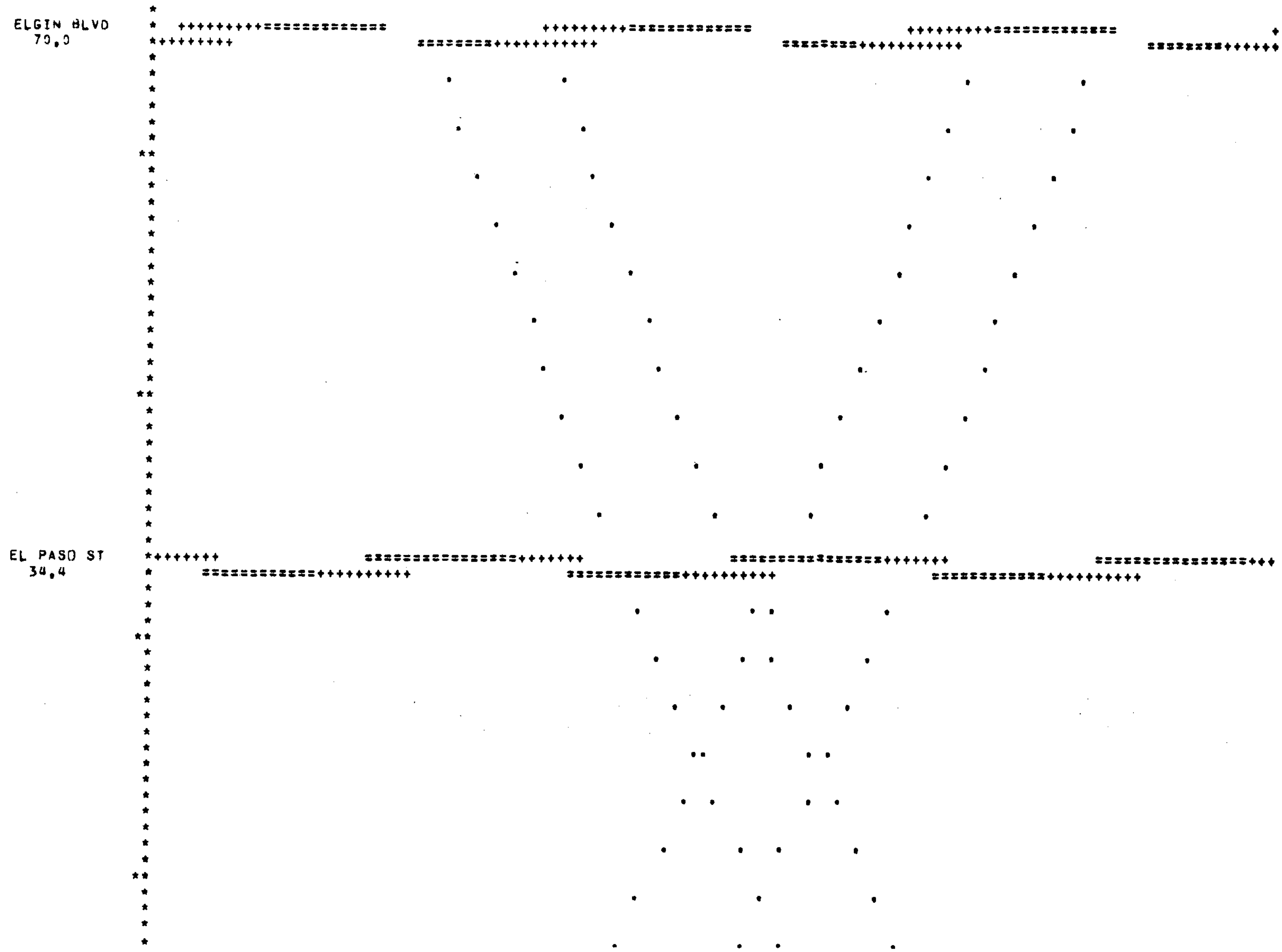


Figure 33

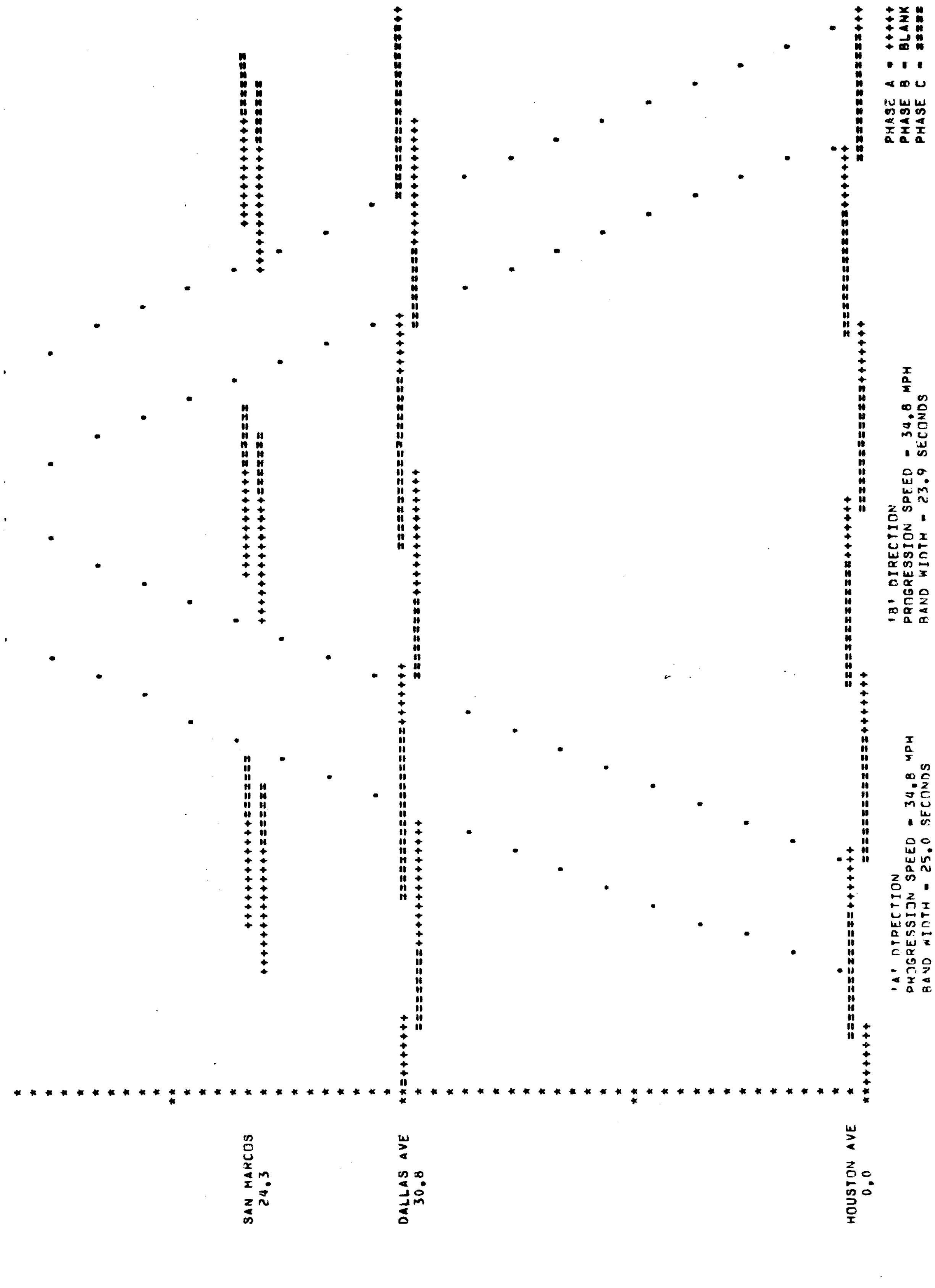

SAN MARCOS
24.3
DALLAS AVE
30.8
HOUSTON AVE
0.0
'A' DIRECTION
PROGRESSION SPEED = 34.8 MPH
BAND WIDTH = 25.0 SECONDS
'B' DIRECTION
PROGRESSION SPEED = 34.8 MPH
BAND WIDTH = 23.9 SECONDS
PHASE A = +++++
PHASE B = BLANK
PHASE C = =====

Figure 34

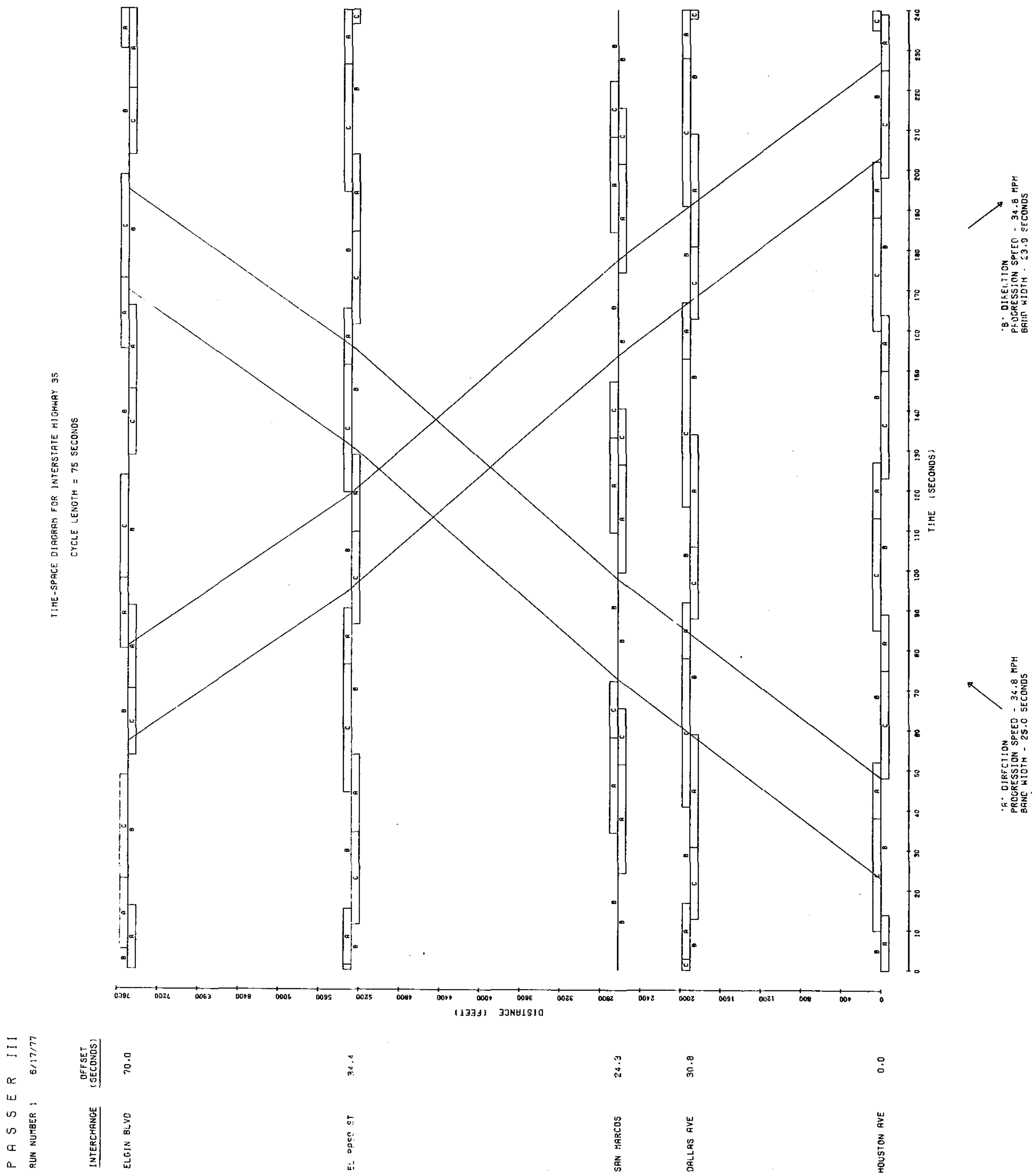

P A S S E R III
RUN NUMBER 1 6/17/77
TIME-SPACE DIAGRAM FOR INTERSTATE HIGHWAY 35
CYCLE LENGTH = 75 SECONDS
INTERCHANGE
OFFSET (SECONDS)
ELGIN BLVD 70.0
EL PASO ST 34.4
SAN MARCOS 24.3
DALLAS AVE 30.8
HOUSTON AVE 0.0
DISTANCE (FEET)
TIME (SECONDS)
'A' DIRECTION
PROGRESSION SPEED - 34.8 MPH
BAND WIDTH - 25.0 SECONDS
'B' DIRECTION
PROGRESSION SPEED - 34.8 MPH
BAND WIDTH - 23.9 SECONDS

Figure 35

ACKNOWLEDGMENTS

The research reported herein was performed within the research project entitled, "Development of a Frontage Road Level of Service Evaluation Program - PASSER III," by the Texas Transportation Institute and sponsored by the Texas Department of Highways and Public Transportation in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This paper does not constitute a standard, specification or regulation.

The authors wish to acknowledge Messrs. Elmer Koeppe and Dale Barnes of the Texas State Department of Highways and Public Transportation for their technical input and constructive comments during the preparation of this report. The assistance provided by Mr. John Hobbs and Mrs. Debbie Durham of the Texas Transportation Institute also is gratefully acknowledged.

REFERENCES

1. Messer, C.J., Whitson, R.H., Dudek, C.L. and Romano, E.J. A Variable Sequence Multiphase Progression Optimization Program. Highway Research Record 445, 1973, pp. 24-33.

2. Messer, C.J. and Gibbs, J.L. Computer Control of the Wayside-Telephone Arterial Street Network. Texas Transportation Institute Research Report 165-3, April 1973.

3. Messer, C.J., Haenel, H.E. and Koeppe, E.A. A Report on the User's Manual for Progression Analysis and Signal System Evaluation Routine -- PASSER II. Texas Transportation Institute Research Report 165-14, August 1974.

4. Messer, C.J., Fambro, D.B. and Andersen, D.A. A Study of the Effects of Design and Operational Performance of Signal Systems -- Final Report. Texas Transportation Institute Research Report 203-2F, August 1975.

5. Messer, C.J., Fambro, D.B. and Turner, J.M. Analysis of Diamond Interchange Operation and Development of a Frontage Road Level of Service Evaluation Program - PASSER III -- Final Report. Texas Transportation Institute Research Report 178-2F, August 1976.

6. Munjal, P.K. An Analysis of Diamond Interchange Signalization. Highway Research Record 349, 1971, pp. 47-64.

7. Webster, F.V. Traffic Signal Settings. Her Majesty's Stationery Office, London, Road Research Technical Paper 39, 1958.

8. Messer, C.J. and Berry, D.J. Effects of Design Alternatives on Quality of Service at Signalized Diamond Interchanges. Transportation Research Record 538, 1975, pp. 20-31.

9. Hutchinson, J.P. Delay at a Fixed Time Traffic Signal - II: Numerical Comparisons of Some Theoretical Expressions. Transportation Science, Vol. 6, No. 3, August, 1972, p. 288.

10. Wagner, F.A., Gerlough, D. L. and Barnes, F.C. Improved Criteria for Traffic Signal Systems on Urban Arterials. NCHRP 73, 1969.

11. Wagner, F.A., Barnes, F. C. and Gerlough, D.L. Improved Criteria for Traffic Signal Systems in Urban Networks. NCHRP 124, 1971.

12. Gartner, N. Microscopic Analysis of Traffic Flow Patterns for Minimizing Delay on Signal-Controlled Links. Highway Research Record 445, 1973, pp. 12-23.

13. Messer, C.J. and Fambro, D.B. A Guide For Designing and Operating Signalized Intersections in Texas. Texas Transportation Research Report 203-1, August 1974.

APPENDIX A

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

$$C = [(1.5 \cdot L) + 5] / (1-Y) \qquad (1)$$

Where: C = Cycle length, sec.

$L = \sum_{i=1}^{n} \ell_i$, n = number of phases.

ℓ_i = Lost time per phase, sec. The recommended value is 4 seconds.

$Y = \sum_{i=1}^{n} y_i$, n = number of phases.

y_i = The ratio between the actual demand volume and the saturation capacity flow rate for each phase.

To calculate splits:

$$G_i = [(y_i/Y) \cdot (C-L)] + \ell_i \qquad (2)$$

Note: Each intersection of a diamond interchange will generally have a different optimal cycle length. The smallest permissible cycle length for the interchange should not be less than 0.85 times the larger optimal cycle length, nor normally be greater than 1.25 times the smaller optimal cycle length for the interchange. For example, assume that the optimal cycle lengths based on the Webster formula for the two intersections which make up the diamond interchange are 45 and 50 seconds. The smallest permissible cycle length for the interchange should not be less than (0.85 x 50) = 43 seconds nor greater than (1.25 x 45) = 56 seconds.

If the frontage road progression option is being utilized, the smallest and largest cycle lengths the program may consider in finding the optimal solution must be determined beforehand. The smallest permissible cycle length for the frontage road system should not be less than 0.85 times the largest optimal cycle length of any individual intersection in the system, nor normally be greater than 1.25 times the smallest optimal cycle length of any individual intersection in the system.

APPENDIX B

METHODS OF CALCULATING OPERATIONAL MEASURES OF EFFECTIVENESS

I. Demand volume to signal capacity ratio, x.

$$x = (Q \cdot C) / (S \cdot g) \qquad (1)$$

Where: x = Demand volume to signal capacity ratio for the critical lane on the approach.

Q = Average arrival rate for the critical lane on the approach, veh./hr.

C = Interchange cycle length, sec.

S = Saturation capacity flow rate for the critical lane on the approach, veh./hr.

g = Length of the effective green phase on the approach, sec.

and

$$g = G - \ell \qquad (2)$$

Where: G = Length of the green plus yellow phases on the approach, sec.

ℓ = Lost time per phase, sec. The program assumes a value of 4 seconds per phase.

II. Average vehicular delay, d.

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

Where: d = Average vehicular delay on the approach, sec./veh.

C = Interchange cycle length, sec.

x = Demand volume to signal capacity ratio on the approach.

q = Average arrival rate on the approach, veh./sec.

and

$$\lambda = g/C \qquad (4)$$

Where: g = Length of the effective green phase on the approach, sec.

C = Interchange cycle length, sec.

III. Probability of clearing the queue, P_c.

$$P_c = 1 - e^{-1.58 \cdot \phi} \qquad (5)$$

Where: P_c = Miller's probability of clearing the queue on the approach.

and $$\phi = \left(\frac{1 - x}{x}\right) \cdot s \cdot g \qquad (6)$$

Where: x = Demand volume to signal capacity ratio for the critical lane on the approach.

s = Saturation capacity flow rate for the critical lane on the approach, veh./sec.

g = Length of the effective green phase on the approach, sec.

IV. Interior storage ratio, S.

$$S_R = Q_M / S_A \qquad (7)$$

Where: S_R = Interior storage ratio.

Q_M = Maximum queue per cycle on the approach, veh.

S_A = Available storage capacity on the approach, veh.