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16. Abstract

This report describes and presents the results of a study to develop a system of freeway corridor evaluation and improvement tools to be known by the acronym PASSER IV. This effort resulted in the production of several computer programs implementing its findings. The first stage of this research involved a detailed appraisal of the existing technology for: the evaluation of the effects of changes in the characteristics of facilities in a freeway corridor upon the traffic flow in the corridor; and improving the timing of traffic signals in a freeway corridor such that the total throughout the corridor is enhanced. The study also included close contact with transportation professionals in Dallas/Fort Worth, Houston, and San Antonio to ensure that the research was directed toward solving problems of importance to practitioners. Procedures and computer programs were developed to quickly analyze urban freeway corridor alternatives. A simple, easy-to-use, progression-based, signal optimization algorithm was developed and implemented as a computer program.

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DEVELOPMENT OF A FREEWAY CORRIDOR EVALUATION SYSTEM

PASSER IV

by

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Research Report 281-2F
Research Study 2-18-80-281
Development of a Freeway Corridor Evaluation System-PASSER IV

Sponsored by

Texas State Department of Highways and Public Transportation

In Cooperation with
The U.S. Department of Transportation
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TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas

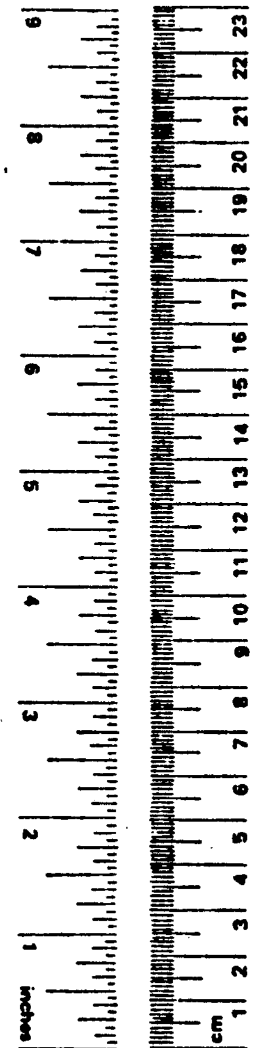
August 1986

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

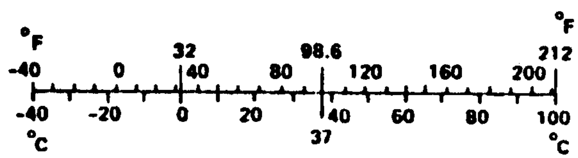
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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This research was sponsored by the Texas State Department of Highways and Public Transportation (SDHPT). Wiley D. Cunagin was the Study Supervisor and Herman E. Haenel was the SDHPT Contact Representative. The following SDHPT personnel served on the Technical Advisory Committee and contributed significantly to this study.

B. G. Marsden
A. C. M. Mao
A. B. Osburn
E. A. Koeppe

The numerous attendees of the PASSER IV workshop sessions in Dallas/Fort Worth, San Antonio, and Houston contributed important ideas and evaluations which were used in the formulation of the PASSER IV corridor evaluation system. Mr. Bill Hensch of the City of Houston was very helpful in implementing the signal timing schedule developed in this research.

Disclaimer

ABSTRACT

This report describes and presents the results of a study to develop a system of freeway corridor evaluation and improvement tools to be known by the acronym PASSER IV. This effort resulted in the production of several computer programs implementing its findings. The first stage of this research involved a detailed appraisal of the existing technology for: the evaluation of the effects of changes in the characteristics of facilities in a freeway corridor upon the traffic flow in the corridor; and improving the timing of traffic signals in a freeway corridor such that the total throughout the corridor is enhanced. The study also included close contact with transportation professionals in Dallas/Fort Worth, Houston, and San Antonio to ensure that the research was directed toward solving problems of importance to practitioners. Procedures and computer programs were developed to quickly analyze urban freeway corridor alternatives. A simple, easy-to-use, progression-based, signal optimization algorithm was developed and implemented as a computer program.

KEY WORDS: Traffic Signal Timing, Traffic Assisgnment, Traffic Diversion Equilibrium Assignment.

SUMMARY

This document describes the methodology, results, and products of a research study to develop a useful evaluation system for traffic conditions in a freeway corridor and the timing of signals on facilities in that corridor to increase the throughput of vehicles. The results of a survey of the perceived needs of transportation professionals for corridor evaluation tools is presented. The quick response procedures developed for the evaluation of freeway corridor traffic conditions are briefly described and referenced to an earlier detailed report. The easy-to-use, progression-based, signal optimization algorithm for urban freeway corridor networks is described. A flowchart of the computer program for this technique is provided. A detailed listing is available from Texas SDHPT. The results of a test of the algorithm on an actual freeway corridor (I-45 North in Houston) are discussed.

IMPLEMENTATION

The system of freeway corridor evaluation and signal timing procedures and computer programs presented in this report should be useful to transportation engineers and planners who need effective tools for assessing the impacts of changes in the characteristics of facilities and for increasing the throughput of and improving the operating characteristics of signalized roadways.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the State Department of Highways and Public Transportation. This report does not constitute a standard, specification, or regulation. The Progression Analysis and Signal System Evaluation Routine for Freeway Corridor-PASSER IV is intended as an engineering tool, the results of which are subject to an engineering reveiw for factual representation and accuracy.

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INTRODUCTION

Urban freeway and expressway corridors are the existing backbone of the transportation systems in every major city in Texas. The effective management of these facilities has become increasingly important in this period of limited resources. Increasing traffic demand and traffic congestion have made the efficient utilization of existing facilities and relatively minor geometric modifications to improve traffic flow a very important function of the various operating agencies involved.

City, area, State, and federal goals and objectives in this area must be coordinated in a cooperative manner. Toward this end, a forum and resulting framework has been established in many Texas cities as a Traffic Management Team. These groups have been established to continuously identify and systematically analyze a range of freeway corridor management problems which are expected to occur in these cities over upcoming five-year periods. This process includes representatives from the major Texas cities, local and/or COG's, and FHWA and SDHPT representatives. Problems identified by these groups were considered in detail in this research.

Existing methods and related computer programs offer proven performance capabilities, but are seriously deficient in several areas. First, they do not allow quick-response analyses to be conducted in a cost-effective manner. Second, most existing freeway programs do not explicitly address the continuous, one-way frontage roads paralleling the freeways which are practically unique to Texas. Third, all existing programs require a large amount of field data and other information that may not be readily available. This requirement presents a serious problem in all Texas cities.

DEFINITION OF EMPHASIS AREAS

A state-of-the-art review and delineation of needs for this effort included: a detailed review of existing models and/or concepts applicable to the freeway corridor signal timing; meetings with other professionals involved in this area of investigation; and continued contact with the various city, area, State, and federal agencies with respect to transportation system management applications to freeway corridors.

Meetings were held with transportation professionals in the cities of San Antonio, Houston, Dallas, and Fort Worth. Following extended discussions as to the objectives and expected products of the research, these practitioners were each asked to complete a survey form designed to elicit a quantitative evaluation of the relative importance of a wide range of specific topics. A copy of the survey is included as Appendix A. In completing the survey, the participants were asked to indicate their potential need for analytical methods in each of 31 topic areas by a number from the following scale:

1. Very important
2. Important
3. Marginally important
4. Does not apply

The evaluations of all participants in the three meetings were pooled to produce composite results. The ten areas of greatest need for analytical methods, as perceived by the transportation professionals, are listed below in descending order of total score.

1. Assess the potential operational impacts of a proposed new major traffic generator (e.g., a new shopping center).
2. Signalization.
3. Improvement of frontage road continuity.
3. Intersection treatments.
5. Ramp additions.
6. Ramp closures.
6. Potential operational impacts of express bus and park and ride service.
8. Ramp metering.
8. Conversion from two-way to one-way street operations.

10. Work rescheduling to reduce peak demand.

The frequency distribution of the responses for each topic are given as Appendix B.

The participants were also asked to suggest topics not explicitly suggested in the survey. Those listed included:

1. Impacts of maintenance and construction activities on operations.
2. Less precise, faster solution techniques with less input data requirements.
3. Freeway corridor analysis techniques, in a general sense.

There was a consensus among the participants that the entire freeway corridor must be considered as a total system. Existing tools work well when considering individual facilities within the corridor, but fall short when addressing an integrated problem.

Members of the study team also met with FHWA representatives and other researchers to identify recent and ongoing projects relevant to this effort. The results of these investigations were included in the design of the products to be included in the PASSER IV system.

PASSER IV QUICK RESPONSE PROCEDURES

The PASSER IV Quick Response Procedures were developed to enable practitioners to analyze a wide range of alternative actions for urban freeway corridors. Estimates of traffic flow levels on parallel freeway, frontage road, and arterial roadways are computed based on equilibrium traffic assignments and descriptions of roadway characteristics. System travel time is also calculated. The procedures contain features which handle route changing choices among travel routes with eratic characteristics. A FORTRAN computer program was provided to automate the application of the procedures to actual freeway corridor networks.

A complete description of this tool is found in a previously published document, entitled "PASSER IV Quick Response Procedures," Texas Transportation Institute Report No. 281-1, Texas SDHPT/FHWA Report No. FHWA/TX-85/19+281-1.

SIGNAL OPTIMIZATION ALGORITHM FOR URBAN FREEWAY CORRIDOR NETWORKS

The need for a simple, easy-to-use, progression-based, signal optimization algorithm for urban freeway corridor networks has been well-recognized. Current computer programs and procedures are often not suitable for analysis since they may require a large amount of field data and computational effort to conduct the analysis. In addition, current network signal timing approaches use total system delay and/or number of stops to define optimality. This definition does not necessarily meet the engineering objective of expediting the primary flow while providing reasonable service to the cross street flow in the corridor. This section describes conceptually an algorithm which explicitly considers this objective.

A practical procedure, based on the widely used PASSER II arterial signal timing computer program was developed for providing progression in the principal direction of traffic flow in urban freeway signal networks while not unreasonably delaying minor cross street traffic. The methodology permits the user to determine desirable signal settings for traffic progression in this context.

For the purpose of illustration, the simple network shown in Figure 1 will be used to describe the basic principles employed in obtaining a signal timing solution.

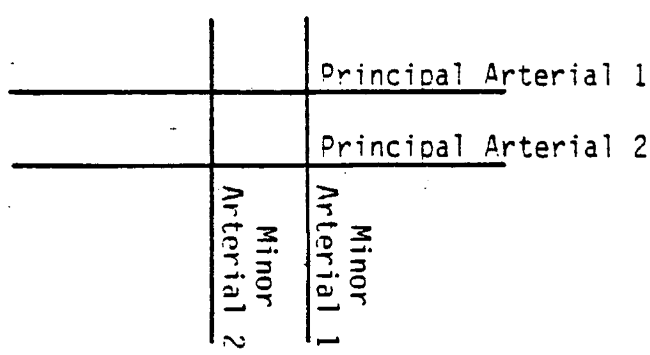

Figure 1. Test Problem for PASSER IV corridor signal timing.

Assume that, in an urban freeway corridor system, Principal Arterials 1 and 2 are parallel to the freeway and are to be assigned an optimal progression-based timing plan. Minor Arterials 1 and 2 may also be operating in progression. The mathematical problem is to maximize the time bandwidth on the Principal Arterials while minimizing the delay to the Minor Arterial (cross street) traffic. The approach used in this algorithm is to:

1. compute the optimal progression-based timing plan for each street independently;
2. model the closed loop as a linear network;
3. adjust the green times and offsets to satisfy the loop constraints; and
4. iterate steps 2 and 3 to produce the best timing plan.

The program NETSIM was used to evaluate the algorithm.

ANALYSIS APPROACH

This research investigated the application of maximum bandwidth-based progression optimization principles to a small but representative traffic signal network. The algorithm developed during the study explicitly considers loop closure constraints. A "fine-tuning" procedure is presented which adjusts cycle length and offsets to meet the requirement for closed loops that

$$nc = \Sigma g_i + \Sigma \delta_i$$

where

n = some integer;

c = cycle length;

g_i = green times around closed loop; and

δ_i = offsets around closed loop.

The starting point for the algorithm is the set of independent arterial optimum progression results, obtained by application of the PASSER II computer program to each arterial separately.

Following an extensive state-of-the-art review and detailed study of the PASSER II, PASSER III, NETSIM, TRANSYT, and MAXBAND computer programs, the following salient system design features were identified:

1. The PASSER II program provided a reasonable and stable base for the PASSER IV system. Therefore, the basic characteristics of the PASSER II program were preserved. These included the input system, evaluation parameters, phasing definitions, and the straight-forward optimization calculation.
2. The simple four node signal network of Figure 1 was used as the study test problem, but expandability to a larger signal system was included.
3. Data input requirements were minimized.
4. User programming effort was kept as simple as possible.
5. The ease of running the program was preserved.
6. The number of required program runs (iterations) for obtaining the "best" solution was minimized. The program compares internally the successive runs with the previous "best" solution to obtain the relative optimum solution with quick calculations and low computer storage requirements.
7. The starting point basis for the urban corridor network optimum timing plan was defined to be the set of individual arterial optimum timing plans.
8. The evaluation criteria for the signal timing optimization plan were defined to be:
    a. maximized bandwidth (progression) parameters; and
    b. minimized delay and stops, subject to loop closure constraints.

THE TEST NETWORK

The simple network shown in Figure 1 was studied to expedite development of the network signal timing optimization procedures which could then be expanded to a more complicated signal system. Test data were derived from the the Skillman Avenue Arterial Progression Problem (studied earlier in other research), as shown in Figure 2.

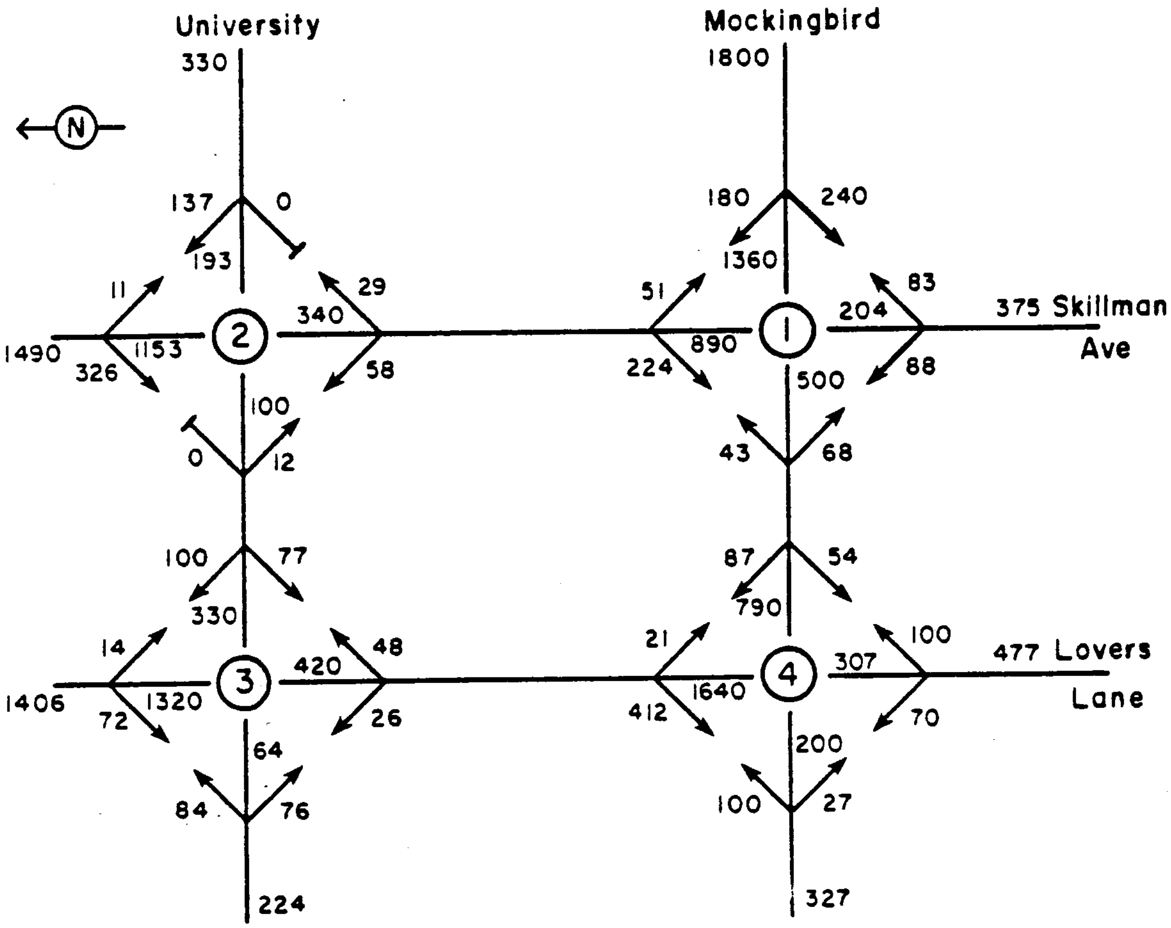

Figure 2. Traffic Volumes for the Test Network.

Using the test network, several sets of simulated PASSER IV runs were performed, consisting of repeated PASSER II runs and manual hand calculator computations. The relationships among cycle length, offsets, and phase sequence with the progression measures of effectiveness (i.e., bandwidth, efficiency, attainability, and average delay per vehicle) under multiple phase or two phase and high volume conditions were examined. Comparisons were made using extensive calculations from NETSIM simulation runs and the optimum solutions yielded by the simulated PASSER IV runs. The operational results, classified as network, arterial street, and circular movements, were evaluated. These results were used to develop a detailed algorithm.

Previous research has shown that using a range of cycle length with proper manipulations of the relative offsets, rather than the specific phase sequence or movement green can best achieve the requirement of satisfying the loop closure constraint. This is true provided the optimum solutions for individual arterial progression runs are used as a starting basis. Therefore, emphasis was placed on selection of cycle length and offsets in this research.

The PASSER IV program retains the ability to run PASSER II for an arterial network. Within the PASSER IV program, the subroutine LOPLNK provides the loop system capability which is, of course, not available in the PASSER II program. The PASSER IV card input stream is essentially the same as with PASSER II, with the addition of the "Loop Calculation Indication Cards".

EVALUATION OF TIMING PLANS

The relationships among progression performance measures were studied using the original PASSER II program with the test sample data. Then, the results of the four arterial runs were fine tuned manually to fulfill the closed loop constraint. The resulting measures of effectiveness (average delay per vehicle, attainability, and efficiency) were then compared with NETSIM evaluations on the arterial direction and systemwide bases. Both multiple phase and two phase signal operations were considered.

Figure 3 illustrates the relationship of measures of effectiveness (MOE's) for different cycle lengths for one principal arterial (Skillman Avenue). One MOE shown is the percentage efficiency E_c of an optimal progression solution for a given cycle length C:

$$E_c = \frac{100 \times B_{c\ max}}{2 \times C}$$

where B_{cmax} is the maximum sum of the progression bands in both directions at cycle length C.

The attainability A_c is a measure of the ability of the progression strategy to utilize the available progressive greens of the intersections within the system. Attainability measures how close the progression solution has come to the best theoretically possible solution for given traffic conditions and green splits. Attainability is expressed as a percentage of the cycle length C by the following equation:

$$A_c = 100 - \frac{I_{imin}}{G_{omin} + G_{imin}} \times 100$$

or

$$A_c = \frac{100 \times B_{cmax}}{G_{omin} + G_{imin}}$$

where I_{imin} is the interference of the green band. Attainability is a measurement of the degree of utilization of available green time G_{omin} and G_{imin} in both directions of travel, respectively. Figure 3 illustrates that the cycle time for satisfying the minimum delay constraint is slightly lower than that satisfying the maximum attainability of efficiency constraints.

Figure 3 illustrates why sometimes the delay cycle length is not always the best for providing the maximum usable green time for progression movements.

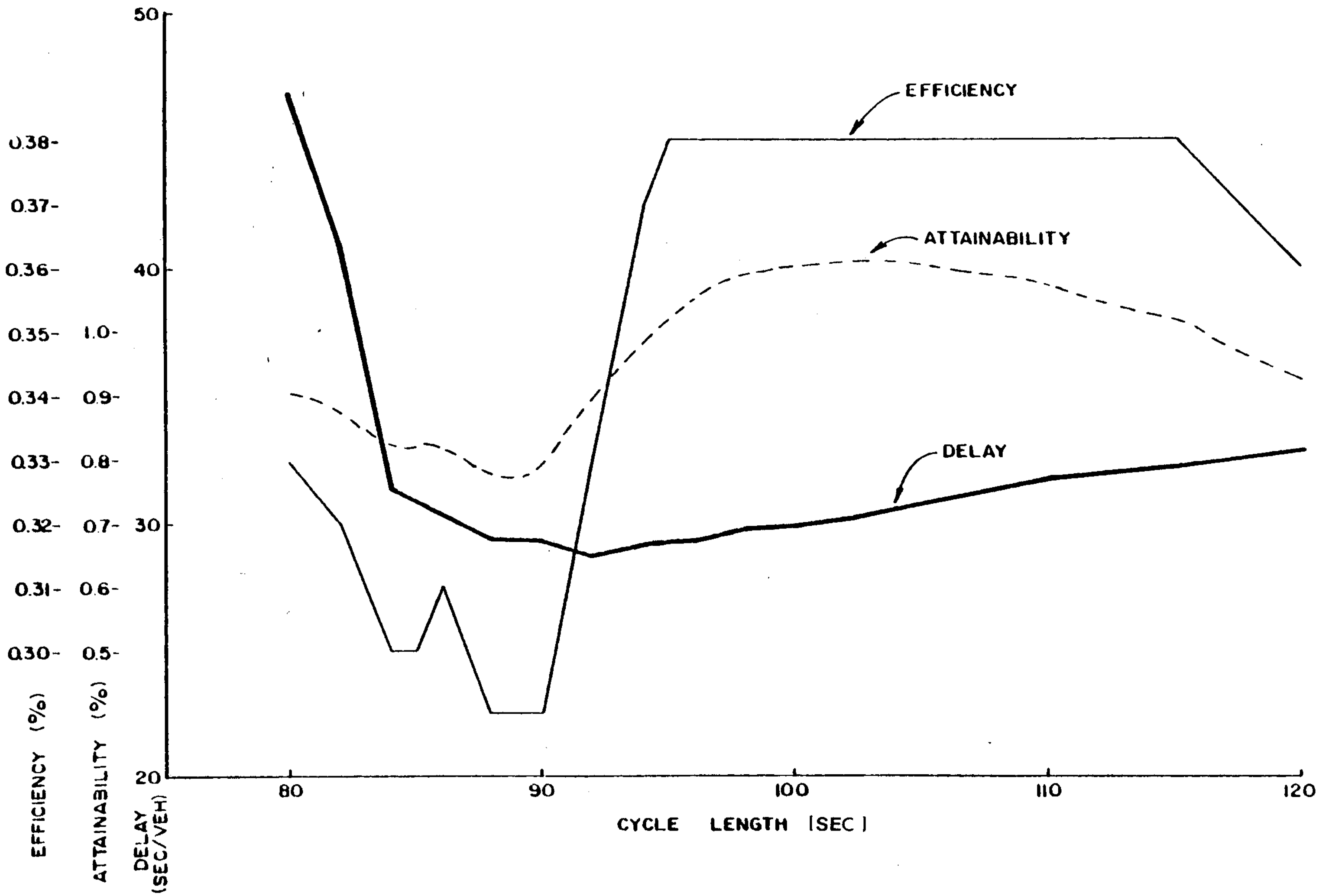

Figure 3. Systematic measurements of average delay per vehicle, attainability and effectiveness respect to Cycle Length of arterial progression system --Skillman Avenue.

Figure 4 shows the relationships between average delay per vehicle and cycle length for each intersection (1 through 4) in the test system, as well as the systemwide average delay per vehicle. Total systemwide average delay per vehicle as a function of cycle length is plotted in Figure 5 with efficiency and attainability values. Clearly, cycle lengths greater than 100 seconds (in this example) slightly increase total delay while reducing attainability and efficiency. However, because of the particular test program used in the illustration, a larger-than-normal optimal cycle length range and sharp increase of average delay per vehicle at the low cycle length range are apparent in Figures 3, 4 and 5. This is primarily due to the lack of a separate left-turn lane on intersection No. 2, the heavy volume concentration on intersections 2 and 3, and the unbalanced traffic variation on the loop system network under test. Nevertheless, this test example does demonstrate the use of the PASSER IV program under different combinations of traffic conditions such as: protected-and-unprotected left-turns; long-and-short spacings; various percentages of midblock flow; and differing numbers of through lanes.

Figure 6 compares the average delay per vehicle from the output of the PASSER IV runs with values for the same conditions produced by NETSIM runs. Both the network and the interior loop system composed of the links between intersections are presented for four-phase signal operation. The dashed line is the locus of equal average delay per vehicle between the NETSIM and PASSER IV runs for cycle lengths between 100 through 105 seconds. Taking NETSIM as the "correct" value in each case, PASSER IV slightly overestimates delay on the interior loop system, but significantly underestimates the average network delay per vehicle.

Cycle lengths of 100 and 105 seconds were used to derive the points shown on Figure 7, which shows a similar comparison of the PASSER IV and NETSIM results for two-phase operation. The average delay per vehicle is nearly

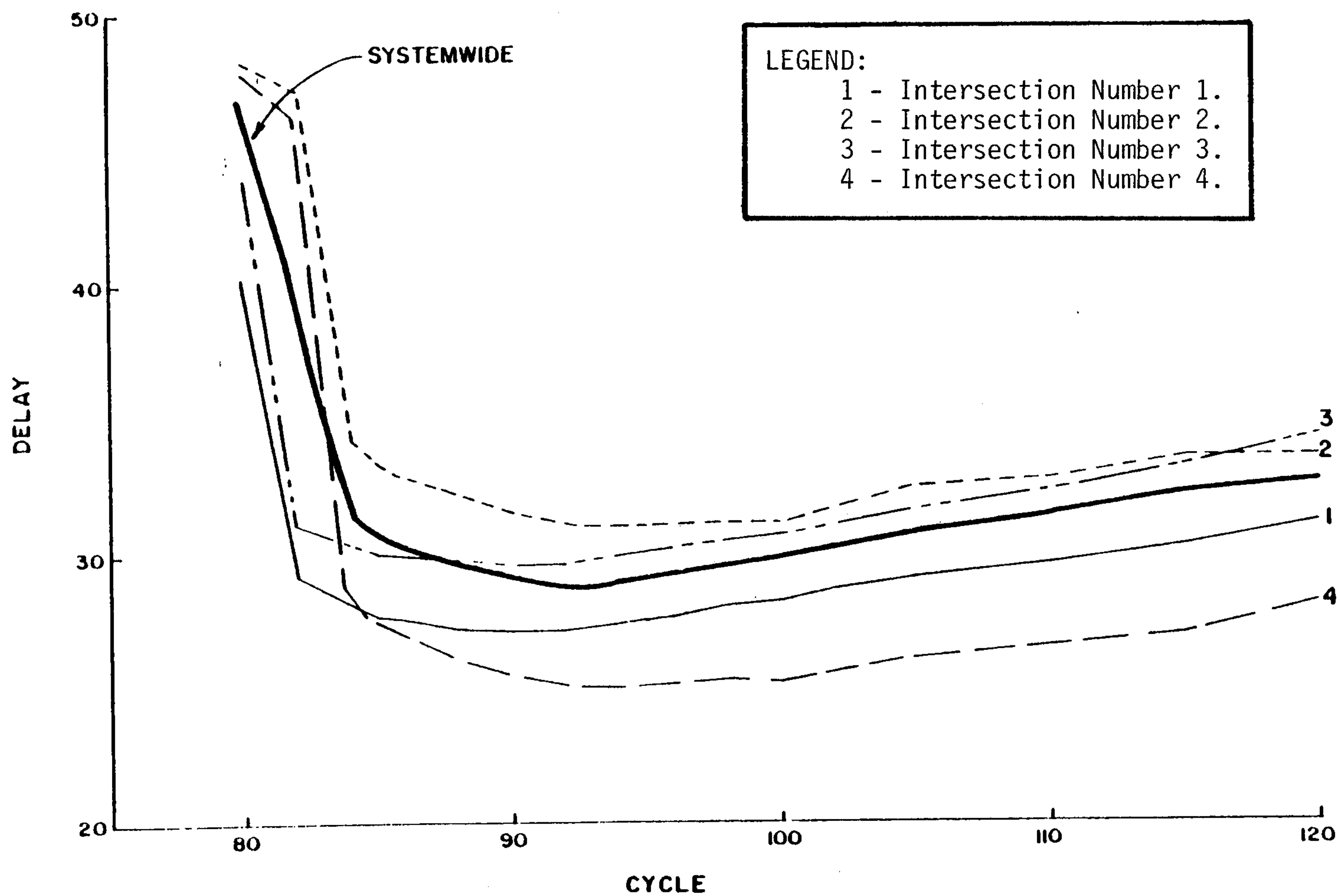

Figure 4. Relationship of cycle length vs. average delay per vehicle of each intersection within the loop system PASSER IV run.

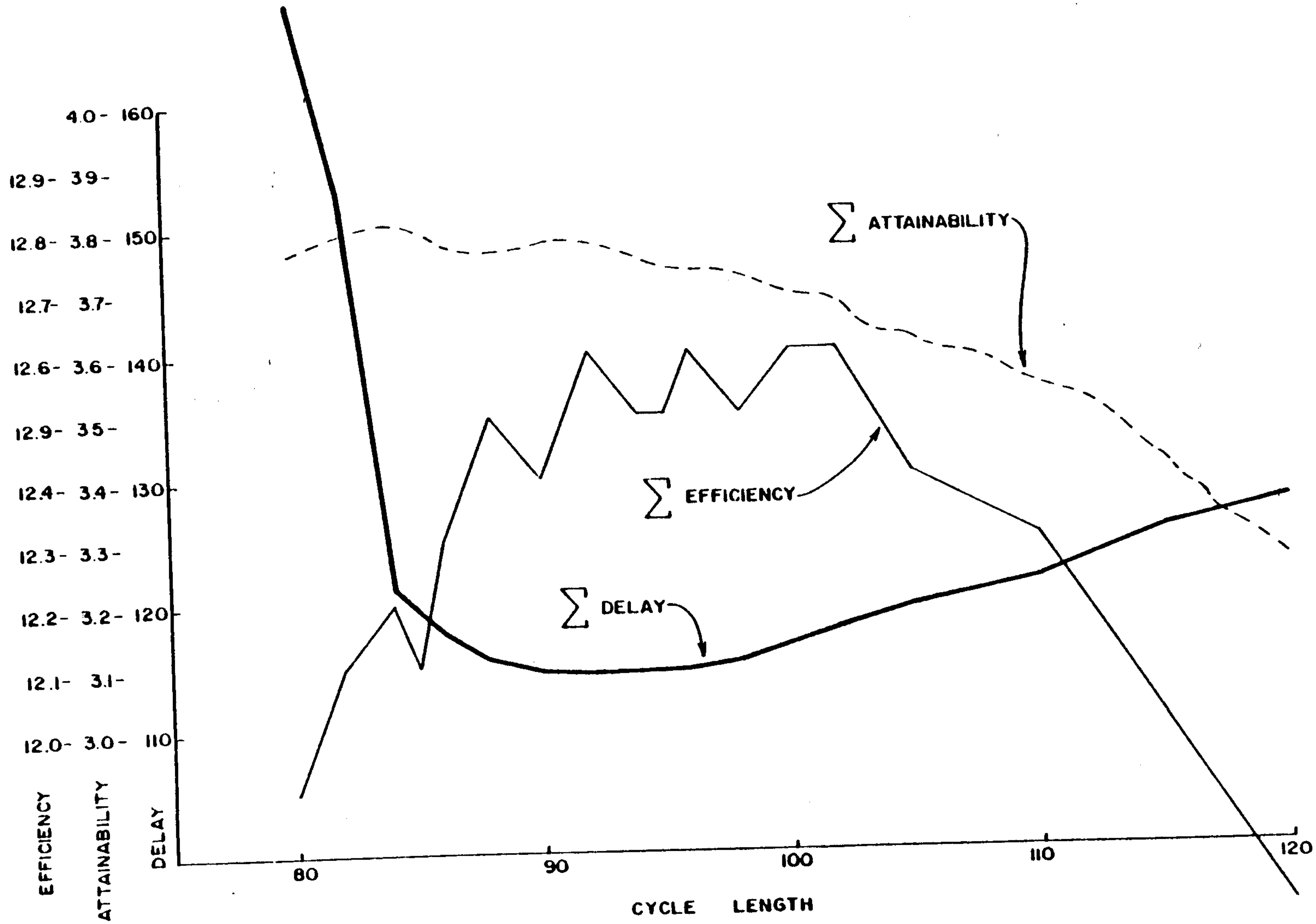

Figure 5. Composite measurements of average delay per vehicle, attainability and effectiveness respect to cycle length of intersections in the loop system.

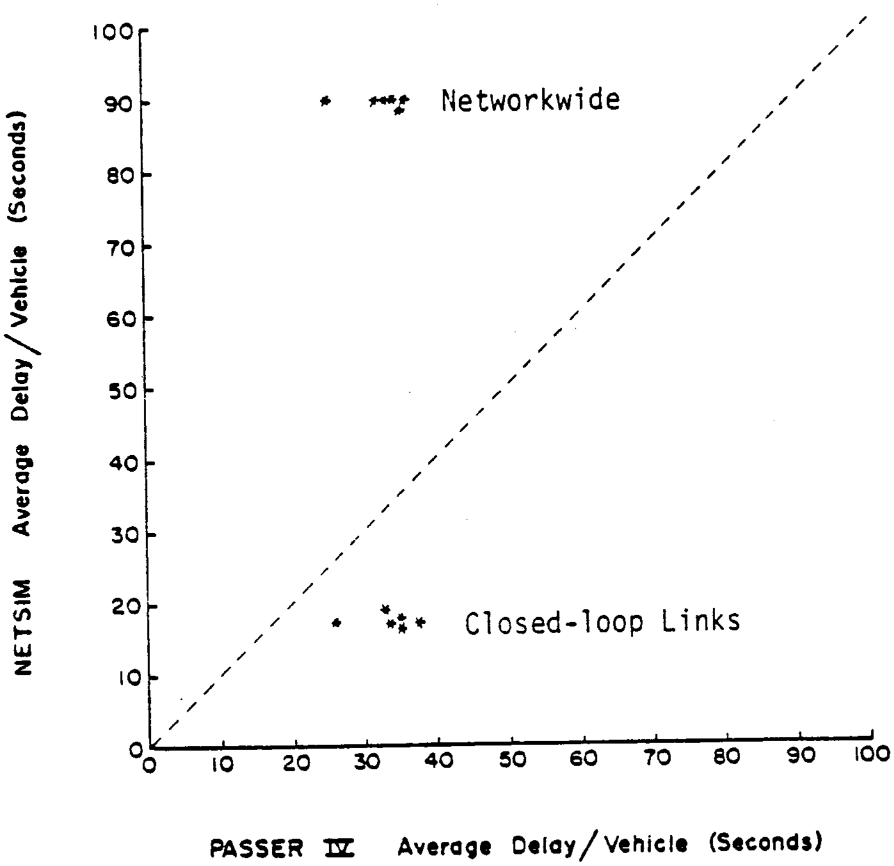

Figure 6. Comparison of average delay per vehicle between PASSER IV Simulated Runs and NETSIM run in four-phase operation.

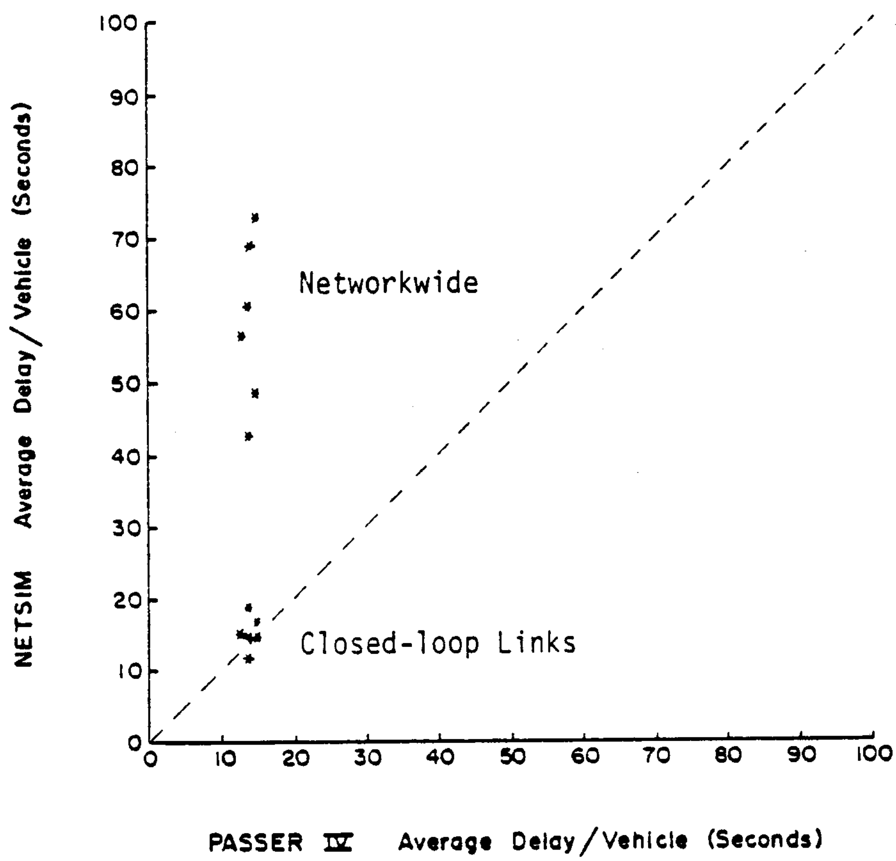

Figure 7. Comparison of average delay per vehicle between PASSER IV Simulated Runs and NETSIM run in two-phase operation.

equal for this phasing on the interior loop, but PASSER IV underestimates the network delay. The cycle lengths used were 60 and 65 seconds.

Heavy volume conditions were analyzed and are presented in Figure 8 using the equivalent through movement procedures suggested in the TTI Report No. 203-2F, "A Guide for Designing and Operating Signalized Intersections in Texas". PASSER IV again slightly overestimated the interior loop delay per vehicle, but underestimated the network delay.

As may be noticed in Figures 6, 7, and 8, high values of average delay per vehicle were generated because of the 6 dummy links and 10 dummy nodes used in the NETSIM program to accomplish the traffic modeling of the longer-than-maximum link length and the unbalanced traffic flow pattern used in the synthetic test network. The comparison of both runs in the closed loop links provided an indication for the need to modify the delay calculation in the PASSER IV program in order to better model the delay for left-turn traffic movements.

RESULTS OF PASSER IV/NETSIM COMPARISONS

In four-phase operation, the effect of adjusting offsets of systemwide average delay per vehicle is insignificant. However, a 1.5 to 3 percent saving in delay is possible on the links of the principal arterial direction by manipulation of the offsets. This indicates that the offsets should be biased to favor the principal arterial direction at the expense of the minor arterial cross streets.

In two-phase operation, the effects of fine tuning the offsets are very significant (- 2 - 5%) for both the systemwide and principal arterial direction evaluations. However, delay for left turn movements and permissive turns are underestimated because the PASSER II program currently lacks the ability to model two-phase operation. The delay calculated by PASSER II is consistent, relative to NETSIM, on both the systemwide and interior link bases. The major problem with the PASSER II delay estimation procedure is the movement basis, rather than the link movement basis employed in the NETSIM program. This deficiency raised the need to add the research findings from TTI Report No. 203-2F and the computation procedure embedded in the PASSER III program to the PASSER IV system. The loop closure constraint has its greatest impact when many saturated intersections exist within the signal network. In less saturated situations, the looping constraint will generally

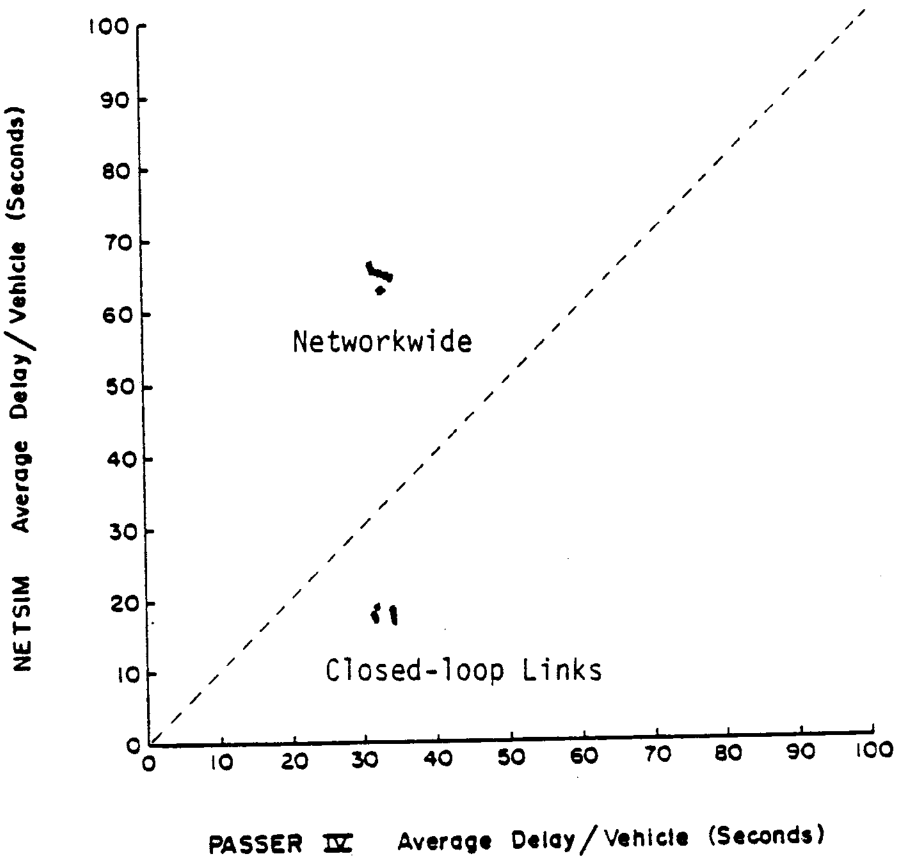

Figure 8. Comparison of average delay per vehicle between PASSER IV Simulated Runs and NETSIM run in two-phase operation with left-turn adjustment suggested in TTI Report 203-2F.

increase the delay in the system as a whole, but will decrease the delay in the principal arterial direction. Therefore, the loop closure constraints should be used as a reference basis for maximum bandwidth optimization or used with a 5 to 10 percent allowance to avoid very large delay and/or impractically large cycle length.

INPUT REQUIREMENTS

The input requirements for coding the simple network version of the PASSER IV are similar to those of PASSER II. The input data stream for the program is shown in Figure 9. This card stream includes the new input for specifying the locations where intersections meet at the "Loop Corners". Four cards (one for each intersection in the rectangular signal system) are required for each loop system run. If the user wants only the regular PASSER II arterial progression run, one card with a zero in column 2 is required before all the other input cards. The instructions for coding the "Loop Calculation Indication Cards" are shown in Figure 10.

The PASSER IV program was designed for easy use. The input requirements are essentially the same as those required for the widely used PASSER II program, with the addition of the "Loop Calculation Indication Cards". The principal modifications required for PASSER IV were made inside the program.

Testing of the PASSER IV program using the test problem shown in Figure 1 indicated that the procedure was feasible, easy-to-use, and gave consistent results. Further research improved the delay calculation algorithm, and to expanded the capability of the program to handle a larger number of intersections. These features were included in the PASSER IV program, for which the input coding forms and program listing are provided as Appendices C and D, respectively.

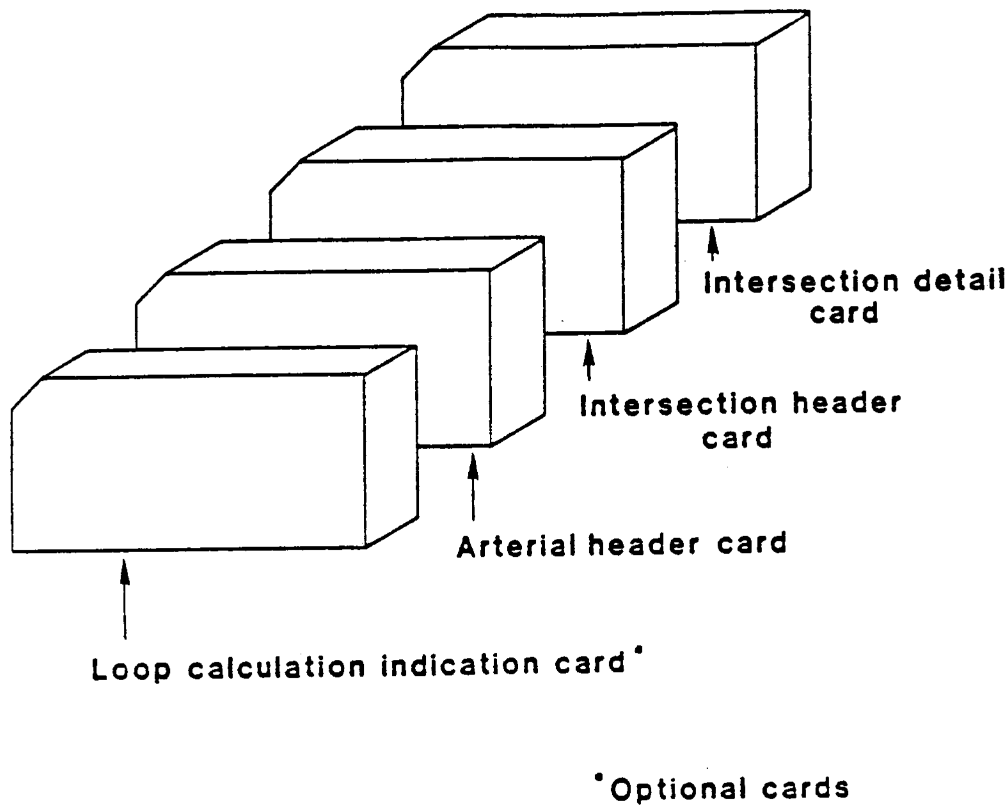

Figure 9. Passer IV Data Deck Stack

PASSER IV 'LOOP CALCULATION INDICATION CARD' INPUT

LOPLNK CALCULATION LABELLING SCHEME

```
                                                  <- N -
         IRUN=3      IRUN=4
           '           '
           '           '
      <---2----------1---      IRUN=1
           '           '
           '           '                2 Major Arterial
           '           '
      <---3----------4---      IRUN=2
           '           '
           '           '
           V           V
         IRUN=3      IRUN=4

        2 Minor Street
```

CODING FORMAT -- "LOOP CALCULATION INDICATION CARD".
NEW IN THE PASSER IV PROGRAM INPUT STREAM.

```
(1) COL. 2 - INT(I) - THE "X"TH INTERSECTION AS SHOWN IN THE FIGURE.
(2) COL. 4 - IRNU(I) - THE LOCATION OF "THE" INT(I) "RUN" NO.
(3)     6-7 - ISEQ(I) - THE "SEQUENCE" IN THE "RUN" (MAJOR ARTERIAL).

(5)  11-12 - SAME AS ABOVE, BUT THE "IRUN" & "ISEQ" OF MINOR ST.
```

IF NO "LOOP RUN" NEEDED, COL.2 OF 1ST CARD MUST BE CODED "O"
THEN THE PASSER II REGULAR RUNS WILL BE PERFORMED.

LOOP CORNER DEFINITION -- I.E.'CORNER' INTERSECTION 1,2,3, & 4

```
 INT(I) - 'CORNER' INTERSECTION NO.
IRUN(I) - RUN NO. - INDIVIDUAL RUNS.
ISEQ(I) - NO. OF 'CORNER' INTERSECTION IN IND. RUNS.
```

EXAMPLE DATA -- A 4-INTERSECTION NETWORK DERIVED FROM THE
DATA OF THE "SKILLMAN AVE" ARTERIAL STREET

```
1 1  1 4  1 - INTERSECTION 1 IS (IRUN=1,ISEQ=1) & (IRUN=4,ISEQ=1)
2 1  2 3  1 - INTERSECTION 2 IS (      1,     2) & (      3,     1)
3 2  2 3  2 - INTERSECTION 3 IS (      2,     2) & (      3,     2)
4 2  1 4  2 - INTERSECTION 4 IS (      2,     1) & (      4,     2)
```

Figure 10. Input Instruction for "Loop Calculation Indication Cards".

PASSER IV FIELD TESTING

The effectiveness of the PASSER IV program was tested on an actual urban freeway corridor network in Houston, Texas. This study involved a massive and comprehensive data collection effort throughout the entire North Freeway (I-45) corridor. Two major data collection sessions were conducted to analyze corridor conditions before and after any signal timing changes were implemented. Each of these efforts consisted of determining turning movement volumes at various intersections and travel time studies on all north-to-south oriented arterials as well as two cast-to-west arterials within the corridor.

DESCRIPTION OF STUDY AREA

The Houston North Freeway Corridor (I-45) was selected for use as the experimental network for testing and evaluating the PASSER IV program. The corridor (see Figure 11) serves as a major thoroughfare to downtown Houston while serving areas north of the central business district.

This corridor was selected for use with this study because of the variety of arterials existing within the corridor. The north-to-south oriented arterials range from two-lane roadways with no shoulders to a freeway designed to interstate standards. The broad variety of types of roadways within the corridor made it an ideal test area for the development of the PASSER IV traffic signal timing program. Appendix E contains a brief description of the geometric characteristics of each arterial in the corridor. These were used to construct the mathematical network required for the analysis.

The geometric configuration of the network remained mostly unchanged between August of 1983 and January 1985. However, one segment of Airline (from Little York to Tidwell) was increased from a 2-lane to a 4-lane cross-section in late 1984. Road construction was also underway in 1983 when the first major data collection effort was scheduled. However, this effort did not appear to adversely affect traffic flow in the already congested construction area.

STUDY SCHEDULE

All data were collected during the morning and afternoon peak traffic periods. The data were collected between the hours of 6:15 to 8:15 AM and 4:00 to 6:00 PM for the morning (AM) and afternoon (PM) peak periods,

- - - DENOTES AREA UNDER STUDY

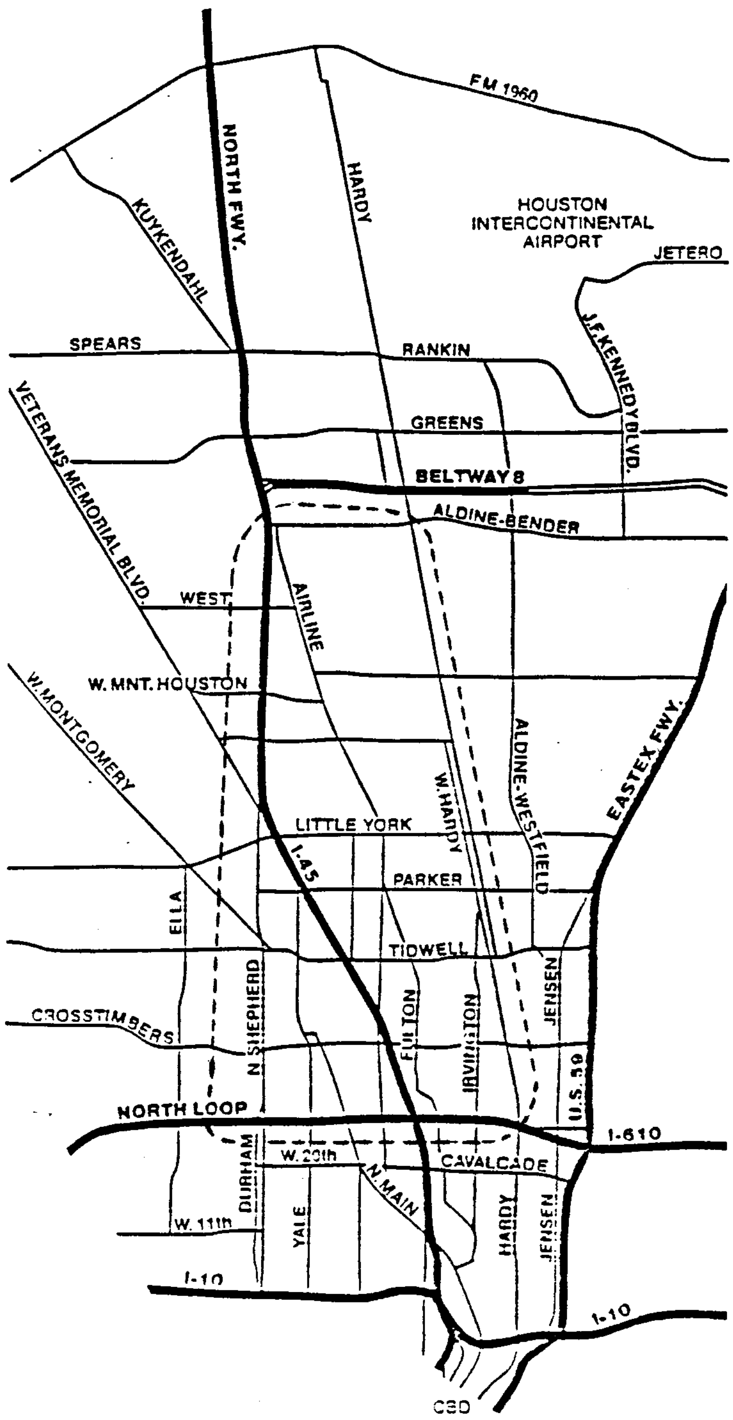

Figure 11. Location of Study Area.

respectively. Data collection activities were conducted only on days in which the traffic flow was considered to be representative of "normal" traffic conditions throughout the corridor. Considering this constraint, no data were collected during Monday morning (AM) or Friday afternoon (PM) peak traffic periods.

The first of two major data collection efforts was conducted during the weeks beginning August 15 and August 22, 1983. This two-week effort consisted of approximately 20 TTI personnel collecting data on six days. Data collection was not conducted several days due to a hurricane entering the Houston area during the first planned week of data collection. The effort resumed only after conditions had returned to normal throughout the study corridor. Travel time studies were conducted on nine (9) north-south routes and two intersecting arterials within the corridor. See Appendix E for a list of these routes and their lengths. Turning movement volumes were collected at 78 intersections during the AM peak and 73 during the PM peak traffic periods. Appendix F contains a list of these intersections and the time periods each was studied. Intersection diagrams of each studied intersection were also constructed during this collection effort to estimate flow capacities of each.

A second major data collection effort was conducted the week of January 9, 1985. This effort concentrated on evaluating traffic conditions throughout the corridor after the signal timing changes based upon results provided by the PASSER IV model were implemented. Travel time studies were again conducted throughout the corridor as in the previous study. Turning movement volumes were measured at a sample of intersections throughout the corridor to evaluate any volume changes. The 18 intersections studied during the AM peak period and 15 during the PM peak period are indicated in Appendix F.

DATA COLLECTION METHODOLOGY

The floating car method was used to determine travel conditions throughout the corridor. Each test car trip along each north-south and two east-west routes within the corridor was randomly begun at either extreme of the corridor limits. The time required to travel between each intersection of the network as well as any queues encountered were recorded. Special circumstances or incidents (i.e., travel restrictions caused by trains or accidents) were also indicated by the data collection personnel throughout each individual travel time study.

The turning movement volume counts were conducted in conjunction with the travel time studies. The volume of left turn, right turn, and straight through movements of each approach to the intersections were recorded in 15-minute intervals throughout each 2-hour peak period. Any incidents or unusual traffic signal operations were noted by the TTI personnel at each intersection.

DATA REDUCTION

Upon completion of each data collection effort, the data was placed on computer files for reduction and analysis. Texas A&M University's Amdahl V6/V8 mainframe computer was used to store and perform all the necessary analyses. The turning movement data from the 1983 collection effort were used for two separate, but interrelated purposes. The volume data was used as a basis for the comparison of conditions both before and after improvements throughout the corridor. The second and major purpose involved using the field data for developing the PASSER IV modelling network. The turning movement data were reduced to the proper formats as required by the computer model. Peak hour volumes were determined and any adjustments were made based upon specified procedures.

The above described process was conducted in conjunction with a methodology to estimate the capacity of each intersection within the corridor which was used to construct the network. This manual determination process used established procedures and intersection drawings as guidelines.

The results obtained from the travel time study data were also placed on Texas A&M University's mainframe computer. The travel time data were used as a means of comparison of mobility throughout the North Freeway Corridor network both before and after the implementation of any changes in signalization patterns. These data were reduced to indicate the travel times and speeds between the various checkpoints throughout the network. The total travel time and the overall average speed for each test car trip was determined to provide a basis of comparison of the "before" and "after" conditions throughout the study area.

VOLUME COMPARISONS

Tables 1 and 2 indicate a comparison of traffic volumes at selected intersections throughout the North Freeway corridor. Table 1 includes volumes collected during the AM (6:15 AM - 8:15 AM) peak traffic period. The table includes the two-hour approach volume for the southbound (inbound) intersection approach as well as the total (all approaches) two-hour intersection volume. Such values as determined in August of 1983 and January of 1985 are compared and percent of increase calculated is included for each. Similar volumes are compared for the PM peak period as shown by Table 2, in which the northbound (outbound) intersection approach volume is indicated.

Table 1 shows a dramatic increase in volumes during the approximate 17 month period between the two field data collection efforts. Of the 17 intersections which may be compared during the AM peak period, only one of these noted a decrease in the peak direction approach volume and total intersection volume. On the average, these sixteen intersections incurred an approximate 16.9 percent increase in peak direction approach volume and a 17.8 percent increase in overall intersection volume throughout the two-hour period.

A comparison of all intersections during the PM peak period also indicates an increase in the volumes. As noted by Table 2, only two intersections did not have an increase in the peak direction approach volume and total intersection volume. Overall, an average 16.8 percent increase in the peak direction approach volume and an average 7.8 percent increase in total intersection volume was noted.

TRAVEL TIME COMPARISONS

Tables 3, 4, 5, and 6 present comparisons of travel speeds on each of the nine north-to-south oriented arterials within the North Freeway corridor. Presented on each table are the results of the travel time studies conducted in August of 1983 and January of 1985. The percent change comparing the "before" and "after" conditions was based on the travel time studies conducted in 1983. These tables indicate that a significant decrease in travel time on most of the nine arterials.

Similar comparisons are possible when considering the travel speeds on the two major east-west arterials which are studied. Tables 7 and 8 present comparisons of the data collected in August of 1983 and January of 1985. These tables indicate only minor changes in the travel time on these two arterials.

Table 1. AM Peak Volume Comparisons

6:15 AM - 8:15 AM

Location	August 1983 *Approach Volume (SB only)	August 1983 Total Intersection Volume	January 1985 *Approach Volume (SB only)	January 1985 Total Intersection Volume	Percent Change Approach Volume	Percent Change Total Volume
Airline @ Gulfbank	1445	2966	1642	3424	+13.6	+15.4
Airline @ Canino	1402	2526	1636	3076	+16.7	+22.3
Airline @ Little York	1316	2858	1734	3640	+31.8	+27.4
Airline @ Crosstimbers	743	3221	1008	4032	+35.7	+25.2
Fulton @ Crosstimbers	883	2859	1080	2981	+22.3	+ 4.3
Fulton @ Tidwell	969	4110	820	3766	-15.4	- 8.4
E. Hardy @ Aldine Bender	953	3094	1218	3681	+27.8	+19.0
E. Hardy @ Little York	1001	2627	1116	3196	+11.5	+21.7
W. Hardy @ Aldine Bender	1129	2453	1224	3358	+ 8.4	+36.9
W. Hardy @ Tidwell	816	2855	1055	3651	+29.3	+27.9
W. Hardy @ Crosstimbers	1619	3378	1747	3540	+ 5.9	+ 4.8
Irvington @ Tidwell	1085	3211	1284	4485	+18.3	+39.7
Irvington @ Berry	1319	2373	1455	2972	+10.3	+25.2
Northline @ Little York	779	2304	1030	2707	+32.2	+17.5
N. Shepherd @ Little York	2348	5888	2772	6443	+18.1	+ 9.4
N. Shepherd @ Crosstimbers	2872	4869	3329	5824	+18.0	+19.6

*Peak directing volumes

Table 2. PM Peak Volume Comparisons

4:00 PM - 6:00 PM

Location	August 1983 *Approach Volume (SB only)	August 1983 Total Intersection Volume	January 1985 *Approach Volume (SB only)	January 1985 Total Intersection Volume	Percent Change Approach Volume	Percent Change Total Volume
Airline @ Canino	1199	3494	1510	3700	+25.9	+ 5.9
Airline @ Little York	1168	3504	1854	4582	+58.7	+30.8
Airline @ Crosstimbers	2280	5754	2573	6284	+12,9	+ 9.2
Fulton @ Crosstimbers	1310	5255	1500	5426	+14.5	+ 3.3
Fulton @ Tidwell	1047	4059	1250	4545	+19.4	+12.0
E. Hardy @ Little York	937	3708	1126	3799	+20.2	+ 2.5
W. Hardy @ Tidwell	1044	3963	1066	3406	+ 2.1	-14.1
W. Hardy @ Crosstimbers	2325	4533	2402	4639	+ 3.3	+ 2.3
N. Shepherd @ Little York	3447	8025	3594	8026	+ 4.3	+ 0.0
N. Shepherd @ Crosstimbers	1906	5056	3247	7036	+70.4	+39.2
Yale @ Crosstimbers	2363	5536	2099	5586	-11.2	+ 0.9

*Peak directing volumes

Table 3. AM Peak Inbound Travel Speeds

Arterial	August 1983			January 1985			% Change (Travel Time)
	Sample	Average Travel Time (min:sec)	Average Speed (mph)	Sample	Average Travel Time (min:sec)	Average Speed (mph)	
North Shepherd	5	9:37	29.7	3	8:04	32.4	-16
Sweetwater	2	5:02	24.8	1	5:16	30.9	+ 5
Northline	1	2:35	25.6	1	2:10	30.2	-16
Yale	3	18:25	26.6	2	5:50	32.3	-24
Airline	3	7:39	25.6	1	13:16	34.3	-28
Fulton	2	6:48	30.2	2	5:58	34.9	-12
Irvington	2	5:14	32.0	2	5:34	30.6	+ 6
West Hardy	2	9:52	35.8	1	12:45	28.6	+29
East Hardy	2	11:52	36.2	2	11:29	38.4	- 3

Table 4. AM Peak Inbound Travel Speeds

Arterial	August 1983			January 1985			% Change (Travel Time)
	Sample	Average Travel Time (min:sec)	Average Speed (mph)	Sample	Average Travel Time (min:sec)	Average Speed (mph)	
North Shepherd	2	16:46	29.9	1	12:41	35.8	-24
Sweetwater	1	4:49	33.4	1	4:46	33.5	- 1
Northline	1	2:06	32.0	1	2:12	30.1	+ 5
Yale	2	5:52	31.2	1	6:27	28.7	+10
Airline	2	16:46	29.9	1	12:41	35.8	-24
Fulton	2	6:46	29.1	2	5:59	33.3	-12
Irvington	2	5:27	30.3	2	5:14	33.0	- 4
West Hardy	1	9:31	32.4	1	9:17	34.0	- 2
East Hardy	1	12:24	35.1	1	10:56	39.0	-12

Table 5. PM Peak Outbound Travel Speeds

Arterial	August 1983			January 1985			
	Sample	Average Travel Time (min:sec)	Average Speed (mph)	Sample	Average Travel Time (min:sec)	Average Speed (mph)	% Change (Travel Time)
North Shepherd	3	11:35	28.0	3	9:29	28.1	-18
Sweetwater	2	5:08	32.0	1	4:45	33.9	- 7
Northline	2	2:24	28.0	1	1:54	34.6	-21
Yale	2	7:59	26.1	1	7:03	28.0	-12
Airline	3	17:43	28.0	1	14:52	31.7	-16
Fulton	2	8:52	26.1	1	6:48	33.0	-23
Irvington	2	8:05	25.6	2	5:46	29.8	-29
West Hardy	1	9:24	34.6	1	10:15	31.0	+ 9
East Hardy	2	12:22	34.6	2	12:57	33.8	+ 5

Table 6. PM Peak Inbound Travel Speeds

Arterial	August 1983			January 1985			% Change (Travel Time)
	Sample	Average Travel Time (min:sec)	Average Speed (mph)	Sample	Average Travel Time (min:sec)	Average Speed (mph)	
North Shepherd	2	7:42	34.0	3	7:35	34.6	- 2
Sweetwater	1	5:24	29.7	1	4:44	34.0	-12
Northline	1	2:11	30.3	1	2:31	29.4	+15
Yale	1	6:28	28.8	1	5:50	32.1	-10
Airline	2	16:25	27.2	1	13:12	34.0	-20
Fulton	2	6:28	31.3	1	5:54	33.7	- 9
Irvington	2	5:20	31.4	2	5:28	31.1	+ 2
West Hardy	2	10:18	32.1	1	8:35	37.0	-17
East Hardy	2	11:46	34.2	2	11:59	36.3	+ 2

Table 7. AM Peak Cross-Street Travel Speeds

		August 1983			January 1985			
	Arterial Direction	Sample	Average Travel Time (min:sec)	Average Speed (mph)	Sample	Average Travel Time (min:sec)	Average Speed (mph)	% Change (Travel Time)
W. Little York	Eastbound	2	10:45	21.5	2	10:30	22.0	-2
W. Little York	Westbound	2	9:45	23.7	2	9:59	23.1	+3
Crosstimber	Eastbound	2	7:30	26.8	3	7:44	26.0	+3
Crosstimber	Westbound	2	8:45	23.0	3	8:35	23.4	-2

Table 8. PM Peak Cross-Street Travel Speeds

		August 1983			January 1985			
	Arterial Direction	Sample	Average Travel Time (min:sec)	Average Speed (mph)	Sample	Average Travel Time (min:sec)	Average Speed (mph)	% Change (Travel Time)
W. Little York	Eastbound	2	11:10	20.7	3	11:14	20.5	+1
W. Little York	Westbound	2	9:15	25.0	1	9:35	24.1	+4
Crosstimbers	Eastbound	2	8:30	23.6	2	8:41	23.1	+2
Crosstimbers	Westbound	2	8:45	26.4	2	8:26	23.8	-4

CONCLUSION

This report has described the research methodology and products of a study conducted to develop useful tools for practitioners involved in the management of urban freeway corridors. This work was sponsored by the Texas State Department of Highways and Public Transportation in cooperation with the Federal Highway Administration of the U.S. Department of Transportation. Through close contact with transportation professionals during all stages of the research, the work was directed at providing practical solutions to actual problems. The most significant products of the research were a quick response procedure to evaluate alternative corridor improvement strategies and a simple, easy-to-use, progression-based corridor network signal timing program. This signal timing program was tested on an actual freeway corridor network in Houston, Texas. The results were very encouraging: system travel time decreased for nearly all routes in the corridor despite a 17% increase in traffic using the corridor.

APPENDIX A

QUESTIONNAIRE

LIST OF TOPICS

The following is a list of topics which may apply to your urban area. In order to help us focus the efforts of the PASSER IV project on the urban transportation options of greatest interest, we request that you indicate your potential need for analytical methods for studying these options.

The scale is:

1. Very Important
2. Important
3. Marginally Important
4. Does Not Apply

A. FREEWAY TRAFFIC MANAGEMENT

_________ 1. Signalization

_________ 2. Ramp closures

_________ 3. Ramp additions

_________ 4. Freeway information sytems

_________ 5. Incident detection and management

_________ 6. Frontage road additions

_________ 7. Improvement of frontage road continuity

B. TRAFFIC FLOW OPTIMIZATION AND OPERATIONAL CONCERNS

_________ 1. Signalization

_________ 2. Intersection treatments

_________ 3. Parking restrictions

_________ 4. Median and marginal access controls

_________ 5. Conversion from two-way to one-way street operations

_________ 6. Reversible flow lanes on arterial streets

_________ 7. Assess the potential operational impacts of a proposed new major traffic generator (e.g., a new shopping center)

C. PREFERENTIAL TREATMENT FOR HIGH OCCUPANCY VEHICLES

_________ 1. Special ramps for buses

_________ 2. Special ramps for buses and carpools

_________ 3. Conversion of an existing freeway lane for exclusive use of high occupancy vehicles

_________ 4. Conversion of an existing arterial lane for exclusive use of high occupancy vehicles

_________ 5. Construction of a new freeway lane for exclusive use of high occupancy vehicles

_________ 6. Construction of a new arterial lane for exclusive use of high occupancy vehicles

_________ 7. Internal transit circulation system

E. TRANSIT IMPROVEMENTS AND RIDE SHARING PROGRAMS

_________ 1. Potential operational impacts of express bus and park and ride service

_________ 2. Potential operational impacts of ride sharing programs and para-transit service

_________ 3. Potential operational impacts of various transit service improvements

F. Other options, not covered in the above, for which analytical methods or techniques are felt to be needed.

____

____

____

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____

____

____

APPENDIX B

SURVEY RESULTS

SURVEY RESULTS

	Rating Frequency 1	2	3	4	Total Points	Rank
A. FREEWAY TRAFFIC MANAGEMENT						
1. Ramp metering	7	15	3	0	46	8
2. Ramp closures	11	9	5	0	44	6
Ramp additions	14	4	7	0	43	5
3. Freeway information systems	3	9	12	1	61	28
4. Incident detection and management	7	8	10	0	53	14
5. Frontage road additions	7	10	7	1	52	13
6. Improvement of frontage road continuity	14	7	3	1	41	3
B. TRAFFIC FLOW OPTIMIZATION AND OPERATIONAL CONCERNS						
1. Signalization	13	10	2	0	39	2
2. Intersection treatments	12	10	3	0	41	3
Parking restrictions	3	10	11	1	60	26
3. Median and marginal access controls	5	8	11	1	55	18
4. Conversion from two-way to one-way street opertions	10	10	4	1	46	8
5. Reversible flow lanes on arterial streets	5	12	7	1	51	11
6. Assess the potential operational impacts of a proposed new major traffic generator (e.g., a new shopping center)	15	7	3	0	38	1
C. PREFERENTIAL TREATMENT FOR HIGH OCCUPANCY VEHICLES						
1. Special ramps for use	6	8	10	1	56	20
2. Special ramps for buses and carpools	6	10	9	0	53	14
3. Conversion of an existing freeway lane for exclusive use of high occupancy vehicles	6	9	6	4	58	23

		Rating Frequency 1	2	3	4	Total Points	Rank
4.	Construction of an existing arterial lane for exclusive use of high occupancy vehicles	5	10	7	3	58	23
5.	Construction of a new freeway lane for exclusive use of high occupancy vehicles	6	11	5	3	55	18
	Construction of a new arterial lane for exclusive use of high occupancy vehicles	6	7	9	3	59	25
	Signal preemption for buses on arterial streets	3	11	8	3	61	28
D.	CENTRAL BUSINESS DISTRICT AND OTHER MAJOR ACTIVITY CENTERS						
	Enhancement of pedestrian movement	2	10	12	1	62	30
	Auto restricted zones	4	7	11	3	63	31
1.	On-street parking	6	10	9	0	53	14
2.	Parking lot locations	8	9	7	1	51	11
3.	Truck movement and loading-restrictions	4	12	8	1	56	20
4.	Work rescheduling	8	9	8	0	50	10
5.	Internal transit circulation system	2	15	8	0	56	20
E.	TRANSIT IMPROVEMNTS AND RIDE SHARING PROGRAMS						
1.	Potential operational impacts of express bus and park and ride service	12	8	4	1	44	6
	Potential operational impacts of ride sharing programs and paratransit service	4	8	12	1	60	26
2.	Potential operational impacts of various transit service improvements	4	14	6	1	54	17

APPENDIX C

INPUT DATA CODING

PASSER IV INPUT DATA CODING INSTRUCTIONS

PASSER IV is executed as a three step procedure as shown in Figure C1. Once the original data are set up to analyze a network of roadways, the PASSER IV program is executed a first time to determine the optimal cycle length for the entire network. This optimal cycle length is then used to update the original data set where both the lower and upper cycle lengths are set to this optimal cycle length. The updated data set is kept as a temporary data set which is used by the second execution of the PASSER IV program. At the end of this second execution, PASSER IV will generate the best solution output for each intersection and the time-space diagram for each arterial. The input data stream used to execute this three step procedure is shown in Figure C2.

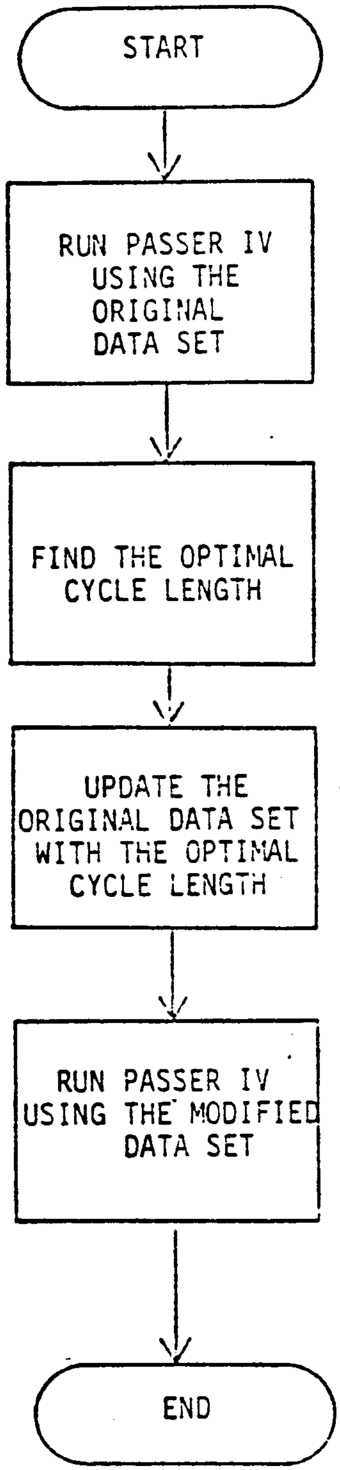

Figure C1. PASSER IV Procedure.

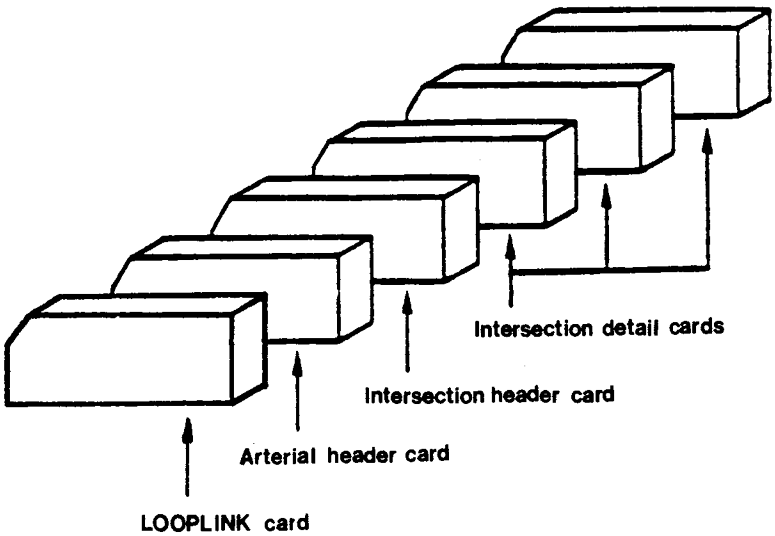

Figure C2. PASSER IV Input Data Deck.

The PASSER II-80 coding form (Form 1444-1) has been modified to be used as a PASSER IV coding form as shown in Figure C3. The modifications include a NETWORK HEADER CARD for each network of roadways and one arterial column, column 73 of the ARTERIAL HEADER CARD, used to distinguish the ARTERIAL HEADER CARD from other INTERSECTION CARDS among the data file.

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

Each set of data for a network must begin with a NETWORK HEADER CARD followed by an ARTERIAL HEADER CARD followed by an INTERSECTION HEADER CARD for each intersection and a set of three INTERSECTION DETAIL CARDS for each intersection on the arterial. Successive arterials does not require a NETWORK HEADER CARD. Note that a "card" is equivalent to a record or a line of data input coding 80 field characters long.

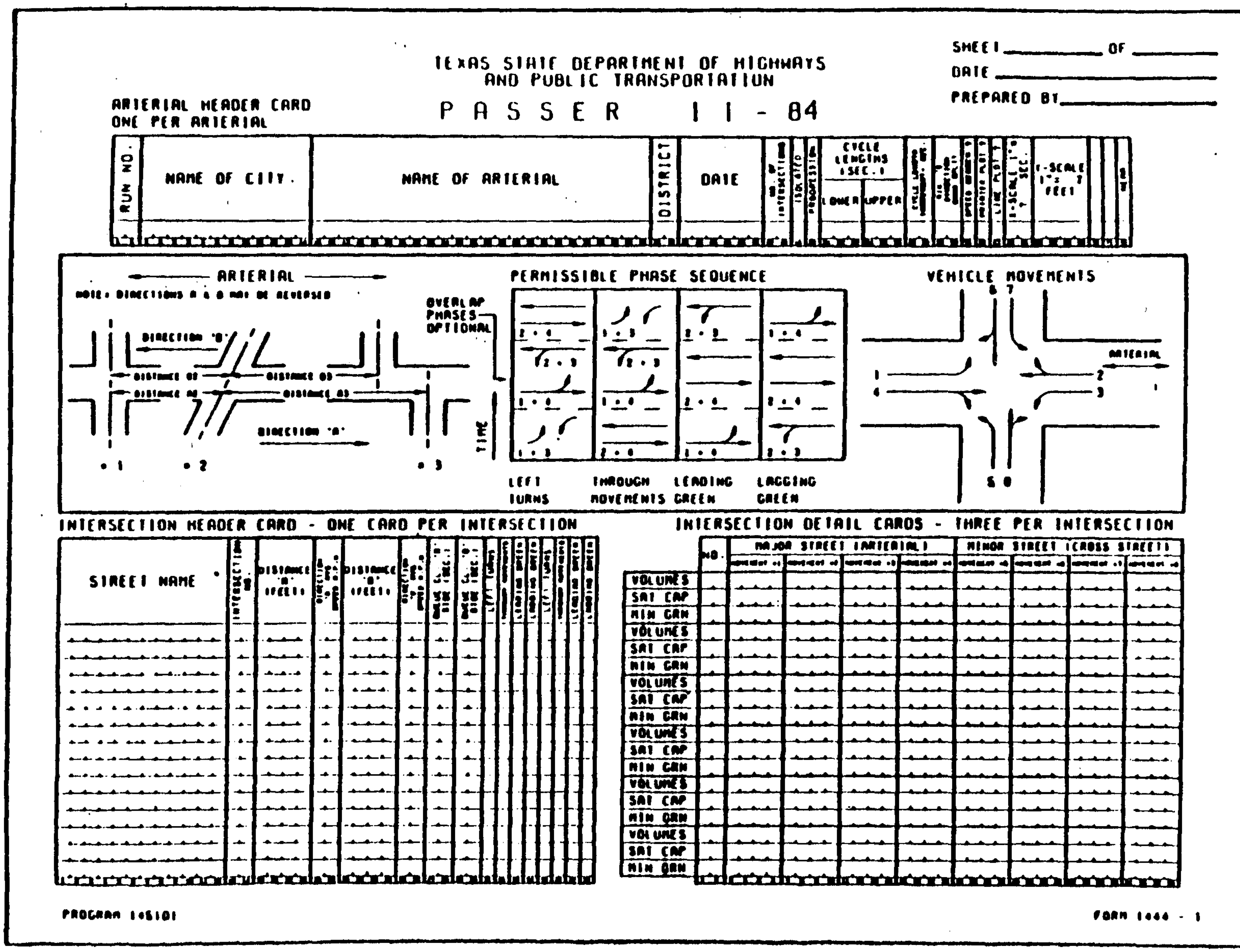

Figure C3. Example of Input Form 1444-1.

NETWORK HEADER CARD

The NETWORK HEADER CARD informs the program that a network of arterials is to be analyzed.

NETWORK (column 1). Code a '1' on this column to analyze a network of roadways. Each set of data for a network must begin with '1' on this column.

COMMENTS (Columns 2-72). Any comments to describe the data set may be entered in these columns for user verification of the data set. This information is not used by the program.

ARTERIAL HEADER CARD

The ARTERIAL HEADER CARD (Figures C4 and C5) supplies information to the program which is common to the arterial and also contains information concerning the identification and geometrics of the arterial street. There must be one and only one ARTERIAL HEADER CARD for each arterial. Multiple arterials may be analyzed in one run of the program where each arterial must begin with an ARTERIAL HEADER CARD followed by the INTERSECTION HEADER and DETAIL cards.

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

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

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

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

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ARTERIAL HEADER CARD

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

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

INTERSECTION HEADER CARDS

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

PERMISSIBLE PHASE SEQUENCE (COLS. 31-38)
REFERENCE PERMISSIBLE PHASE SEQUENCE CHART ON FRONT OF THE CODING FORM. IF THE PHASE SEQUENCE IS NOT PERMITTED. CODE A ZERO OR LEAVE BLANK. IF THE PHASE IS PERMITTED WITH NO OVERLAP. CODE A ONE (1). IF THE PHASE IS PERMITTED WITH OVERLAP. CODE A TWO (2)
NOTE:
FOR COLS. 31-34 ANY COMBINATION OF ZEROS. ONES AND TWOS MAY BE CODED IN ALL FOUR COLUMNS. FOR COLUMNS 35-38 THREE OF THE COLUMNS MUST BE CODED WITH A ZERO OR LEFT BLANK.

INTERSECTION DETAIL CARDS

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

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

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

PROGRAM 145101

FORM 1444 - 2

Figure C4. Example of Input Form 1444-2.

ARTERIAL HEADER CARD
ONE PER ARTERIAL

RUN NO.	NAME OF CITY	NAME OF ARTERIAL

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

Figure C5. Example of Input Form 1444-2
(Arterial Hearder Card, One per Arterial).

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

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

ISOLATED (Column 49). The number one (1) is entered if the signalized intersections are not coordinated but are isolated. If the isolated mode

is used, both the LOWER and UPPER CYCLE LENGTHS (Columns 51-56) must be set to the same value. In the isolated mode, only one arterial phase sequence may be evaluated per intersection. Time-space diagrams are not printed when using the isolated mode.

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

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

LOWER (Columns 51-53). The smallest cycle length (in seconds) the program may consider for a solution is entered here. It should be at least four seconds greater than the sum of the minimum conflicting greens or equal to this sum if an evaluation of existing timings is being attempted. An example of determining the sum of the minimum greens is shown in Figure C6.

The smallest permissible cycle should be determined beforehand by using Webster's method, the Poisson method, or some other suitable method at the critical intersection.

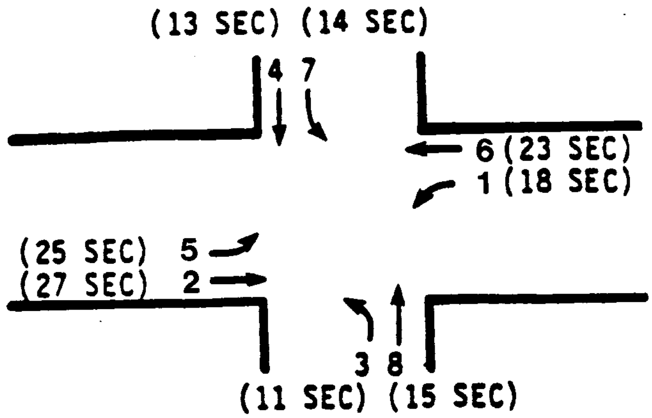
Each intersection in an arterial system will generally have a different minimum delay cycle length from the other intersections. The smallest permissible cycle length for the arterial should not be less than 0.85 times the largest individual cycle length, nor greater than 1.25 times the smallest cycle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

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

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

CYCLE LENGTH INCREMENT (SEC.) (Columns 57-48). The number of seconds the program will increase as a step between the lower and upper cycle length limits is coded. A 5-second increment is recommended for pretimed signal systems, but a different increment could be used for digital or analog traffic responsive systems.

MIN. "B" DIRECTION BAND SPLIT (Columns 59-50). The user may specify the percent of the total progression bandwidth to be provided in the "B"



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

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

Figure C6. Example of determining the sum of the minimum greens for "over-lapped" multiphase signalization.

direction. If no percentage is entered, "A" and "B" direction bands will be split in proportion to the traffic volume distributed in "A" and "B" directions. If one direction is favored over the other, irrespective of volumes, the favored direction must be coded as it impacts the "B" direction.

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

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

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

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

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

NEMA (Column 72). A one (1) is entered if it is desired to utilize NEMA (National Electrical Manufacturers' Association) phase movement designations. If this option is used, the vehicle movements as shown on the coding form should be disregarded. Otherwise, the program will assume the default PASSER IV phase definition--option zero (0). It is also possible now in PASSER IV to make a translation between the PASSER IV phase definition and the NEMA phase definition. If the user prefers to use the NEMA phase as input but desires the output in PASSER's phase definition, a three (3) should be coded. NEMA and PASSER vehicle movement numbering are shown in Figure C7. The designation of major street movements on the INTERSECTION DETAIL CARDS is no longer valid when the NEMA option is used. Enter data according to the movement numbers in the diagram.

INTERSECTION HEADER CARD

The INTERSECTION HEADER CARD (Figure C8) provides signal phasing information for each intersection. One card (one line of information) is required for each intersection. Descriptive information about the downstream link is also provided. A maximum of 20 INTERSECTION HEADER CARDS can be input for one PASSER IV problem.

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

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

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

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

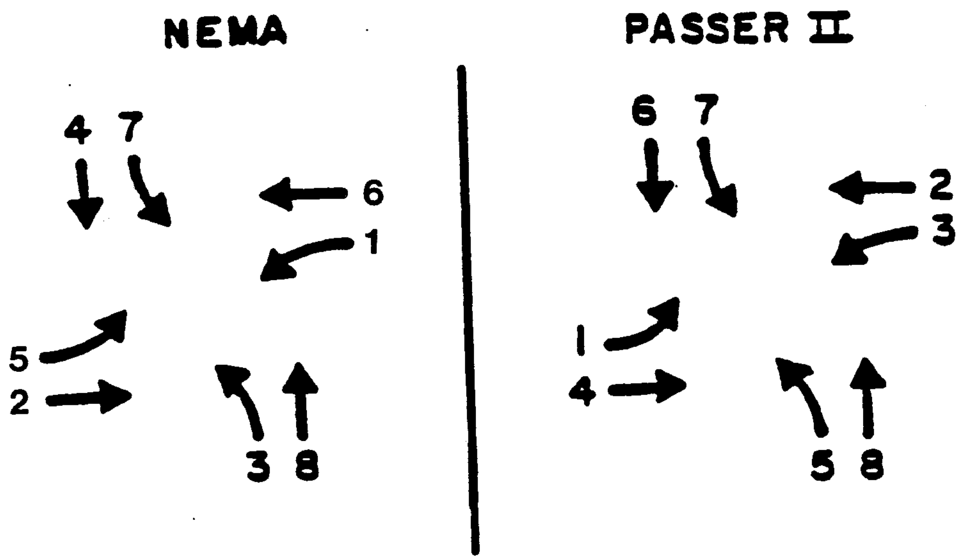


Figure C7 . NEMA & PASSER II's Phase Movement Definitions.

INTERSECTION HEADER CARD - ONE CARD PER INTERSECTION

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

Figure C8. Intersection Header Card - One Card Per Intersection.

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

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

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

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

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

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

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

An intersection having a simple two-phase operation would have only one major street phase and one minor street phase. The appropriate phase sequence to select would be the THROUGH MOVEMENTS FIRST sequence is deleted in the program by not coding left turn movement volumes or minimum green times.

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

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

INTERSECTION DETAIL CARDS

Three INTERSECTION DETAIL CARDS (Figure C9) are required for each intersection on the major street. A maximum of 60 INTERSECTION DETAIL CARDS can be input for each arterial. All elements related to the VEHICLE MOVEMENTS should be numbered according to the diagram in the center of the coding form. All entries must be right justified.

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

SAT CAP (Saturation Flow Rate or "Capacities"). Reasonably accurate values should be established since the movement green time is calculated based

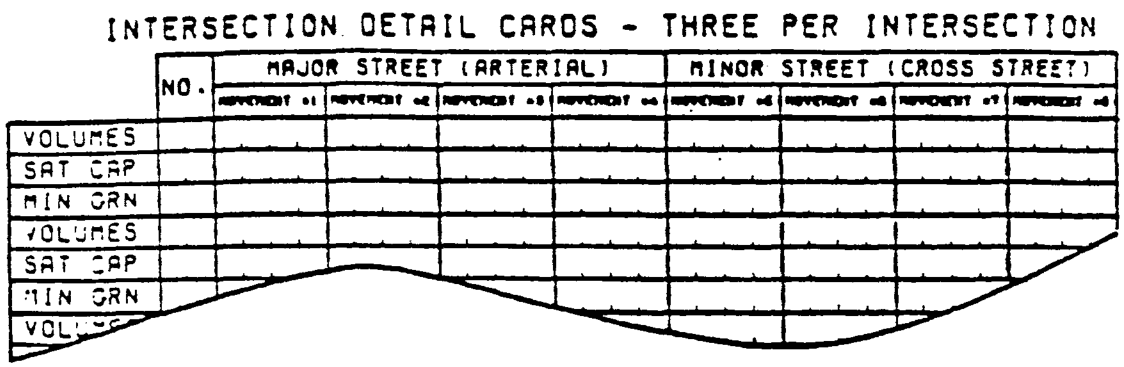


Figure C9. Intersection Detail Cards - Three Per Intersection.

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

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

Table C1. Saturation Flow Rates.

SATURATION FLOW RATES

(Vehicles Per Hour of Green Per Lane)

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

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

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

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

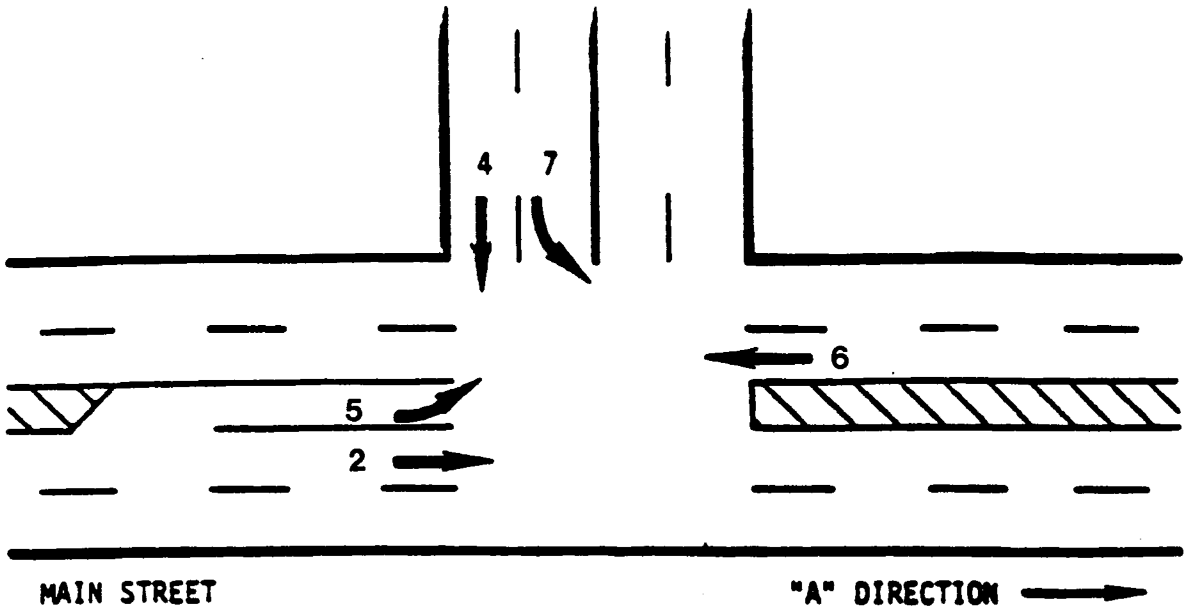
T INTERSECTION

A T intersection requires special coding. An example, as shown on Figure C10 on the next page, demonstrates the intersection and phase sequence. In this example, a protected left turn is desired for the left turning traffic from Main Street to Stem Street, which is movement 1 in the NEMA phase movement designations. Possible signal phasing for Main Street is either a leading left turn (phase codes 1 and 6) or through movements first (phase codes 2 and 6). "Leading left turn" refers to the left turn movements in the "A" direction along Main Street.

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

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

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



PHASE SEQUENCE (NEMA)

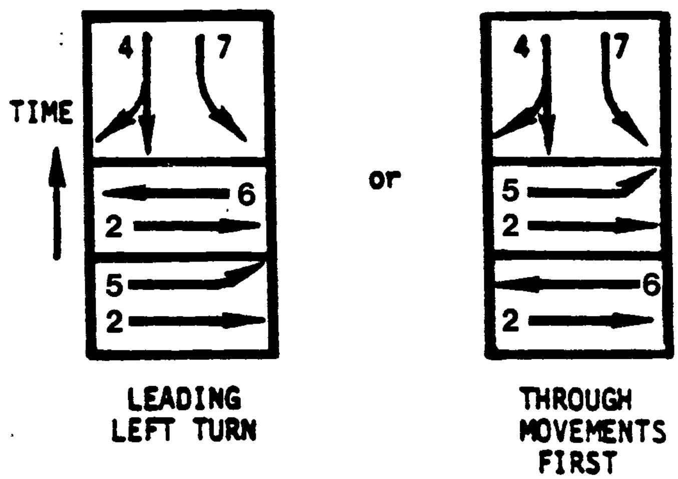


Figure C10. Example of "T" - Intersection At Stem Street.

SPLITTING THE CROSS STREET GREEN - CROSS STREET PHASING WITH NO OVERLAP

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

An overlap phase is created when one of two paired movements requires more time than the other, and another compatible movement is also available. The following figures illustrate the case of "splitting the cross street green". The movement minimum green times are as follows:

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

Overlap phasing would result in the following:

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

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

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

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

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

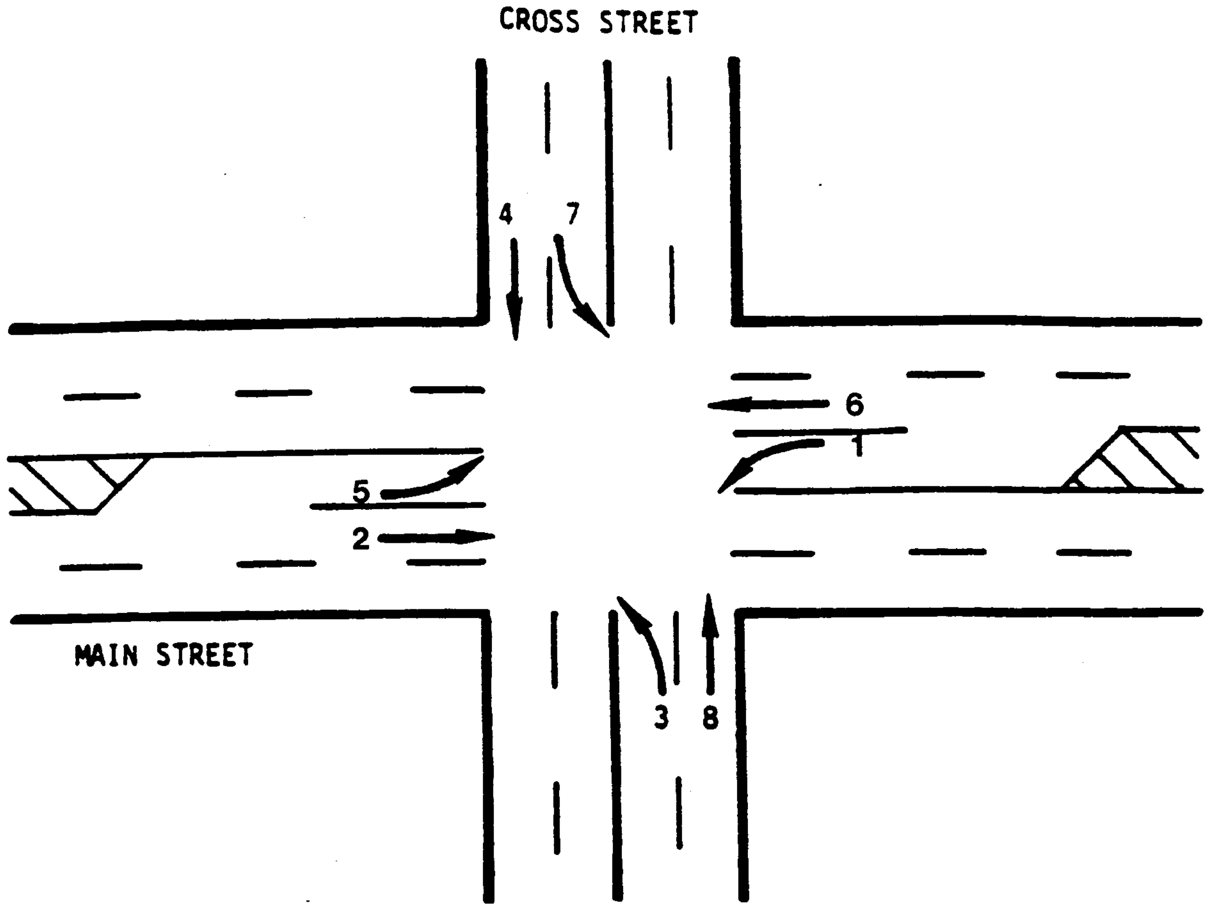
Because the program will seek to maximize utilization of green time, good progression will be more difficult to obtain with a no overlap solution. The user must code identical minimum green times for the paired movements in a split phase and consider all the possible slack time at that intersection. This special case is illustrated in Figure C11.

ONE WAY PROGRESSION

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

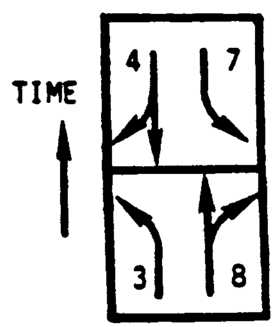
ONE-WAY STREETS

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



PHASE SEQUENCE (NEMA)
FOR MAIN STREET

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

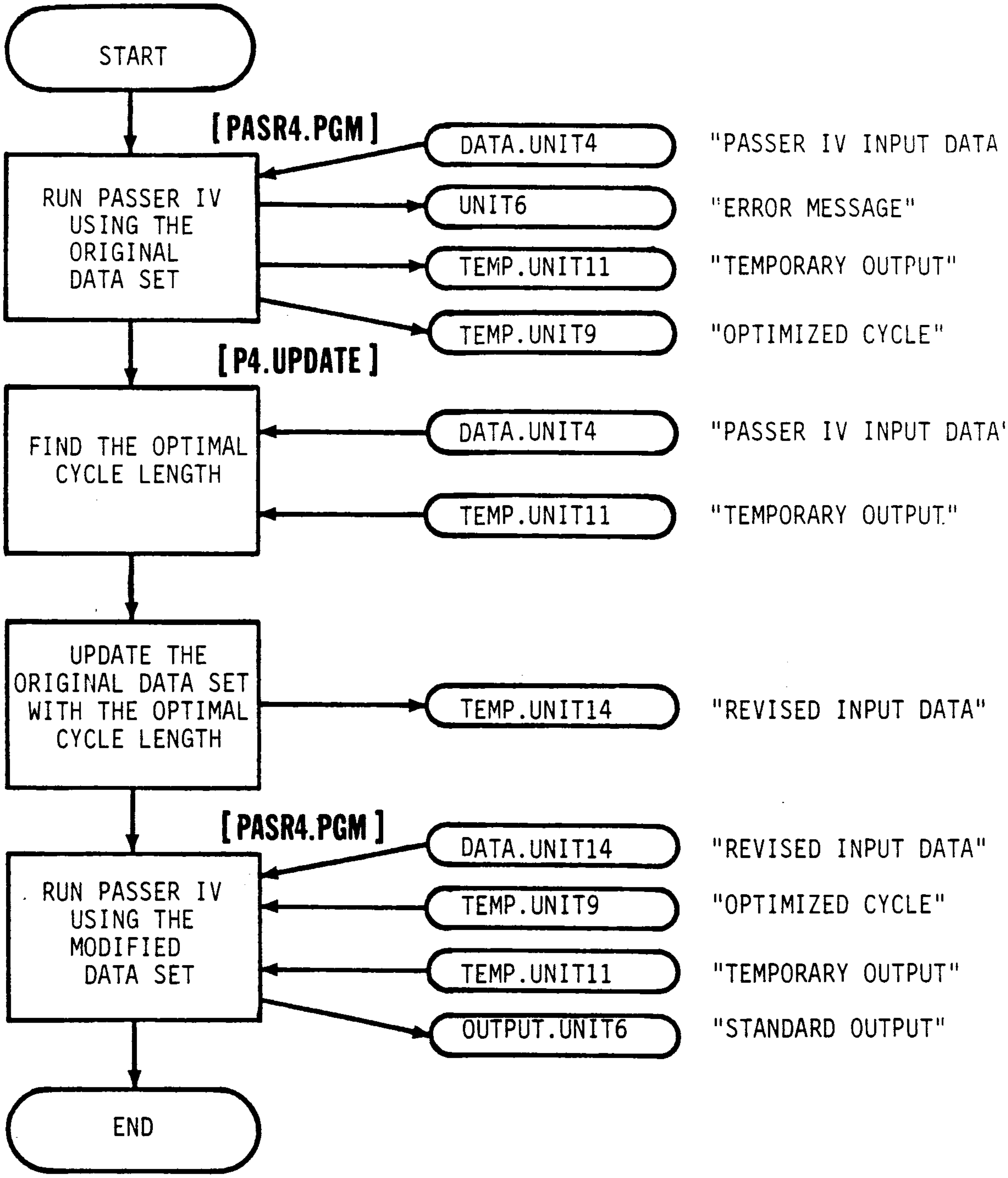


Split phase
with no overlap

Figure C11. Example of Cross Street Phasing "With No Overlap".

APPENDIX D

FLOW CHART



LEGEND:
[ ] - indicates the program used in execution
( ) - indicates the system utilities used
← - indicates input files to the PASSER IV program
→ - indicates output files to the PASSER IV program

APPENDIX E

CORRIDOR ROUTE DESCRIPTION

ROUTE DESCRIPTIONS

Route	Limits	Description	Distance (Miles)
Airline	FM 525 to Little York	2-lane undivided	4.65
Fulton	Little York to I-610	4-lane divided	2.95
East Hardy	FM 525 to Crosstimbers	2-lane undivided	3.25
West Hardy	Gulf Bank to Crosstimbers	2-lane undivided	7.34
	Crosstimbers to I-610	4-lane divided	1.00
Irvington	West Hardy to Crosstimbers	2-lane undivided	2.85
Sweetwater	West Rd. to Canino	2-lane undivided	2.77
Northline	Canino to Parker	2-lane undivided	1.10
Yale	Parker to Crosstimbers	2-lane divided	2.13
	Crosstimbers to I-610	4-lane divided	1.00
N. Shepherd	Steubner Airline to I-610	4-lane divided	4.44
W. Little York	East Hardy to W. Montgomery	2-lane individual	3.85
Crosstimbers	East Hardy to N. Shepherd	4-lane divided	3.35

APPENDIX F

INTERSECTION LOCATIONS

TURNING MOVEMENT VOLUME COUNT LOCATIONS

Intersection	1983 AM	1983 PM	1985 AM	1985 PM
Airline @ FM 525	X			
Airline @ Aldine Bender	X	X	X	
Airline @ Oshmans	X			
Airline @ Buckboard	X	X		
Airline @ Goodson	X	X		
Airline @ Dyna	X	X		
Airline @ Hardwicke	X	X		
Airline @ West Road	X	X		
Airline @ Aldine Mail	X	X		
Airline @ W. Mt. Houston	X	X		
Airline @ Gulfbank	X	X	X	
Airline @ Mitchell	X	X		
Airline @ Canino	X	X	X	X
Airline @ Little York	X	X	X	X
Airline @ Rittenhouse	X	X		
Airline @ Parker	X	X		
Airline @ Tidwell	X	X		
Airline @ Berry	X	X		
Airline @ I-45	X	X		
Airline @ Crosstimbers	X	X	X	X
Bauman @ Parker	X	X		
Bauman @ Crosstimbers	X	X		
Fulton @ Parker	X	X		
Fulton @ Tidwell	X	X	X	X
Fulton @ Berry	X	X		
Fulton @ Crosstimbers	X	X	X	X
E. Hardy @ Hill	X	X		

E. Hardy @ Canino	X	X		
E. Hardy @ Little York	X	X	X	X
E. Hardy @ Parker	X	X		
E. Hardy @ Turner	X	X		
E. Hardy @ Tidwell	X	X		
E. Hardy @ Berry	X	X		
E. Hardy @ Crosstimbers	X	X		
W. Hardy @ Gulfbank	X	X		
W. Hardy @ Mitchell	X	X		
W. Hardy @ Canino	X	X		
W. Hardy @ Little York	X	X	X	X
W. Hardy @ Parker	X	X		
W. Hardy @ Irvington	X	X		
W. Hardy @ Turner	X	X		
W. Hardy @ Tidwell	X	X	X	X
W. Hardy @ Berry	X	X		
W. Hardy @ Crosstimbers	X	X	X	X
W. Hardy @ Kelly	X	X		

TURNING MOVEMENT COUNT LOCATIONS, CONTINUED

	1983		1985	
Intersection	AM	PM	AM	PM
Irvington @ Turner	X	X		
Irvington @ Tidwell	X	X		
Irvington @ Berry	X		X	X
Irvington @ Crosstimbers	X			
Kelly @ 610		X		
Northline @ Canino	X	X		
Northline @ Little York	X	X	X	X
Northline @ Parker	X			
N. Shepherd @ Crosstimbers	X	X	X	X
N. Shepherd @ Little York	X	X	X	X
N. Shepherd @ W. Gulf Bank	X			
N. Shepherd @ W. Parker	X			
N. Shepherd @ Tidwell	X			
N. Shepherd @ W. Montgomery	X			
N. Shepherd @ Donovan	X			
N. Shepherd @ Pinemont	X			
N. Shepherd @ 43rd	X			
N. Shepherd @ Grad Oaks	X			
Sweetwater @ West Rd	X	X		
Sweetwater @ Helms	X	X		
Sweetwater @ W. Mt. Houston	X	X		
Sweetwater @ Gulfbank	X	X		
Sweetwater @ Canino				
Yale @ Parker	X	X		
Yale @ Donovan	X	X		
Yale @ Tidwell	X	X		

Yale @ Crosstimbers	X	X		X	X
Yale @ Victoria	X	X			