REAL-TIME APPLICATION OF PASSER IV: PROJECT SUMMARY AND GUIDELINES

by

Nadeem A. Chaudhary, Ph.D., P.E.
Associate Research Engineer
Texas Transportation Institute

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16. Abstract

PASSER IV is a program for timing traffic signals in networks based on progression bandwidth optimization. It is capable of optimizing signal timings for arterials as well as multi-arterial closed-loop networks. This report presents a summary of work conducted under a three-year research project funded by TxDOT. It provides guidelines for using PASSER IV as a 1.5 generation real-time traffic control system using a test-bed from the city of Richardson, Texas. In addition, the report addresses the issue of signal timing transition and provides the description of a preliminary algorithm for finding the cost of transition. Finally, the report provides new PASSER IV developments and describes new features.

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IMPLEMENTATION STATEMENT

This project enhanced PASSER IV, a program for optimizing bandwidth-based signal timings in signalized arterial networks. TTI released PASSER IV, Version 2.1, and the accompanied user manual, in early 1997. Several TxDOT districts are currently using the program to time traffic signals in their respective jurisdictions. In addition, TTI researchers taught a PASSER IV pilot training course in July 1997 at TxDOT facilities in Austin, Texas. A selected group of TxDOT employees attended this two-day course on how to effectively use PASSER IV. TTI published a report (Report 1477-2) based on the course material and course participant comments. This manual is prepared for use in teaching future training courses. As part of the training course preparation, the research team also optimized signal timings for the city of Nacogdoches, Texas.

Further, the researchers worked in a cooperative effort to develop guidelines and design for the real-time use of PASSER IV in a 1.5 generation traffic control system. Partners in this effort included: TxDOT, the city of Richardson, Texas, Naztec, Inc., and TTI. This partnership provided insight into real-time traffic control issues from three different angles: the researchers/developers, hardware manufacturers, and end users. These partners resolved a number of issues related to the implementation of real-time control. Each partner included these solutions in designing and developing various components needed for a real-time control system. The hardware/software upgrade in the city of Richardson is scheduled for completion in early 1998. A real-time implementation of PASSER IV will be fully tested at that time.

DISCLAIMER

The contents of this report reflect the views of the author who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Texas Department of Transportation (TxDOT), or the Federal Highway Administration (FHWA). This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. The Engineer in charge of the project was Nadeem A. Chaudhary, P.E. # 66470.

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PASSER IV software and any related documentation are copyrighted. The users are advised to use the program and related documentation at their own risk. TTI, TxDOT, and FHWA are not liable for any damages (direct or indirect) resulting from the use of PASSER IV or related documentation.

ACKNOWLEDGMENT

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We would also like to thank the Project Director, Mr. Nader Ayoub, of the Texas Department of Transportation, for his support and encouragement throughout this project. He was always ready and willing to provide any needed assistance. Mr. Ayoub actively participated in all partners' meeting to discuss real-time data and interface needs for the real-time application of PASSER IV.

Special thanks go to Mr. John Black, city of Richardson, Texas, for his support throughout this project. Mr. Black provided historic data for use in the project and made necessary modifications to Richardson's software to provide real-time data over the Internet.

A number of other individuals provided key contributions to the project. These individuals include: Ms. Shweta Jain, Mr. Vajay Kovvali, Mr. K. S. Rao, Mr. David Berry, and Mr. Sonchoel Baeg. These individuals worked for the Texas Transportation Institute. We thank all these individuals for their contributions.

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SUMMARY

This is the project summary of a three-year TxDOT project. The objectives of the project were to enhance PASSER IV and to design an architecture for the real-time application of PASSER IV. This report is accompanied by three research reports and presents a summary of research results. In addition, it presents material not included in the other three project reports. Specifically, the report contains the following material:

- Chapter I provides background and a summary of research results.
- Chapter II addresses several issues related to the real-time application of PASSER IV. These include: system architecture and its components, system stability, and the test-bed used in the project.
- Chapter III addresses the issue of signal timing transition and describes an algorithm to calculate the cost of transition.
- Chapter IV provides information on additional PASSER IV enhancements and developments.
- Appendix A provides the formats of records in a PASSER IV input data file. This information is needed to create data files for the real-time application of PASSER IV.
- Appendix B provides a sample file to illustrate a new feature of PASSER IV that allows saving of information from the optimization algorithm. This information can also be used to find quick solutions to a problem.

CHAPTER I
INTRODUCTION

BACKGROUND

In recent years, urban traffic demand in the U.S. has grown at an alarming rate. A majority of Texas cities currently face daily traffic congestion within their signalized arterial networks. In some cases, peak hour congestion lasts for hours. This trend is expected to continue through the turn of the century. Furthermore, due to financial, right-of-way, and environmental constraints, it is becoming increasingly difficult for the cities and the state to build out of this situation. One solution, and in many cases, the only solution, is to implement strategies that make full use of the available capacity of the existing urban arterials and signalized networks.

Capacity of signalized roadways is a fixed commodity that must be fully utilized during the peak demand periods. If not utilized when needed, capacity is lost like perishable goods. Traffic demand, on the other hand, is dynamic in nature in that it varies by time-of-day and by the day-of-week. In addition, there may be seasonal and long-term growth trends. Thus, optimum utilization of capacity requires that traffic control be responsive and adaptive to the changing traffic demand patterns. Existing technology and state of practice, however, are not flexible enough to cope adequately with the changing traffic demand. To this end, statewide traffic control system development is rapidly moving toward real-time traffic adaptive control systems.

Current State-of-Practice

In most Texas cities with populations of 50,000 or less, traffic signals on state highways are maintained and operated by the Texas Department of Transportation (TxDOT). In addition, TxDOT operates and maintains all signalized interchanges, except those for which cities are contracted to provide maintenance of signal timings. For maintaining TxDOT roadways, the entire state is divided into several, rather large, districts. Each TxDOT district office employs a limited number of professionals who are responsible for maintaining the signals in their respective jurisdictions. Given the small number of professionals, and the large size of their respective jurisdictions, it is not possible for them to keep the signal control up-to-date with the changes in traffic patterns. In most cases, signals are timed only at the time of their installation.

Most cities with populations of 50,000 or more, have their own traffic engineering departments. Although these cities are better staffed when compared to TxDOT, they only have a fraction of the staff needed to regularly maintain optimal signal timings. Usually, most cities retime their signals no less than five years after the previous retiming effort. During this long time there could be large changes in traffic patterns.

Often, these agencies hire consultants to upgrade their signal systems. These consultants perform the following tasks in order to time or retime the traffic signals:

- Select some representative days of the week and manually collect traffic counts for a.m.-peak, noon-peak, p.m.-Peak, and off-peak periods,
- Optimize signal timings using one or more signal timing optimization packages available to them,
- Work with the sponsoring agency to program the proposed signal timings for time-of-day implementation, and
- Suggest adjustments based on observations.

At the current rates, it costs the sponsor about $2000 per intersection for a one-time data collection effort. The total cost of timing traffic signals is generally higher, depending on the additional cost for the remaining tasks. For instance, a small city with thirty signals may have to spend $80,000 for retiming its system of signals. Thus, it is economically infeasible for TxDOT and the cities to retime their signal systems on a regular basis. There is a need to develop effective real-time traffic control systems that automate the routine tasks of data collection by making use of an extensive network of existing loop detectors. The first step towards real-time control with automated data collection capabilities is the traffic responsive control.

Traffic Responsive Control

A traffic responsive, or first generation control (1GC), system uses system detectors to assess traffic demand for a given time period. Then, it goes through a table lookup procedure to select values of signal timing parameters (cycle length, splits, phasing sequence, and offsets) that best match the detected traffic conditions. Finally, it updates the signal timings. This process is repeated at specified time intervals. In this process, the signal timing parameters are initially determined using manual data collection and off-line analysis tools as in the case of pretimed signals. An example of such a system is the FACTS (Flexible Advanced Computer Traffic Signal System) system developed by TxDOT in the eighties [1]. Traffic responsive systems have the following potential benefits:

- Reduced operational costs and
- Improved systems performance.

Although most existing controllers are capable of operating signals in traffic responsive mode, signal systems in Texas are more commonly operated in a time-of-day mode. This is due to the lack of guidelines for using these features. In addition, traffic responsive control systems have the following weaknesses:

1. Engineers must optimize signal timing for a wide range of traffic conditions in order to construct signal timing tables for each parameter. Thus, the initial system update cost is high.

2. For a detected set of traffic conditions, the table lookup process finds the values of signal timing parameters by using a different table for each parameter. This can result in the

selection of a set of incompatible signal timing parameters, especially for grid networks. As a result, the signal control can degrade traffic flow instead of improving it.

Traffic responsive systems can be improved significantly by replacing the table lookup process by a more proactive real-time signal timing optimization process.

Real-Time Traffic Control

The next level of real-time control is a 1.5 generation system. This system is based on the same principles as a traffic responsive system. However, it replaces the table lookup process by a real-time signal timing optimization capability. Since TxDOT and many cities already have a large number of existing detectors, updating traffic responsive control to a 1.5 generation real-time control only needs the following additional capabilities:

- An efficient algorithm for optimizing signal timings in real time, and
- The development of control software to enable downloading of optimized signal timings to the controllers in real-time.

Research Objectives

The primary objective of this project was to develop and test a 1.5 generation real-time traffic control system based on the PASSER IV signal timing optimization program. TTI developed PASSER IV for off-line use. Its key features include the ability to optimize left-turn phasing sequences in a grid network. The specific objectives of the project were:

1. to enhance the computational efficiency of PASSER IV,

2. to enhance the analysis capabilities of PASSER IV,

3. to identify data interface modules for automated real-time application of PASSER IV,

4. to identify on-line display needs of real-time control,

5. to enhance PASSER IV for generating easy-to-transition timing plans,

6. to develop an algorithm for calculating the cost of signal timing transition,

7. to test a 1.5 generation application of the program using a multi-arterial sub-network from the city of Richardson, Texas, and

8. to teach a two-day pilot training course on PASSER IV.

OVERVIEW OF PROJECT PROGRESS

The research team completed the following tasks:

1. Enhanced the existing version of PASSER IV and released an offline version (Version 2.1) of the software in early 1997. This version accompanies an updated user manual [2]. New and enhanced features in PASSER IV include:

    - Ability to optimize split phasing sequences.
    - Ability to optimize lead-lead or lag-lag phasing without overlap.
    - Increased computational efficiency. Now it is twice as fast as the previous version.
    - Map capability improved to display larger networks.
    - A new feature provides for the user selection of any signal as the master signals for referencing offsets.
    - Ability to choose start or end of phases as offset reference points.
    - Ability to specify different units for input data and output report.
    - Output report is enhanced to provide signal timings in a form ready for input to modern controllers. In addition, several new measures-of-effectiveness have been added. These include: stops, queue lengths, fuel consumption, and emissions.

2. Developed a draft PASSER IV training manual and taught a two-day pilot training course at TxDOT facilities in Austin, Texas.

3. Revised and published the PASSER IV training manual [3]. Revisions to the training manual included comments received from course participants and addition of material to enable its use as a self-study guide.

4. Developed an enhanced delay estimation procedure and implemented this procedure in a computer program [4].

5. Performed an in-lab test of the real-time operation of PASSER IV. This is described in Chapter II.

6. Developed a preliminary algorithm for determining signal timing transition cost. This procedure is described in Chapter III.

7. Developed a Windows 95-based version of PASSER IV that links to Federal Highway Administration's (FHWA's) CORSIM simulation package [5] and is described in Chapter IV of this report.

8. Developed a significant portion of the next generation of PASSER IV program. Chapter IV describes this development.

ORGANIZATION OF THIS REPORT

This report presents the project summary and additional research results not provided in the other project reports. The previous section provided an overview of research progress. The following chapters provide more detailed information about the following topics:

- Issues related to real-time application of PASSER IV (Chapter II),
- Development of a preliminary algorithm for determining timing transition cost, and
- Additional enhancements and development of PASSER IV development.

CHAPTER II
REAL-TIME APPLICATION OF PASSER IV

INTRODUCTION

In this chapter, we present the architecture of a real-time traffic control (1.5GC) system and discuss various components of this system. In addition, we provide guidelines for using PASSER IV as a component within such a system.

As explained in the previous chapter, a 1.5GC system is similar to a traffic responsive (1GC) system. The only difference between the two systems is that a 1.5GC system is equipped with a real-time signal timing optimization module instead of the table lookup process for selecting signal timings. Figure 1 illustrates the basic components of a 1.5GC system. In this figure, boxes with solid lines represent key components of the system, and lines connecting the boxes imply two-way data communication between the components.

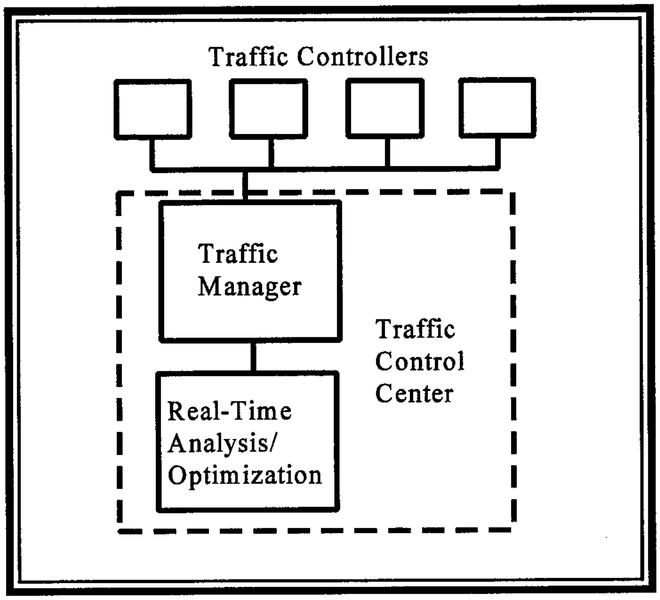


Figure 1: Key Components of a 1.5GC System.

As illustrated in figure 1, traffic management software (traffic manager) is located on a personal computer housed at the central location. The traffic manager is linked to the controllers in the field through communication lines. The traffic manager is also linked to other software for providing data analysis and real-time signal timing optimization capabilities. The analysis/optimization software can be located on the same computer or on a different computer connected via local or wide-area network. This system operates by performing the following functions at every specified time step:

1. The traffic manager uploads raw data from the controllers, processes these data, and stores the processed data on disk.

2. The analysis/optimization software reads the data stored by the traffic manager. Then, it processes these data, generates (new) optimal signal timings, performs any additional analysis, and stores new signal timings for use by the traffic manager.

3. The traffic manager takes the new signal timings and downloads them to the controllers.

The steps described above provide a global picture of a real-time system. The next section provides more insight into a real-time system. Development and testing of such a system require cooperation with a city that meets the following criteria:

- Availability of all necessary hardware and software. The needed hardware includes an infrastructure of detectors and communication lines. The software must be capable of uploading and downloading data and some data processing capability.
- Availability of traffic data.
- The ability and willingness of the city and its staff to provide any needed support.

The city of Richardson, Texas, met all the above criteria and was chosen as a test site. In a following section, we will provide a brief description of the events that led to the partnership between TTI and the city of Richardson.

STABILITY OF A REAL-TIME SYSTEM

A number of issues need to be addressed in order to ensure the stability of a real-time traffic control system. In this section, we address system stability issues as they relate to real-time control system. We begin by providing a description of the control process in 1.5GC system.

Real-Time Traffic Control Process

Figure 2 illustrates the data transfer and signal timing optimization processes in a 1.5GC system. The top part of the figure provides a hypothetical plot of traffic demand at an approach as time elapses from an off-peak period to a peak period. While demand is increasing during this period, the plot illustrates that short term fluctuations (from one signal cycle to another) in demand can occur. This requires that data aggregation period be long enough to smooth out these fluctuations or noise in demand. At the end of each period (T0, T1, T2, etc.), the raw data (i.e., detector counts and occupancies) are uploaded from the controllers.

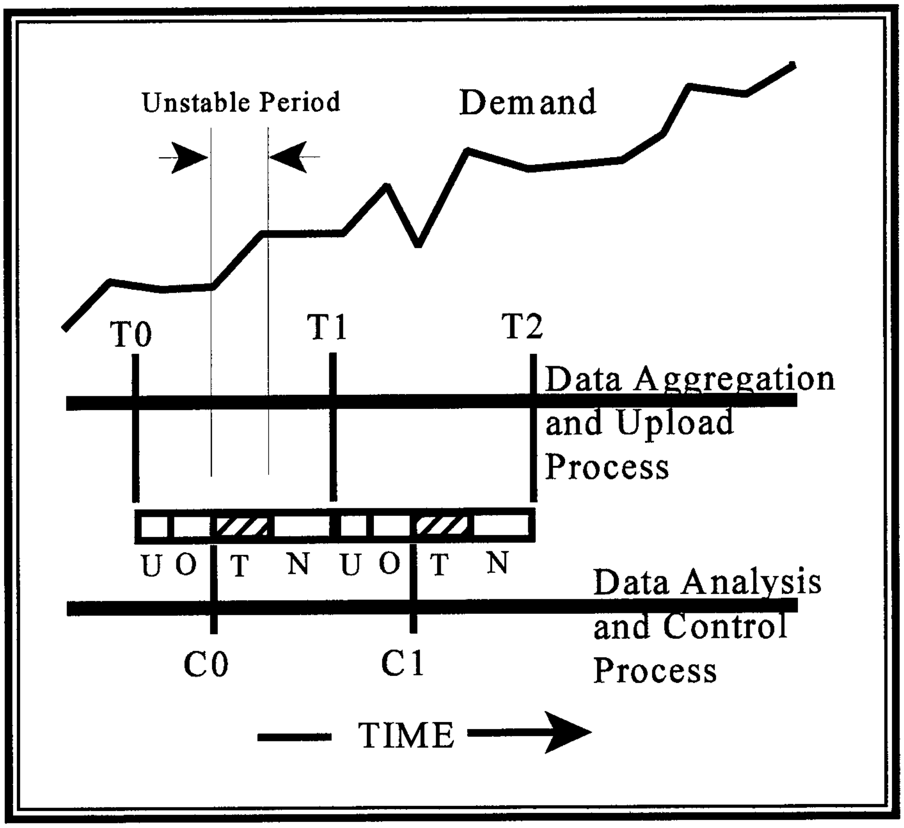


Figure 2: A 1.5 Generation Control System.

The bottom portion of the figure illustrates the data analysis and control process. This process consists of the following four stages:

1. Data upload from the signals and data aggregation (U);
2. Signal timing optimization, transition cost analysis, and downloading new timings to the controllers (O);
3. If new signal timings, signal timing transition time (T); and
4. The length of time from the end of transition period to the next upload of data (N).

Signal timing transition can cause severe disruption to the flow of traffic. The length of time it takes for a signal to transition to a new plan depends on the method of transition and the magnitude of difference in the two timing plans. The severity of these disruptions depends on the transition method, the length of time it takes to transition, and traffic conditions. Further, these adverse effects can last for several cycles after the new timings are in place. We consider data collected during this time period to be unstable. The period of stable traffic flow starts after the effects of signal timing transition have disappeared. This period lasts until the next signal timing transition. Its length is the sum of time periods N, U, and O.

In order for a real-time traffic control system to be stable, the length of the stable period must be significantly larger than the length of the transition period. This can be achieved by using a long enough control period (control time slice) that allows the system to be responsive to changing traffic conditions, while maintaining its stability. For instance, a highly unstable system would result if the control period length is close to that of the transition period. On the other hand, a long time slice would result in a system similar to a pretimed traffic control system with automated data collection capabilities. Although this kind of system would be better than the current systems, we selected a fifteen minute control-time-slice length for the real-time application of PASSER IV. It is anticipated that this time slice will provide sufficient responsiveness.

Assessment of Traffic Demand

In addition to the factors discussed in the previous section, an ability to accurately estimate traffic demand at signalized approaches is essential for implementing an effective real-time traffic control system. Traffic demand at a signalized approach is the number of vehicles arriving during one signal cycle. Vehicle arrival (traffic demand) is random in the absence of an upstream signal. When an upstream signal exists, vehicles arrive in platoons released during various phases at the upstream signal. Regardless of the random or non-random (grouped in platoons) nature of arrival patterns, the vehicles generally arrive continually during the entire cycle. The downstream signal, however, services these vehicles only during a small part (green phase time) of the cycle. This results in the presence of approach queues at the beginning of the green phase.

During undersaturated conditions, all vehicles arriving at an approach during a signal cycle (red plus green for the approach) are serviced during the green phase. Under these conditions, the vehicle count (service volume) provided by a loop detector is equal to traffic demand. As demand becomes closer to capacity (demand to capacity ratio between 0.95 and 1.0), some vehicles arriving during the green phase may not get service during the same cycle. This condition is called a cycle failure. During undersaturated conditions, occasional cycle failures occur due to randomness in demand from one cycle to the next. When this happens, detector counts averaged over several cycles still provide a reasonably good measure of traffic demand.

When an approach becomes saturated or oversaturated (that is, demand becomes equal to or more than capacity), cycle failures start to occur consistently. Under these conditions, the detector count is dependent on the length of the green phase and provides only a portion of traffic demand. Thus, additional data are needed to estimate demand. We propose the use of detector occupancy for this purpose. Loop occupancy over a span of time (i.e., during green), is the percentage of that time the loop is occupied. The basic equation for estimating demand during oversaturated conditions is given below.

$$Demand = Count + K(Occupancy)$$

In the above equation, K is a constant that is dependent on the location of the loop and the part of the signal cycle during which occupancy is measured. The value of K must be determined through field studies. In addition, it is a function of detector location. For instance, the occupancy (measured during the same time interval) for a stop-bar detector is higher than the occupancy of an upstream detector.

COOPERATION BETWEEN TTI AND RICHARDSON

The city of Richardson, Texas, is one of many cities in the Dallas metropolitan area. It adjoins the cities of Dallas, Plano, and Garland. As illustrated in figure 3, the North Central Expressway (US 75) divides Richardson's signal system into two parts: eastside and westside. In 1992, Richardson had provided extensive data for testing the original version of PASSER IV. City staff had also beta-tested PASSER IV and indicated their willingness to supports TTI's future research. Therefore, at the start of this project, the research team contacted Richardson requesting support for the real-time PASSER IV project.

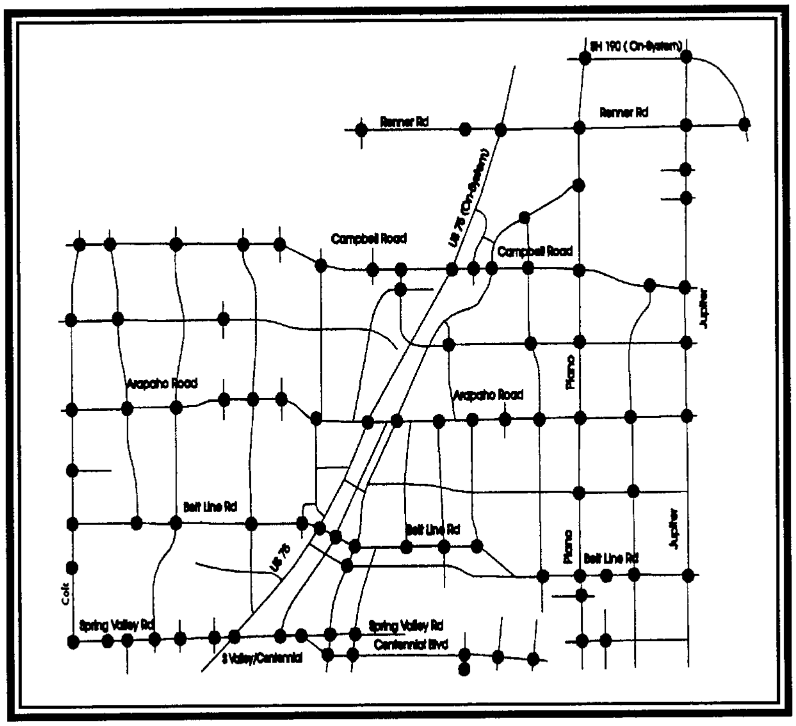


Figure 3: City of Richardson Signal System.

Upon initial contact, we were informed that Richardson had just developed specifications for their advanced traffic management system (ATMS). This specification required upgrading all NEMA signal controllers and cable TV (CATV) modems. This ATMS specification also called for real-time (15 minute) detector uploads from all local intersection controllers in addition to the once per day historical data uploaded in Richardson's existing system. Additional real-time measures-of-effectiveness (MOE's) were specified to complement the ATMS functions needed for a state-of-the-art system. Further discussions between TTI and Richardson concluded that mutual cooperation of the two organization would enhance their respective projects. This resulted in a decision to form a cooperative partnership between TTI, Richardson and TxDOT.

Very soon thereafter, the partners met with several proposers to develop the specifications for real-time application of PASSER IV. In 1996, Naztec, Inc. from Sugar Land, Texas, was awarded a contract to supply new hardware and to develop controller software enhancements for this system by May of 1998. In subsequent months, the partners held numerous technical meetings with the contractor to identify data and interface needs for the real-time application of PASSER. During these meetings, both short-term and long-term needs were identified. Based on these developments, TxDOT also granted a one-year project extension. The following sections provide a detailed description of Richardson's hardware and data collection system.

Description of Field Hardware

Richardson has two basic types of detectors: presence detectors located at the stop-bar, and approach detectors placed far enough upstream of the stop-bar to minimize the dilemma zone for a given approach speed. Figure 4 illustrates the configuration of these detectors. Recent advances in loop detector technology provide counts from presence detectors (long loops) even when more than one vehicle occupies the loop. This approach is cost effective because local detectors needed for actuated signal control also serve as system detectors.

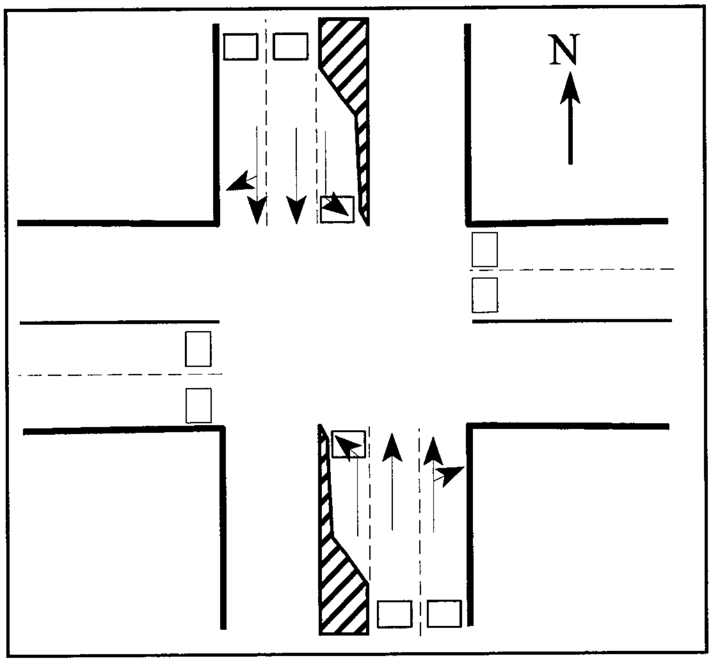


Figure 4: Typical Detector Configuration.

Detector data are accumulated in the intersection controller and uploaded to a central computer over the CATV (cable TV) network. One key requirement was to design a system that relies only on these data as opposed to more advanced video-based systems currently being developed. Figure 4 shows the typical detector layout and lane assignments. As illustrated in this figure, detectors on all minor approach lanes and left-turn bays are located at the stop-bar. Detectors on all through lanes at major approaches are located three hundred feet upstream of the stop-bar. As pointed out earlier, this placement of the approach detectors upstream of entrance to the turn pockets provides for their use as system detectors. In addition to the loop detectors, Richardson also utilizes a limited number of video cameras, placed at strategic locations, for use by operators to identify problems.

Richardson's Count System and Historic Data

In 1992, Richardson developed software to collect and store traffic movement counts (TMCs). This system uploads detector data once per day, and estimates fifteen-minute TMCs. The next section provides the logic for estimating TMCs. The historical data includes the following information:

- One record containing left-turn, through, and right-turn counts for all signalized approaches. Each signal has 96 records (one every 15 minutes) of data per day.
- These data are grouped by day-of-week, and by week-of-year. Therefore, there are 52 groups of data for each week-day.

The software also allows data retrieval by specifying certain qualifiers. For instance, the operator can request data for a certain day of a specified week or specify that the data for a requested day (i.e., Monday) be retrieved using a given percentile value. When the operator uses the later option, the software retrieves data for each time slice (i.e., 8:15 a.m.) of the selected day as follows:

- Calculates sum of critical volumes for each of the 52 data records.
- Selects the time-slice data from the day that meets the specified percentile criterion.

At our request, Richardson provided historical data for all signals for years 1993 and 1994. An 85th percentile value was used to obtain these data.

Real-Time Traffic Movement Counts

Based on the need for a real-time application of PASSER IV, Richardson modified its specifications for allowing data upload every fifteen minutes, in addition to the once per day upload capability. The logic for estimating fifteen-minute TMCs is the same as before. For a minor approach with stop-bar detectors only, the system determines TMCs as follows:

1. For an exclusive lane, TMC is equal to the detector count.

2. For a shared lane, the count of turning traffic is equal to a specified percentage value. Time-of-day turning (TOD) percentages have been established through field studies.

In Richardson, most major approaches have exclusive left-turn bays and shared right-turn lanes. Stop-bar detectors in the left-turn lanes directly provide the volume for left-turn lanes. The system calculated the TMCs for the through and the right-turn movements as follows:

1. Subtract the left-turn count from the sum of approach detector counts. This results in total count of through and right-turn traffic.
2. Apply TOD percentage to the through plus right count to obtain right-turn volume.
3. Subtract the right-turn volume from the through plus right-turn count to obtain the through volume.

Description of the Test-Bed

For testing the real-time application of PASSER IV, we needed a group of signals that emphasized PASSER IV's ability to optimize signals timings for multi-arterial closed-loop networks. Richardson's experience has shown that the group of signals located west of US 75 operates best when divided into several single-artery sub-systems. The eastside signal system, on the other hand, possesses the characteristics needed to allow their operation as a coordinated network. Thus, we selected a thirty-one (31) intersection sub-network located on the eastside of North Central Expressway (figure 5).

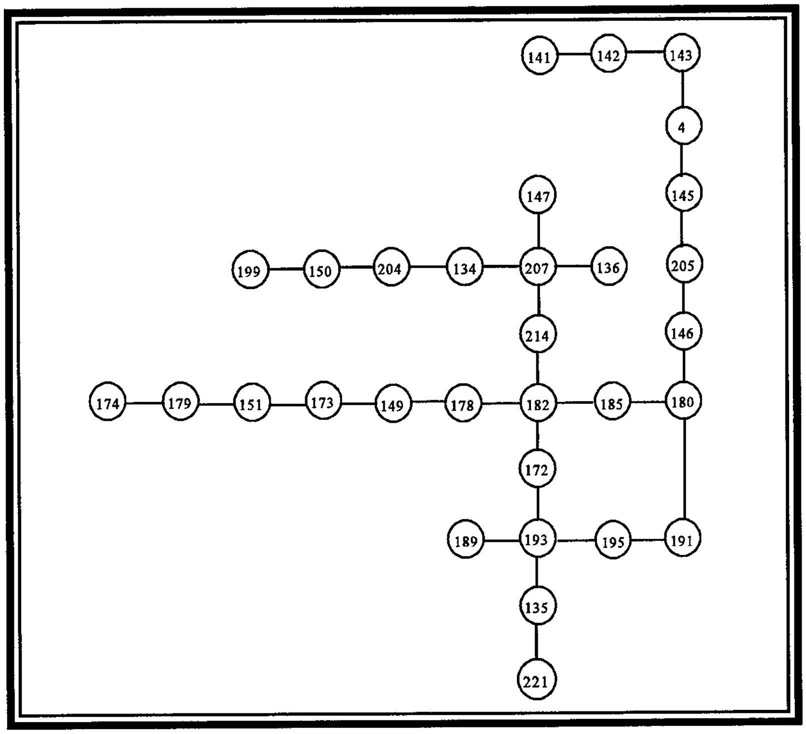


Figure 5: Graph of Richardson Test-Bed.

This network consists of six (6) arterials and one (1) closed loop. Historical data for these signals were obtained from Richardson. These data included all peak and off-peak periods.

REAL-TIME PASSER IV AND ITS COMPONENTS

As identified earlier, one key feature of a real-time system is the automation of routine tasks commonly performed by humans. These tasks include:

- Data collection and aggregation of raw data,
- Generation of input data file for the optimization program,
- Running the optimization program,
- Interpreting results and performing further analysis, and
- Transferring optimal signal timings to the controller.

In this section, we discuss the details of data analysis/optimization function identified in figure 1. Earlier, it was mentioned that these functions need not be performed on the same computer. For the real-time application of PASSER IV, we selected a configuration that allows the distribution of various software components. Figure 6 illustrates the expanded configuration.

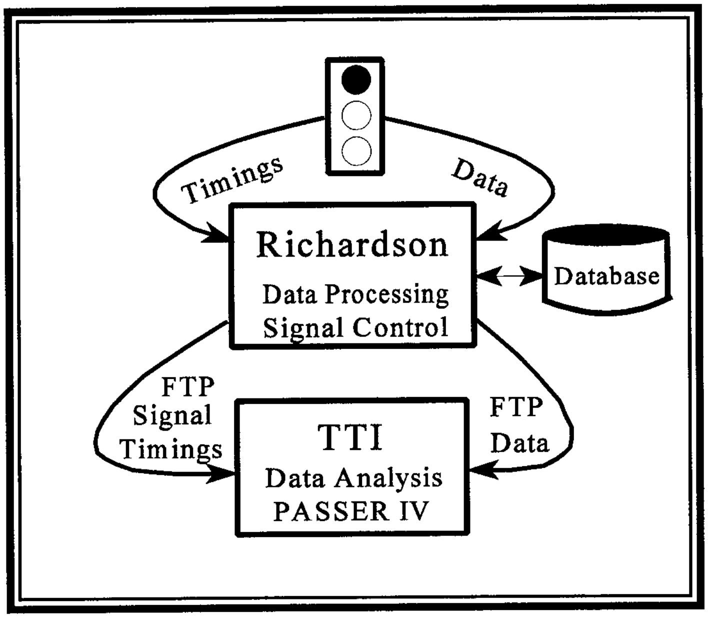


Figure 6: Richardson-TTI Real-Time Data Flow.

This configuration distributes the data analysis and the optimization components over two personal computers (PCs) connected to each other via Internet. It allows the PCs to communicate regardless of their location. The two PCs communicate with each other using the file transfer protocol (FTP) and perform several functions. The following subsections describe these functions.

Computer Server at Richardson

Every fifteen minutes, this PC performs the following functions:

- It uploads detector counts and occupancies from each controller;
- It calculates left-turn, through, and right-turn volumes for the approaches;
- It uses a database to assign geometric directions to these volumes; and finally
- It creates a file that contains these volumes for each signal.

The server also stores data in the historical database described earlier. This function, however, is performed once every day at night.

TTI Computer

Using FTP, the TTI computer uploads the files containing fifteen-minute TMCs. Then, it performs the following functions:

- Generates a PASSER IV input data file;
- Runs PASSER IV;
- Performs further analysis; and
- Using FTP, sends optimal signal timings back to Richardson.

Synchronization of Data Communications

Communication delays can occur between Richardson's server and field hardware. In addition, the amount of time needed by the TTI PC for completing the analysis and optimization tasks is also variable. Because of these delays, it is difficult to specify an exact time when the data/results are available for upload during the two-way communication. Therefore, we had to implement a scheme for determining the presence of files to be transferred between the two PCs. A simple, but dynamic, technique was implemented to achieve this synchronization. This technique tags the name of the file to be transferred with a time stamp based on a twenty-four hour clock. For instance, the file containing data for the fifteen-minute period ending at 5:15 p.m. is named TMC1715. Every fifteen minutes, the TTI process performs the following function:

Step 1: It logs into the server and searches for a file tagged with the current time.

Step 2: If a file is found, it downloads the file. Performs the optimization and analysis functions, and uploads optimal signal timings to Richardson's PC.

Step 3: If the file is not found, it waits for a minute and goes back to Step 1.

A similar process runs at Richardson's server to determine the availability of the file containing optimal signal timings for downloading into the controller.

PASSER IV Input Data Generation and Optimization

The current application assumes that the network configuration (number of arteries and signals in the test-bed) remains constant between several peak and off-peak periods. Time-of-day PASSER IV data files have been pre-created using historic data. Figure 7 gives the basic structure of PASSER IV files. Appendix A provides a detailed description of data records. Future expansion to allow adding or dropping signals from the network by time-of-day will require addition of a component that provides a capability to create an input data file from scratch.

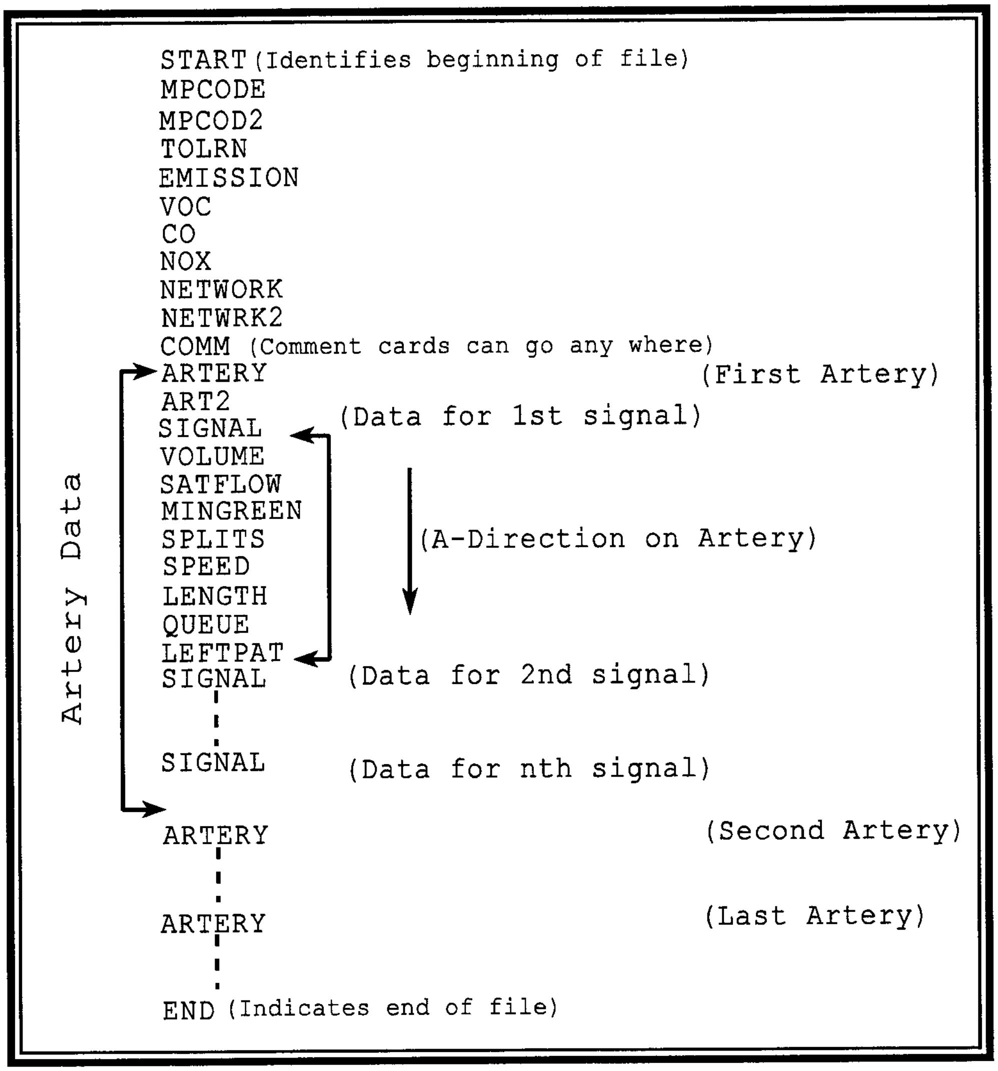


Figure 7: Structure of PASSER IV Input Data Files.

After successfully downloading data from Richardson, the TTI process performs the following functions to generate signal timings for the next time slice:

1. It uses the count and occupancy data to estimate demand. At this time, enhanced controller software has not been installed in Richardson, and the occupancy data are not valid; therefore, we use real-time volumes only.

2. It selects the appropriate base-data file. It parses the data file and replaces the historical volumes with the real-time volumes. If for any reason, real-time volumes are not available for a signal, it retains the historical volumes. This scheme ensures that the PASSER IV data file is complete. This situation can frequently occur due to detector malfunction or breakdown of a communication link.

3. It runs PASSER IV by issuing the command: *passr4 data-file-name output-file-name.* Use of this command allows running PASSER IV without having to go through the its user interface. Optimal signal timings for each signal are stored in an alternate output file. For each signal, the following information is contained in the file.

```
146,120                    /Signal Number, Cycle Length/
11,30,27,52,14,27,12,67    /Green Times (Sec.)for NEMA Phases 1-8/
1001,9                     /Phase Reversal in Binary and Real Formats/
21,96,30,53,96,8,86,30     /Offsets (percent) for phases 1-8/
```

   This is the same information provided in the signal timing summary of the standard output. However, in this file the data are comma separated. Please note that the comments, enclosed by forward slashes, have been added for this document.

4. The architecture includes a module to provide signal timing transition analysis to determine if it is worthwhile to update signal timings. The next section discusses this issue.

5. The output file is sent to Richardson via the Internet. Upgraded software to allow the real-time downloading of these signal timings to Richardson's controllers has not been installed yet.

Signal Timing Transition Cost Estimation

Whenever signal timings are changed, vehicular flow is disrupted. The amount of this disruption depends on the number of signal timing parameters changed and the magnitude of changes. The purpose of transition cost analysis is to determine if it is worthwhile to change signal timings during a given control period. The proposed Richardson/PASSER IV real-time system design includes the following transition cost analysis:

Step 1: Determine the delay for projected conditions assuming signal timing are kept unchanged.

Step 2: Determine the cost of transition from existing timing plan to the proposed plan.

Step 3: Determine the delay for projected conditions assuming proposed signal timings.

Step 4: If the total cost in Steps two and three is significantly (i.e., 5 percent) less than that of maintaining the status quo (Step 1), then it is worthwhile to implement the new timing plan.

This simplistic approach needs to be further enhanced to incorporate a situation when the isolated analysis of several successive time-slices chooses status quo, but the data aggregated over these time-slices warrants updating signal timings. At this time, however, there are two other important issues that need to be addressed:

1. The state-of-the-art signal controllers installed in Texas do not have capabilities to specify a transition method in real-time. Controller software needs enhancement to provide this ability.

2. No tools are currently available to determine a system wide estimate of signal timing transitions cost for multi-phase signals. We address this issue in the next chapter.

Laboratory Testing of Real-Time PASSER IV

This project used a laboratory setting to test the components of the real-time PASSER IV. This testing consisted of two stages. The first stage used computers located in separate buildings –TTI and Computer Science (CS) – at the Texas A&M University campus. Computers located in the two buildings communicated via the Internet. In this setup, a Unix workstation located at CS requested data from the TTI PC every fifteen minutes, ran PASSER IV, and transferred its results (optimal signal timing report) back to the TTI PC. Then the TTI PC displayed the received output. In the second stage, we moved the process/functionality of the TTI-PC to Richardson and the other process to a PC in the TTI lab. In addition, this setup used real-time data instead of the historical data. The two stages to test the components of real-time PASSER were completed successfully.

Since the Richardson signal system upgrade is not complete yet, we used CORSIM [5] to simulate the real-time operation of Richardson's signal system. CORSIM is the most advanced of the network simulation packages available to practitioners. This task identified several practical problems associated with the use of computer simulation for evaluating real-time systems. These are discussed below.

1. There is a need to automate the process of data exchange between PASSER IV and CORSIM. In this project, we demonstrated a proof-of-concept to develop such a linkage. Chapter IV, dealing with enhancements to PASSER IV, provides further information on this research product.

2. Although CORSIM is an advanced simulation package, its basic controller logic does not adequately model the operation of modern controllers. There are two ways this problem can

be resolved. The first option is to enhance its controller logic to provide advanced features of modern controllers. This approach, however, is not robust enough to stay abreast of the advancements in controller technology. The second approach is to build a capability to connect CORSIM with real controllers. This capability would allow the use of actual controllers instead of simulated ones. FHWA recently identified this need and funded a project to accomplish this task.

3. A more basic issue, however, relates to the validity of using computer simulation for evaluating a real-time signal control system. The problem arises due to the fact that there is no correspondence between the input data and optimal signal timings after the first iteration of the process. In other words, the input data depends on signal timings in the field, which are different from the signal timings being simulated. Resolving this problem is a research project in itself and requires systematic generation of synthetic data.

Future Enhancements

The 1.5GC real-time PASSER IV architecture developed and tested in this project needs several enhancements to upgrade it to a higher level. The following list discusses potential enhancements identified in this project:

1. Improved estimation of traffic demand: At the heart of a real-time system is the assumption that it can accurately estimate demand. In traffic signal networks, demand at a signalized approach depends on traffic arriving from an upstream source. If the upstream source happens to be a signal, the traffic released by it depends on its timings. Thus, in general, it is not possible to fully estimate demand at an approach by ignoring the counts from the upstream signal feeding traffic to it. Thus, better estimates of demand can be obtained by supplementing data from detectors at the approach with volume data from the upstream signal, if any. In addition, the estimated demand reflects what happened in the recent past and must be projected in order to provide a more adaptive control for the next control period.

2. Self assessment and calibration capability: The system should be able to assess its performance and take corrective action. These tasks include: detection and resolution of incidents and lane blockages and comparison of predicted and actual demand to automatically calibrate the prediction model.

Both enhancements described above can be made by uploading signal timing information from the controllers. These timings can be used to estimate: the capacity of a movement, signal capacity, volume-to-capacity ratios and other MOEs. These MOEs can then be used to guide the real-time signal operation. Based on these recommendations, Richardson modified its specifications to include controller enhancements to provide these data.

Current Status of the System

To date, Naztec has completed the installation and testing of field hardware in Richardson. The contractor has completed the enhanced software for providing several new occupancy measures and signal timing information. These measures include: occupancy during green, occupancy during the clearance interval (yellow plus all-red), and occupancy during the last two seconds of green plus the clearance interval. These measures will be extremely useful in estimating demand, especially for stop-bar detectors since occupancy during the entire cycle is not a useful measure for these detectors. This software upgrade is expected to be completed during the fall of 1997.

Based on future enhancements identified earlier, TTI recently requested Richardson to provide raw data from detectors. Richardson staff has completed software enhancements to trap data errors and to provide these data to TTI. Now TTI software is being enhanced to perform data aggregation and demand estimation functions.

CHAPTER III
ESTIMATION OF SIGNAL TIMING TRANSITION COST

INTRODUCTION

A real-time traffic signal control system responds to the changing traffic conditions by frequently updating signals timings. Transition from the current timing plan to a new timing plan can have significant detrimental effects on traffic flow in the signal system. The severity of these effects depend on the traffic conditions, differences between the old and the new timing plans, and the selected transition method. Therefore, it is imperative that the cost of transition be explicitly considered in the operation of a real-time system. The following two steps are needed for a complete consideration of, and effective solution of, the disruption problems associated with signal timing transition:

1. Generation of a new timing plan that is as close as possible to the existing timing plan and
2. Selection of a transition method which minimizes the cost of transition.

Here, we address the later issue by developing a preliminary algorithm to determine the cost of signal timing transition. For a given set of traffic conditions, the old timing plan, and the proposed (new) timing plan, the system should select that method which achieves the following objectives:

1. Minimize Transition Delay: Transition delay is the additional delay to motorists caused due to signal timing transitions.

2. Minimize Transition Queue: During undersaturated conditions, the method should avoid the formation of additional queues. The minimum delay solution will achieve this objective as well. However, if it is not possible to achieve this objective, the secondary objective should be to minimize the length of queues formed.

3. Avoid Oversaturation: Maintain the status of all undersaturated signals. This means providing enough green time to all movements to satisfy the existing demand. If this objective cannot be satisfied, the queue length objective takes precedence.

4. Minimize Transition Time: No matter how good the system is, there will be uncertainties in the predicted conditions. In order to avoid the detrimental effects of these uncertainties, the transition time should be minimized.

5. Maintain Driver Safety: Sudden transitions, where signal indications are changed instantaneously or changed without sufficient change interval, should be avoided. Although this objective does not lend itself very well for explicit incorporation in a mathematical formulation of the problem, any transition strategy should account for driver expectancy.

Finally, if the total system transition takes too long, those sub-systems (i.e., adjacent signals) which can transition faster should be considered first.

BACKGROUND

An increasing number of urban traffic signals are being brought under computerized traffic control. One of the primary advantages of real-time traffic control is the ability to change signal timing in response to changing traffic conditions. Entailing each change in the timing pattern is a period of transition. These transition periods can have highly disruptive effects on traffic operations. Based on field experience, some engineers believe that the transition from one plan to another during peak traffic periods is more disruptive than having a non-optimal plan in operation.

Transition is a critical aspect of the development of modern real-time traffic responsive plans. During the initial implementation of traffic responsive systems, the issue of transition was not given due importance. The FACTS system, a real-time-traffic-responsive system developed by TxDOT, falls in this category. The implementation of FACTS system on NASA Road 1 in Houston, Texas, provided useful insight into the transition aspects of a real-time system. The system was originally implemented to update timing plans every five minutes in response to the traffic data collected from the system detectors. Initially, it was not realized that transition from one plan to another may require several minutes, and often more than five minutes. Thus, there were times when the system was perpetually in a state of transition, a highly unstable state. When TxDOT realized this, they changed the frequency of signal timing update to about 15 minutes.

Experiences with systems such as the FACTS system have prompted traffic engineers to direct more attention towards the transition aspects of signal timings. Engineers have proposed several transition methods/algorithms. However, there are no means for the engineer to determine which one of these are more suitable for particular traffic conditions. Different controller manufacturers provide various signal timing transition options, yet there is no analytical basis for selecting the appropriate transition method. Thus, engineers generally use trial-and-error methods or conservative approaches based on field experience.

Earlier studies have attempted to evaluate transition methods and modified microscopic simulation models like UTCS-1 and ROSIM (a microscopic arterial simulation model used in UK) to simulate the particular method(s) of transition [6 ,7 ,8]. The findings of these studies were limited to the particular traffic conditions used in the studies. Although signal timing transition evaluation based on microscopic simulation models is suitable for laboratory analysis, it cannot be used in a real-time system to estimate the transition cost. This is because of the complexity of the models and the time constraints associated with real-time control. Thus, there is a need to develop a macroscopic model of evaluation that is simple to use and capable of estimating the cost of transition for any combination of traffic conditions, timing plans, and method of transition in a reasonable amount of time.

Task Objectives

The objectives of this research task was to develop an algorithm for determining a minimum cost signal timing transition strategy suitable for real-time as well as off-line use. The specific research objectives were:

1. To understand the system-wide transition process and the various transition methods proposed in the past and available in modern traffic controllers.
2. To develop a methodology to simulate the transition process and estimate the delay during transition, given a transition method and the two (old and new) timing plans.
3. To develop an optimization algorithm that could be superimposed on the simulation algorithm to allow the selection of the minimum cost transition method.

In this chapter, we discuss the issues related to signal timing transition and describe the results of a transition cost estimation model developed in the project.

SIGNAL TIMING TRANSITION METHODS

For isolated signals, timing transition is simple and may require changes in one or more of the following three signal timings parameters: cycle length, green splits, and phasing sequences. The new plan is implemented immediately. Generally, after the initiation of the signal timing transition, the current cycle is allowed to continue until it is complete. After the completion of the current cycle, the new phase sequences and splits are activated. In this process, some phases may experience longer red periods due to the change in phasing sequence and cycle length. However, there is no need to further adjust the phase splits.

In an interconnected signal system, signal offsets must also be considered in addition to the other three signal timing parameters. An offset is generally defined as the time gap between a common reference point and a fixed point in the local controller cycle (e.g., start of main street green, end of main street green, start of dual through greens, etc.). In this report, we assume an offset to be the time gap between the system reference point and the start of main street green at a signal.

When the timing plan in a coordinated system changes, any or all of the timing parameters, including phase sequences, splits, and offsets, may change. A change in timing plan also causes the controller reference to change. However, the current cycle at the intersection in not altered until it is complete. After the completion of the current cycle, the new phase sequence is activated.

Since the system sets the reference independent of the local signal controller, the actual offset at the commencement of the new plan is generally different from the specified offset In order to achieve the new offset, the phase durations are either shortened or lengthened over consecutive cycles until the new offset is achieved. This process of lengthening or shortening individual phases may continue for several cycles based on the method adopted for transition.

The simplest and most frequently used method of transition is the extended main-street green method. This method extends the green for the progressed main-street movement until the new offset is attained. The extension can never be more than one cycle. This method of transition often results in long periods of red and excessive queues at non-progressed movements. Often, it is not the best method of transition. In order to achieve the transition objectives outlined earlier, traffic engineers have employed other methods of transition. These transition methods differ in how and by how much the cycle length, splits, and offset reference are varied in various stages. These variations are discussed below.

Cycle Extension Versus Reduction

Any offset correction can be achieved by either extending or reducing the cycle length. The amount of addition can be obtained by subtracting the amount of reduction from the cycle length. This implies that the maximum correction required to obtain any offset is not more than 50 percent of the cycle length if both extension and reduction of cycle are equally desired. For example, if an extension of 70 percent of the cycle length is needed to achieve the design offset, a reduction of 30 percent can be made.

A 50 percent maximum correction is only possible when both cycle extension and reduction are equally favored. In some instances, it is more desirable to add than to subtract. Most transition methods have a parameter to enable the engineer to specify a preference for addition or subtraction. When an intersection is operating at demand levels close to saturation, it may not be prudent to reduce the cycle length. In such cases it is possible to synchronize the intersection only through cycle extension.

Maximum Cycle Change

In order to avoid long periods of red and excessive queuing and to provide enough pedestrian walk times, many methods of transition often restrict the maximum correction that can be applied in one cycle. If the required amount of correction exceeds the maximum correction amount per cycle, the remaining correction is applied in the subsequent cycle(s).

Maximum Number of Cycles

Instead of requiring the maximum change per cycle, some methods require as input the maximum number of cycles during which correction must be made. Irrespective of the magnitude of correction, this method equally spreads the correction over the specified number of cycles.

Maximum Phase Correction

This method achieves the required correction by extending or reducing individual phase durations. Instead of restricting the maximum amount of change applied per cycle, it restricts the maximum amount of correction per phase. In this method of transition, the sum of the phase corrections for all the phases determines the maximum change per cycle.

Correction Phases

Transition methods often restrict the phases to which correction can be applied. A positive correction is applied only to the phases servicing the progressed movements, while a negative correction is distributed among all phase. Some methods restrict corrections to the phases servicing the progressed movements only.

DEVELOPMENT OF A MODEL FOR ESTIMATING TRANSITION COST

In this section, we describe the development of a macroscopic model to estimate the cost of signal timing transition given that a transition method is specified. This method is based on the macroscopic delay estimation model employed in PASSER II-90 and PASSER IV-96 [9, 10]. First, we provide a brief discussion of the PASSER delay estimation model. Then, we describe the proposed methodology for estimating delay due to transition, followed by results and recommendations for further research.

PASSER Delay Model

This model uses platoon length at the upstream intersection to estimate platoon length at the downstream intersection. As shown in figure 8, the length of the platoon at the upstream intersection i, LP_i, is given by:

$$LP_i = g_o + PVG(g-g_o)^2/g, \qquad (1)$$

where

LP_i = Length of platoon at upstream intersection, i (sec),
g_o = Time required for queued vehicles to clear the intersection at i (sec),
PVG = Percent of vehicles arriving on green at i, and
g = Effective green time for the progressed movement at i.

The model computes the percent vehicles arriving during green (PVG) as follows:

$$PVG = PTT_j * GO_j / LP_j + (1-PTT_j)\, RO_j / (C-LP_j), \qquad (2)$$

where

PTT_j = Percent of total through traffic at j arriving from i,

GO_j = Green overlap for the platoon traffic from i at j as shown in figure 8 (sec),
RO_j = Green overlap for the nonplatoon traffic component from i at j (sec), and
LP_j = Platoon length at the downstream intersection j (sec).

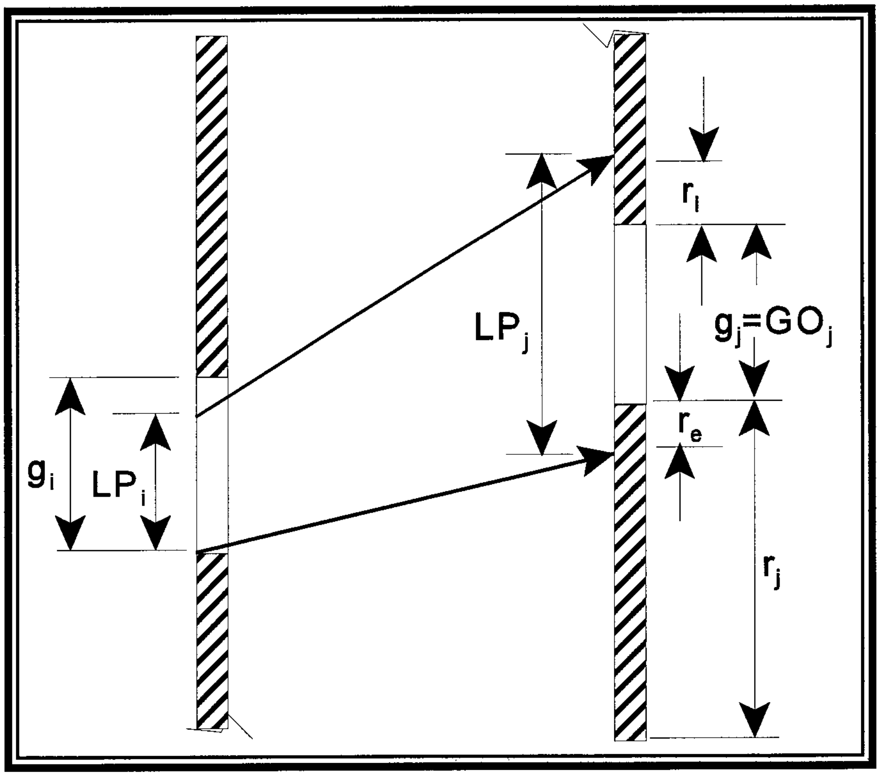


Figure 8: PASSER Delay Model Definitions.

The model estimates the platoon length at the downstream intersection j, LP_j, using the following equation:

$$LP_j = LP_i * PD_{ij} + 0.8*(0.9 + 0.056t_{ij}), \qquad (3)$$

where

LP_j = Length of platoon at downstream intersection, j (sec),
LP_i = Length of platoon at upstream intersection, i (sec),
PD_{ij} = Platoon dispersion factor (*5*)
= $1.0 + (0.026 - 0.0014*NP)*t_{ij}$,
t_{ij} = Travel time between i and j in seconds, and
NP = Number of vehicles in platoon at i.

The delay calculation for vehicles arriving in the red period depends on different platoon and non-platoon flow rates. The model defines three arrival rates during the red period at the downstream intersection: a flow rate for the early traffic arrivals, which are part of the main street platoon traffic; a flow rate for late arrivals, also part of the main street platoon traffic; and a flow rate for the non-progressed traffic during red.

As shown in figure 8, the flow rates q_{re} and q_{rl} are equal because of the assumption of a constant flow rate in the platoon length LP_i. The non-platoon flow will arrive late whenever the platoon flow is early or straddles the red. Similarly, non-platoon traffic will arrive early whenever the platoon traffic is late.

Using these assumptions about the platoon and non-platoon flow rates and the length of the platoon as described above, the model estimates the uniform delay (UD) through step-wise demand integration. The uniform delay equation consists of three parts. The first part (UD1) represents platoon traffic delay during red, the second part (UD2) represents the non-platoon traffic delay during red, and the third part (UD3) represents the delay during queue dissipation.

The first part of the equation is as follows:

$$UD1 = [q_{rp} r^2 / (2qC)] * FEAL, \tag{4}$$

where

q_{rp} = Platoon flow rate in red, (veh/sec)
= $PTT_j (1 - GO_j / LP_j) * q*C/r$,
q = Average flow rate (veh/sec),
r = Effective red for the progressed movement at j (sec),
C = Cycle length (sec),
FEAL = Factor for early and/or late arrivals as given by
$[(r_e - r_l)/r] + [2 * r_l / (r_l + r_e)]$, and
all other variables are as defined earlier (see figure 8 for r_e and r_l).

The equation below shows the second part of the uniform delay equation:

$$UD2 = [q_{rnp} r^2 / (2qC)] * FEAL, \tag{5}$$

where

q_{rnp} = Non-platoon flow rate in red, (veh/sec)
= $(1-PTT_j)* [1 - RO_j/(C- LP_j)] * q*C/r$.

All other variables are as defined above, except FEAL. FEAL will be different because the values of r_e and r_l (see figure 8) are different for the non-platoon traffic flow. The adjustment factor FEAL is derived based on the platoon arrival patterns. It not only differs from platoon to non-platoon traffic, but also from pattern to pattern. For further details, please refer to the discussion by Malakapalli [11].

The third part of the uniform delay equation represents the delay for queue dissipation after the start of green, as described by the following equation:

$$UD3 = q_r * r^2 / (2qC) * [1/(s - q_g)], \tag{6}$$

where

q_r = Combined mean flow rate during red (veh/sec),
q_g = combined, mean flow rate during green (veh/sec), and
s = Saturation flow rate (veh/sec).

Combining the three parts, UD1, UD2, and UD3, the total uniform delay result. The random delay computation uses the Highway Capacity Manual second-term delay component [12]. This is the delay due to incremental and overflow effects.

Proposed Transition Cost Estimation Model

The proposed model for estimating delay during transition uses the PASSER delay estimation model given above. We developed a FORTRAN routine to implement this methodology. The program reads travel times, traffic volumes, saturation flow rates, and the old and new signal timing plans as input. In this program, we implemented and tested only one method of transition. Transportation professionals know this method as shortway transition. We also assumed that all signals in the system use the same method of transition.

In a fixed-time signal system, the sequence of red and green repeat over time during regular (non-transition) periods. If the system is coordinated, the time relationship between consecutive signals in a system also remains constant. Therefore, the platoon arrival patterns can be assumed to be similar cycle after cycle. During transition, however, neither the duration of red and green nor the time relationships between consecutive signals remain constant. Rather, the red/green durations and the time relationships vary from cycle to cycle until the new plan (cycle, offsets, splits, and sequence) becomes effective.

Because of these variation in timing at individual signals and in the time relationship between different signals (i.e., variation in offset), the platoon arrival patterns change from cycle to cycle during transition. In order to estimate delay, therefore, the proposed model constructs the sequence of red and green periods for each movement from the beginning of transition until the new timing plan is attained. Figure 9 illustrates this transition sequence for one-way progressed through movements in a four-signal arterial system. The model constructs similar sequences for all movements. The time relationship between consecutive signals, however, is not important for non-progressed movements.

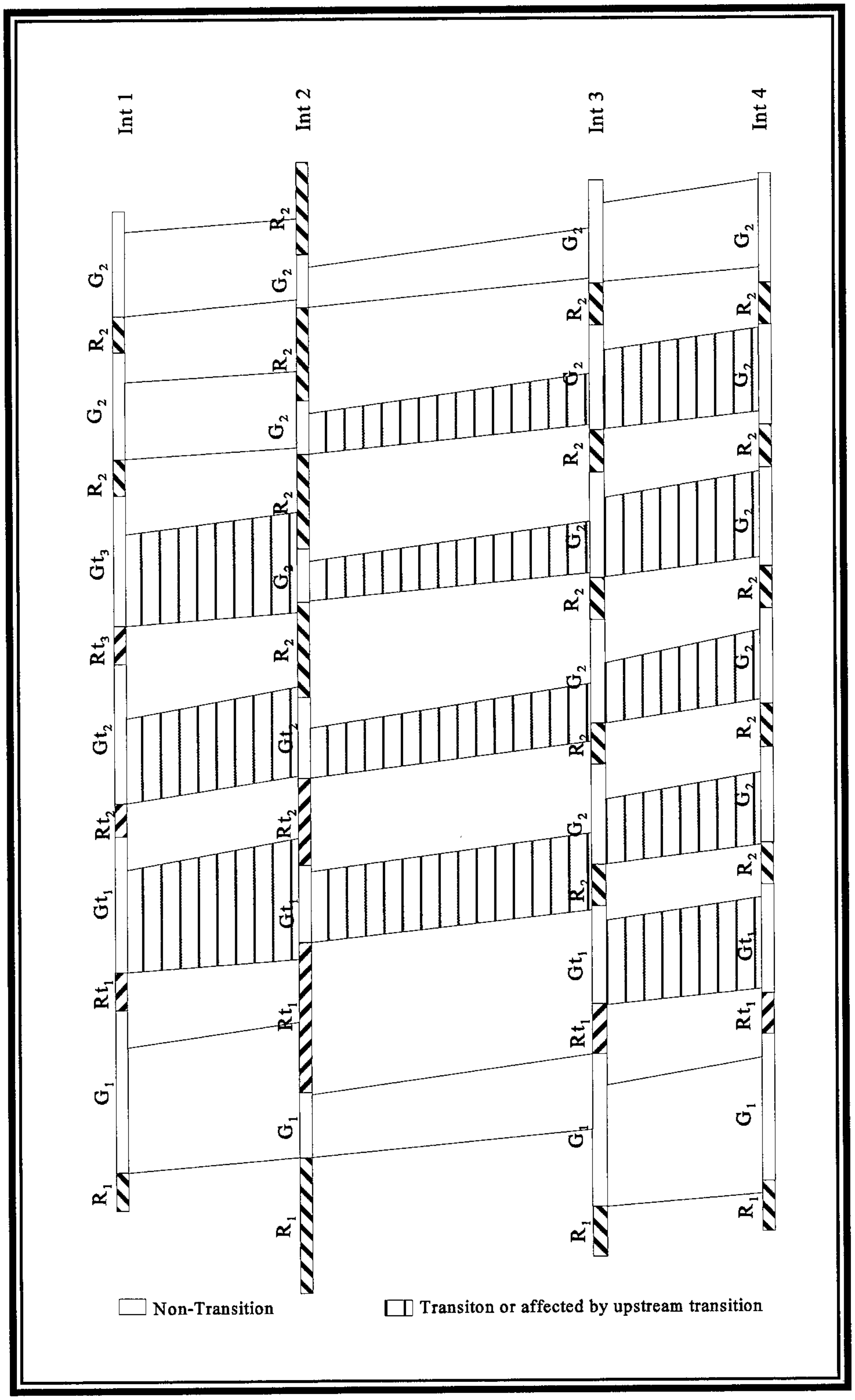


Figure 9: Timing and Arrival Patterns During Transition.

In figure 9, R_1 and G_1 represent the red and green durations in the old plan, and R_2 and G_2 represent the splits for the new plan. All durations in between these times represent transition cycles. The analysis of flow during sequence of red and green (R_2 and G_2) continues after the new timing is attained at intersections 2, 3 and 4. This is due to the fact that the platoons arriving at the intersection during these periods are generated during an upstream transition cycle, even though the new timings have been attained at these signals. Hence, the platoon arrivals during these cycles are not regular patterns. In the proposed methodology, all cycles that are either actual transition cycles or those that receive platoons affected by transition at an upstream signal are transition cycles. For non-progressed movements, the model assumes random arrivals; therefore, it only accounts for traffic delay during actual transition cycles. The sum of all transition cycles equals the transition duration. Different movements experience different durations of transition.

As described above, the model estimates delay the PASSER methodology. Based on the arrival patterns during red, different flow rates for platoon and non-platoon flows are used to compute the total queue, delay during red, and delay during queue dissipation. The only distinction between this methodology and the PASSER implementation is that the early-and-late factors are not used here. Since the time of platoon arrival is taken into consideration to compute delay for each transition cycle, the resulting estimate is the same. Figure 10 shows a delay polygon. The shaded area is the delay during the cycle. It should be noted that since the platoon arrival times and patterns during successive transition cycles vary, the delay also varies during each cycle. The model verification process confirmed that the delay estimated using this procedure is comparable to the delay estimated using the PASSER model for non-transition cycles.

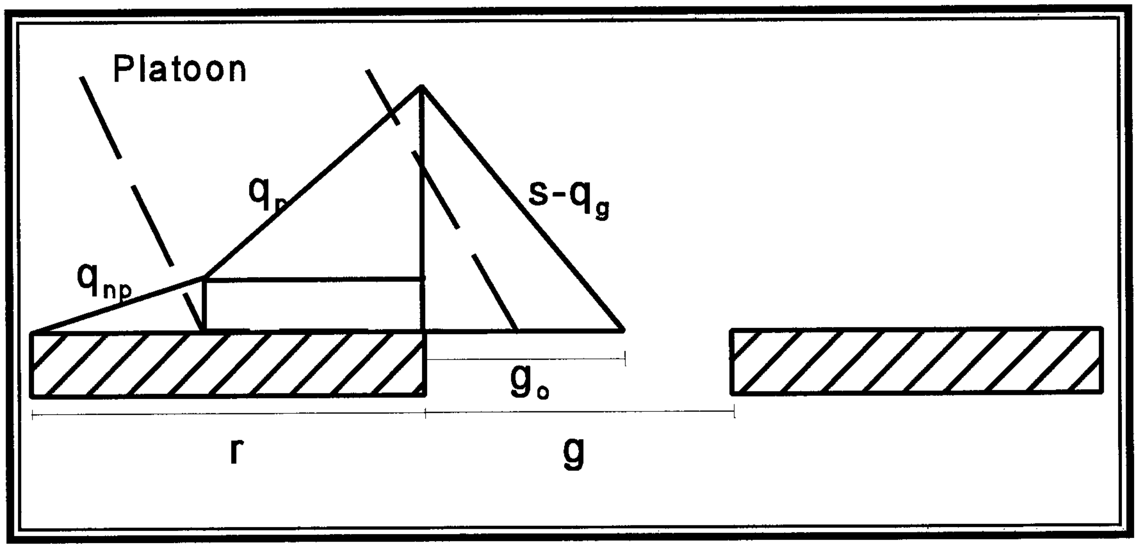


Figure 10: Delay Estimation for Progressed Movement.

As mentioned earlier, the model also uses the same model (figure 9) for calculating delay for non-progressed movements. This is done by constructing the sequence of red and green as for the progressed movements. The delay calculation for these movements, however, assumes a constant arrival rate during the red and the green periods.

MODEL VERIFICATION AND VALIDATION

The methodology for estimating delay during transition in a system of coordinated signals was implemented in a computer program. First, this model was verified against the PASSER delay model for non-transition cycles. This testing/verification was conducted by using the same parameters for the existing and the new timing plans. This analysis showed that for non-transition cycles, the model produces similar delays as the PASSER delay model.

Further validation was conducted using CORSIM simulations. These simulations showed that, in many cases, there were significant differences in the transition delay from the two models. Further investigation revealed the cause of this discrepancy to be oversaturation resulting from signal timing transition. We also discovered cases for which transition results in oversaturation even when the actual traffic demand is undersaturated. Since the PASSER delay model only applies to undersaturated conditions, it responds to a detected oversaturation condition by forcing the volume-to-capacity ratio to a value less than one. Therefore, the proposed model cannot estimate the extent and effects of this oversaturation on delay.

CONCLUSIONS AND RECOMMENDATIONS

One serious detrimental effect of transition is that oversaturation might occur for some phases even when the traffic conditions are undersaturated. Since the PASSER delay model assumes undersaturated conditions, it is not adequate for use in a model for determining the cost of signal timing transition. Thus, we recommend that this delay estimation model be replaced by another delay estimation procedure that can explicitly account for queues. Since none of the existing macroscopic models provide this capability, the research team developed a new model [4]. This development required considerable effort and did not leave sufficient time to allow the incorporation of the new delay model into the signal timing transition algorithm. Based on the validation results for the new model, we strongly recommend that this model replace the PASSER delay model.

In addition to the above modification, the signal timing transition cost determination algorithm should be further enhanced to overcome some of its other limitations in order to realize the full benefits of the transition cost estimation methodology developed in this research. A primary advantage of the methodology presented here is its ability to quickly estimate transition delay for any method of transition. To realize its full potential, more transition methods should be built into the program. Incorporating different transition methods will allow comparative evaluation of different methods of transition for any user specified pair of timing plans and traffic conditions. A future extension could also allow use of different transition methods for various signals in a system.

Another limitation of the current implementation is that only one phase can be designated as a correction phase. In several systems, however, correction during transition is applied to more than one phase. We recommend that the program also be enhanced to permit corrections to more than one phase. This modification is independent of the delay estimation methodology.

CHAPTER IV
PASSER IV ENHANCEMENTS

INTRODUCTION

In this chapter, we describe additional development of PASSER IV not described in other project reports. These developments are based on needs identified in the project and include: additional program optimization capabilities, a proof-of-concept version of PASSER IV that links with Federal Highway Administration's CORSIM [5] package to automate sequential use of two programs, and the development status of the next version of PASSER IV. The following sections describe these developments.

ENHANCEMENTS TO PASSER IV OPTIMIZATION ROUTINE

One of the inherent features of a real-time signal control system is its ability to update timings at short intervals. This implies that during most times of a day, there will be small differences in traffic conditions between two consecutive control periods. As a result, the new timing plan will not be drastically different from the existing one, resulting in small transition times. In addition to the program inputs that can be used to restrict which signal timing parameters are optimized for a specific control period, a new feature has been added. This feature provides the following options:

1. During the optimization process, PASSER IV optionally creates an additional output file. This file contains information about the problem, the optimization process and key characteristics of feasible solutions found.

2. After a file has been created, information contained in the file can be used to determine characteristics of signal timing solutions for the associated network, or it could be used to perform quick optimizations with minor variations in the data.

In the current version, this feature cannot be invoked from the user interface. In order to use this capability, the user must edit the data file using a text editor. The following sections provide further details about this file and how to utilize it.

Saving and Re-using Optimization Status Information

Appendix A provides the detailed formats of records (cards) used to create a PASSER IV data file. In the data file, the user enters a 1 in column 45 of the MPCOD2 card to request the program to create the alternate data file. The program selects a name for this file by adding an *int* as extension to the first part of data file name. For instance, assume that the user executes the program by typing the following command:

passr4 texas.dat bryan.out.

Then, the program will name the alternate output file as *texas.int*. Further, a quick optimization run can be made by changing the value in column 45 of the MPCOD2 card to zero and by entering a 1 in column 35 of the same card. When executed, the program reads the information from the quick optimization file. By default, the program assumes the name of this file to be *data-name.int*. Optionally, the user can specify the name of the quick start file in columns 62 through 73 of the MPCOD2 card.

Given that an appropriated file exists, the quick start option allows the program the skip a major portion of the optimization process by reading the saved information. In order for this option to properly work, the quick start file must match the data file.

Optimization Process Information

Appendix B provides optimization information (contents of file *w509.int*) for sample data named *w509.dat* supplied with PASSER IV. This data defines a five-arterial, nine-intersection network shown in figure 11 .

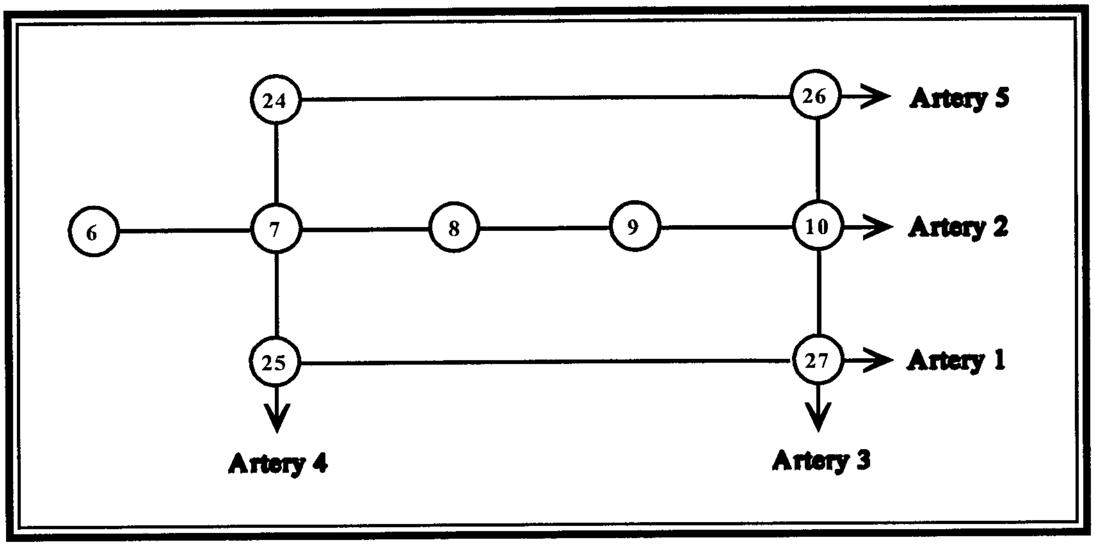


Figure 11: A Sample Network.

In addition, the network configuration is as follows:

- One link on arterial 1,
- Four links on arterial 2,
- Two links on arterial 3,
- Two links on arterial 4,
- One link on arterial 5, and
- Two closed loops.

The above configuration requires the synchronization of offsets around 12 (10 two-way links on arterials, plus two closed loops in the network) closed loops. The program assigns variables named *m* and *n* for the link and network loops, respectively.

We selected the three-step optimization procedure to solve this problem. Note that a meaningful solution to the signal timing optimization problem does not exist until the last step of a multi-step optimization procedure. Now let us examine the contents of the file *w509.int* given in Appendix B. In the appendix, we have identified each section by making its first line bold.

The first section provides the lower and upper bounds for all the link synchronization (*m*) variables. These bounds are calculated in the preprocessor and identify the range of values for each variable. These ranges are calculated using the speed data supplied by the user and the link distances. In general, the bounds are loose if large speed variation is allowed for a link. For instance, the bounds [0, 2] indicate that the sum of offsets around this loop can be 0, 1 or two cycles. A negative value means that the offset can be negative, implying backward progression. When the lower and upper bound is the same, we know the answer before optimization. For instance, from this section, we can tell that for the second to last link in the problem (second link on arterial 4), the sum of offsets is equal to one cycle. In such a case, the program fixes this value and reduces the number of variables by one.

The next section tells the number of optimization steps selected by the user, the number of arterials in the network (one row of *m* variable for each artery), and the number of closed loops in the network. After this, there is a section for each optimization step.

The first line of the next section provides several key pieces of information. These are:

- Step number (1 here),
- Solution number (1, 2, ..),
- The objective function value for this solution,
- Average network efficiency for this solution, and
- The cycle length.

After this, it prints the values of sum-of-offsets for each arterial link. It prints one line per arterial. The optimization process prints the above information for each successive feasible solution it finds. In this solution, it found two solutions. Note that the cycle length is fixed for this problem. In general, various solutions can have different cycle lengths.

The next section is from the second step of the optimization process. In a three step process, the second step picks the values of sum-of-offset from the first step and determines the sum-of-offsets for closed loops (*n*). From the contents of the file we can tell that it found two solutions. In the best solution, for instance, the sum-of-offsets around the two loops is equal to seven cycles.

Using Information From a Previous Solution

As mentioned previously, the saved information from a past solution can be used to obtain quick solutions to a slightly modified case of the problems. When this option is selected, the program read the values of sum-of-offsets from the previous solution and finds the values of remaining variables in the problem. Since the determination of these sum-of-offsets to provide network synchronization is the most time consuming part of the optimization process, using old information saves that effort. In general, this capability can be used for the following reasons:

1. Making runs by modifying data that does not affect optimization results. For instance, changing time space diagram scales or output units. If this option is not used, the program will unnecessarily perform full optimization.

2. Making runs with minor changes in traffic data. This will also minimize signal timings transition time by restricting the amount of changes from one solution to the next.

3. Using several runs to manually create a quick optimization file. By doing this the user can capture characteristics of a network for various traffic demand levels and speeds into one file. Once a custom file is created, it can be used for all traffic conditions. This process is similar to a table lookup process in a traffic responsive system but with the advantage that all signal timings parameters will match to provide a mathematically feasible set of signal timings.

CORSIM VERSION OF PASSER IV

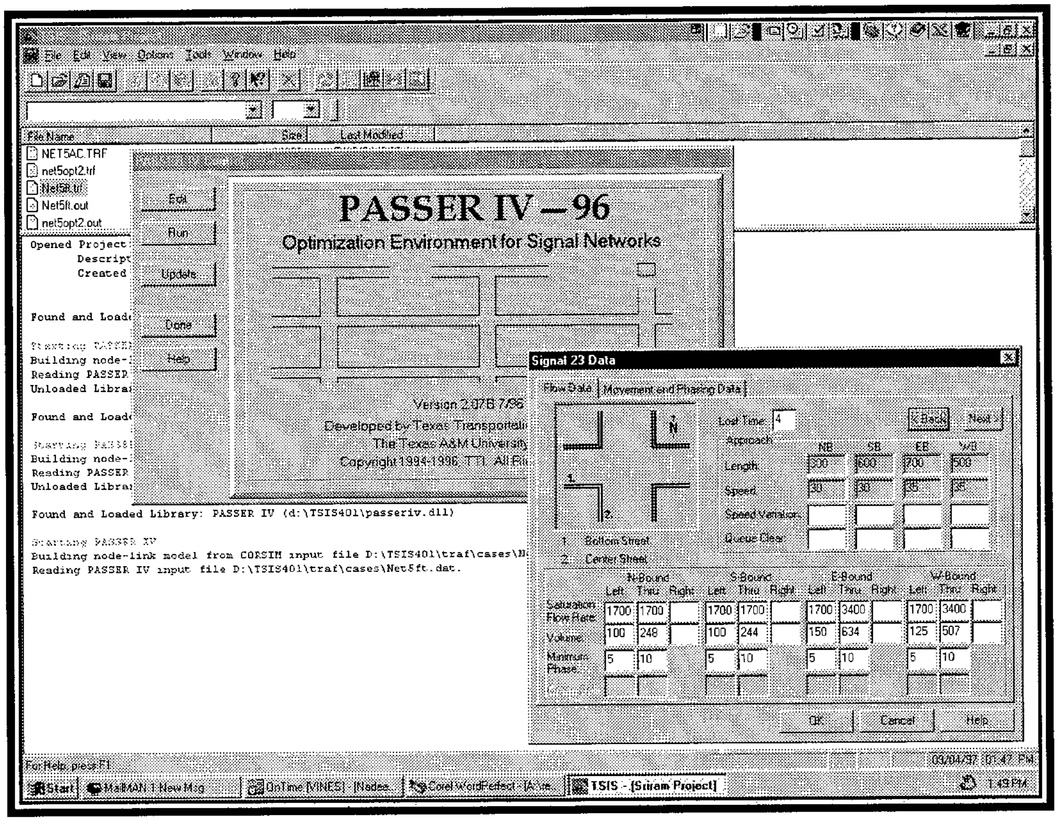
The project identified a need for an automated capability for optimizing and simulating a series of signal timing problems. Based on this need, the research team joined in a cooperative agreement with Kaman Sciences Corporation (Kaman) to develop a CORSIM version of PASSER IV. Working with Kaman, the research team developed a Windows 95-based version of PASSER IV that automatically links with CORSIM This version of PASSER IV, developed to illustrate a proof-of-concept, shares a common database with CORSIM and was demonstrated by FHWA at numerous national conferences. It provides the following features:

- Reads CORSIM data. This saves the user additional effort required to enter the same data again in the PASSER IV format.

- Allows the user to select and optimize a selected section of the full network defined for simulation.

- Updates CORSIM data file by inserting optimal signal timings from PASSER IV. Then, the user can use CORSIM to simulate these timing and compare with the previous case, all using a few key strokes.

Figure 12 illustrates a computer screen showing TSIS running PASSER IV. This version of PASSER IV demonstrated that changing the design of existing and new traffic software can significantly improve the productivity of users. However, this proof-of-concept version has several limitations. Two of them are the most restrictive. These are described below.



```
Opened Project:
       Descript
       Created

Found and Load

Starting PASSE
Building node-l
Reading PASSER
Unloaded Libra

Found and Load

Starting PASSE
Building node-l
Reading PASSER
Unloaded Libra

Found and Loaded Library: PASSER IV (d:\TSIS401\passeriv.dll)

Starting PASSER IV
Building node-link model from CORSIM input file D:\TSIS401\traf\cases\N
Reading PASSER IV input file D:\TSIS401\traf\cases\Net5ft.dat.
```

Lost Time: 4

Approach	NB	SB	EB	WB
Length	300	600	700	500
Speed	30	30	35	35
Speed Variation				
Queue Clear				

	N-Bound			S-Bound			E-Bound			W-Bound		
	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
Saturation Flow Rate	1700	1700		1700	1700		1700	3400		1700	3400	
Volume	100	248		100	244		150	634		125	507	
Minimum Phase	5	10		5	10		5	10		5	10	

Figure 12: CORSIM Version of PASSER IV

1. The current version does not import all CORSIM data needed to completely specify a PASSER IV data set. The reason is that the data requirements for CORSIM and PASSER IV do not have a one-to-one correspondence. Two key problems or limitations are due to the following reasons:

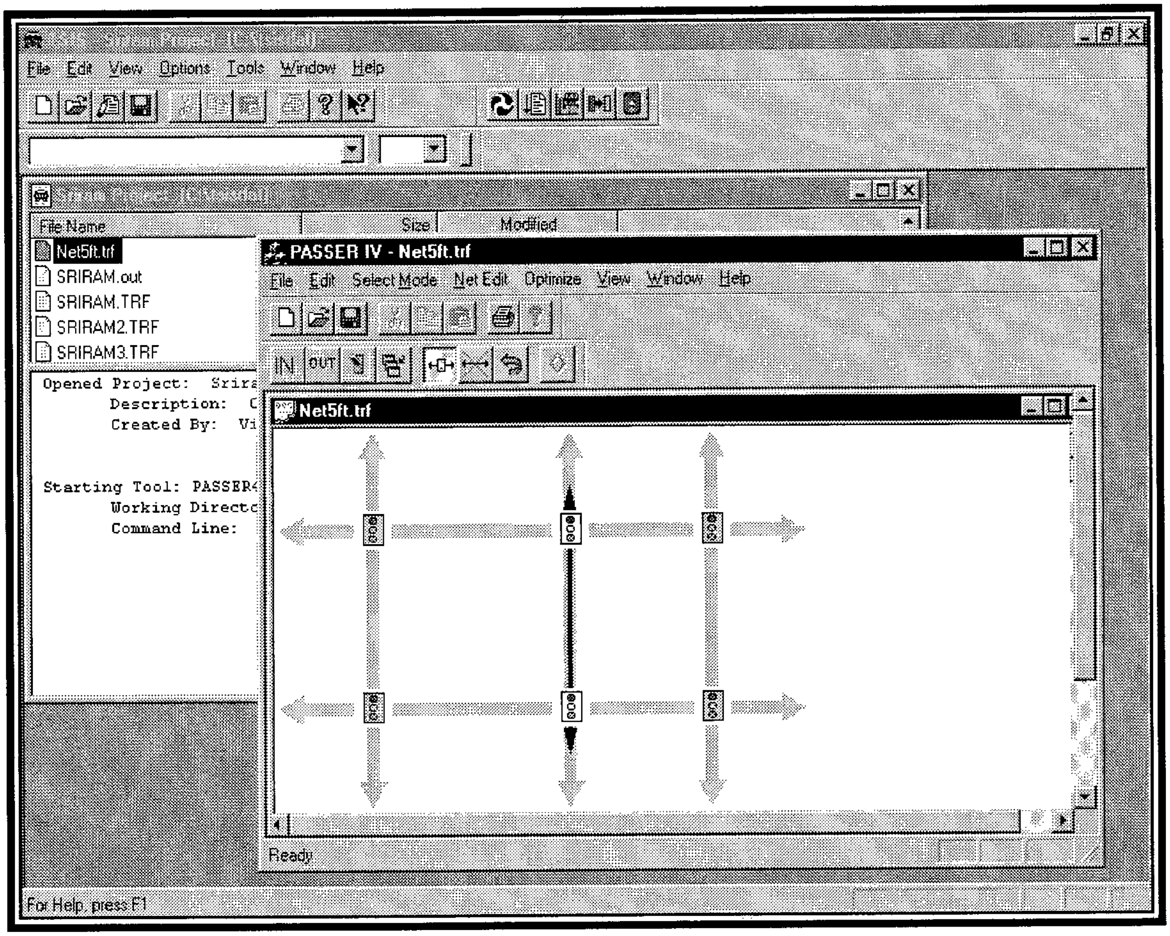
   - CORSIM requires complete geometric details for each approach, whereas, PASSER IV needs saturation flow. This limitation can be removed by adding a detailed saturation flow calculation module in PASSER IV.

   - CORSIM data requires turning volume percentages for all internal approaches, while PASSER IV requires flow rates (volumes). An easy way of removing this limitation is by adding a module in PASSER IV to read volumes from CORSIM output.

2. The absence of a graphical network representation makes it extremely difficult to select the sub-network to be optimized. This limitation can be removed by developing a graphical user interface for PASSER IV.

NEXT GENERATION OF PASSER IV

The demonstration version of PASSER IV described in the previous section provides several benefits. There is a need to further develop this concept into a final product. Based on this need, the research team began development work to achieve this objective. The research team has made significant progress in that direction. Figure 13 illustrates a computer screen showing the next generation of PASSER IV running from within TSIS. This version is planned for completion in the fall of 1998.



```
Opened Project:  Srira
       Description:  C
       Created By:  Vi


Starting Tool: PASSER4
       Working Directo
       Command Line:
```

Figure 13: The Next Generation of PASSER IV.

The new version of PASSER IV currently under development is for Windows 95 and NT operating systems. It can be used as a standalone package, or from within CORSIM's user interface (TSIS). Thus, the objective is to develop a version that replaces the currently released version (Version 2.1) of PASSER IV as well as the demonstration version for CORSIM. It operates in two modes described below.

1. When invoked as a standalone package, the program allows the user to draw the network using a mouse. After the network geometry has been specified, the user enters the remaining data by pointing and clicking the mouse on various entities (i.e., a signal).

2. When invoked from TSIS, the program reads CORSIM data and displays the graph of the network. Using a mouse, the user selects the sub-network for PASSER IV optimization (figure 13). In this mode, the program does not allow addition or deletion to the basic network structure (shown using dim lines in the figure) defined by CORSIM data.

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APPENDIX A
PASSER IV INPUT DATA RECORDS

Data are entered on input data records (also called cards) with unique names. The data cards are identified by their names. Each card name must be typed, using capital letters, starting in the first (left most) column of a line. Some cards are used only once, while other cards are used as needed to fully define the network and traffic data. For detailed information about data fields, please refer to the section that describes the Edit option. The following is a description of each card type.

START Card

This card is used only once at the beginning of the data file and is used to select the output and warning level. If this card is missing, a warning message is printed and the maximum output level is assumed. A detailed description of information on this card follows:

Warning Level (Integer)

Columns 16-20	0	Print warning messages.
	1	Do not print warning messages.

Output Level (Integer)

Column 15	0	Check data, optimize signal timings, and print full report.
	1	Same as 0, but only print solution report.
	2	Check data only, print summary report, do not optimize.
	Blank	Same as 0.

Run Number (Alphanumeric)
Columns 21-25 (optional data)

District Number (Alphanumeric)
Columns 26-30 (optional data)

Date (Integer: Integer: Integer)
Columns: 35-40, Format: mm/dd/yy (optional)

City Name (Alphanumeric)
Columns 41-63 (optional)

MPCODE Card

This card is optional and is used to provide the following data for the MPCODE optimization module:

Maximum Branch and Bound Iterations (Integer)
Columns 11-20

Maximum Branch and Bound Re-inversions (Integer)
Columns 21-25

Maximum Linear Program Iterations (Integer)
Columns 26-30

Maximum Linear Program Re-inversions (Integer)
Columns 31-35

Restart This Problem (Integer)

Column 40	0	Not a restart problem.
	1	Restart this problem using user data and the restart file. The file *restart.out* should be renamed to *restart.dat*. If PASSR4 is being run from the UI, the restart file is automatically renamed.

Print MPCODE Performance Plot (Integer)

Column 45	0	Do not print performance plot.
	1	Print performance plot.

MPCOD2 Card

This optional card is used to select the following data for the MPCODE optimization program:

Optimization Procedure (Integer)

Column 15	1	Simultaneous optimization of all variables.
	2	Two-Step optimization.
	3	Three-Step optimization.

Solutions Saved In Step-1 (Integer)
Column 20; Range 1 to 5.

Solutions Saved In Step-2 (Integer)
Column 25; Range 1 to 5. Only valid for Two-Step and Three-Step methods.

Solutions Saved In Step-3 (Integer)
Column 30; Range 1 to 5. Only valid for Three-Step method.

Quick Start Flag (Integer)

Column 35	1	Read previously saved data and perform quick optimization.
	0	Normal Optimization.

In-depth Search
Column 40 0 No.
1 Yes (For research purposes only).

Print Signal Timing Solution
Column 45: in file datafile.int.

Minimize Cycle Length
Column 50 0 No.
1 Yes.

Objective Function Coefficient of Z (1/C, the inverse of cycle length)
Columns 51-55; Range 0 to 10. (Only used if above flag is equal to 1.)

Quick Start Filename
Columns 62-73, default: path\groupname.int.

TOLRN Card

This card is used to supply tolerances for the MPCODE optimization module. A TOLRN card can be supplied for each step. If no TOLRN card is given, default values of tolerances are used.

Optimization Step
Column 15, number identifies the optimization step for which this information applies.

Tolerances 1 to 7, and Tolf
Columns 16-20; Default value 1.0x10^{-3}.
Columns 21-25; Default value 1.0x10^{-3}.
Columns 26-30; Default value 1.0x10^{-3}.
Columns 31-35; Default value 1.0x10^{-3}.
Columns 36-40; Default value 5.0x10^{-4}.
Columns 41-45; Default value 3.0x10^{-3}.
Columns 46-50; Default value 1.0x10^{-3}.
Columns 51-55; Default value 0.

Note: Format of these fields is xxEy (i.e., 1.5E5 = 0.000015). The last of these tolerances is used to specify the amount by which the next feasible solution must be better than the current best before it is accepted as the current best.

EMISSION Card

This card identifies the beginning of the section for emissions factors data. Emissions factors are provided for: volatile organic compounds (VOC), carbon monoxide (CO), and oxides of nitrogen. This set of cards is optional. The following information is provided on Emissions card:

County Name (Optional)
Columns 11-26

Year (Optional)
Columns 27:30

Name of file containing the table used in this data file. (Optional)
Columns 31-42; A valid DOS file name.

VOC Card

This card is used to provide emissions rates for volatile organic compounds. All data on this card is real with two decimal places.

Columns 11-16; emissions, in grams per hour, for an idling vehicle.
Columns 17-22; emissions, in grams per mile, for a vehicle traveling at 10 mph.
Columns 23-28; emissions, in grams per mile, for a vehicle traveling at 15 mph.
Columns 29-34; emissions, in grams per mile, for a vehicle traveling at 20 mph.
Columns 35-40; emissions, in grams per mile, for a vehicle traveling at 25 mph.
Columns 41-46; emissions, in grams per mile, for a vehicle traveling at 30 mph.
Columns 47-52; emissions, in grams per mile, for a vehicle traveling at 35 mph.
Columns 53-58; emissions, in grams per mile, for a vehicle traveling at 40 mph.
Columns 59-64; emissions, in grams per mile, for a vehicle traveling at 45 mph.
Columns 65-70; emissions, in grams per mile, for a vehicle traveling at 50 mph.
Columns 71-76; emissions, in grams per mile, for a vehicle traveling at 55 mph.

CO Card

This card is used to provide emissions rates for carbon monoxide. The type and format of this data are the same as those on the VOC card.

NOX Card

This card is used to provide emissions rates for oxides of nitrogen. The type and format of this data are the same as those on the VOC card.

NETWORK Card

This card is mandatory and is used to supply the following information:

Number of signals in the network
Columns 19-20. Valid range is 2 to 35.

Number of arteries in the network
Columns 24-25. Valid range is 1 to 20.

Lower cycle length
Columns 33-35. Valid range is 40 to 200 seconds.

Upper cycle length
Columns 37-40. Valid range is 40 to 200, and larger than the lower limit.

Measurement units for data

Column 45	0	English (e.g., distance in feet and speed in miles per hour).
	1	Metric (e.g., distance in meters and speed in kilometers/hour).

Measurement units for output

Column 47	0	English (e.g., distance in feet and speed in miles per hour).
	1	Metric (e.g., distance in meters and speed in kilometers/hour).

Systemwide lost time
Column 50. Range 3, 4, or 5 seconds.

Network name
Columns 62-77 (Optional).

NETWRK2 Card

This optional card is used to provide data for the master signal. The master signal data is used to define the base reference point for printing offsets. The user can provide the following data:

Node identification number (Integer)
Columns 16-20. Default is the first signal on the first arterial entered.

Master Direction (northbound, southbound, eastbound, or westbound)
Column 25. Range: N, S, E, or W. Default: A-direction on the first artery at signal.

Base Offset (Integer)
Columns 28-30. Default value is zero (0). Value modulo cycle length is added to all offsets.

Phase reference point (beginning or ending of phase for referencing offsets)
Column 35. Range: B or E. Default is B (beginning of master approach through phase).

ARTERY Card

This card is mandatory and identifies the beginning of data for an arterial. A SETUP card must be given to identify each arterial in the network. The following information is given on this card:

Number of signals on this artery
Columns 19-20. Range 2 to 20.

Time scale for time-space diagram
Columns 26-30. Default 3 seconds/character.

Distance scale for time-space diagram
Column 31-35. Default 67 feet/line or 20 meters/line, depending on data units.

A-direction for this arterial
Column 56. Range N, S, E, or W (e.g., Northbound, Southbound, etc.).

Artery name
Columns 62-77 (optional).

ART2 Card

This card is mandatory and must follow each SETUP card. The following information is given on this card:

Priority (Weight) of artery compared to other arteries

Columns 13-15	0	Ignore.
	1-100	Uses specified weight.
	101	Calculated using total volumes on artery.

Weight of A-direction of artery

Columns 18-20	0	For more information refer to Edit section.
	1-100	User specified weight.
	101	Calculated using total directional volumes.

Weight of B-direction of artery

Columns 23-25	0	For more information refer to Edit section.
	1-100	User specified weight.
	101	Calculated using total directional volumes.

Average travel speed, common to most links, in A-direction of the artery
Columns 29-30.

Speed variation in A-direction (used to define a range of speed for the entire artery)
Columns 34-35.

Allowed speed changes between adjacent links in A-direction
Columns 39-40.

Average travel speed, common to most links, in B-direction of the artery
Columns 44-45.

Speed variation in B-direction (used to define a range of speed for the entire artery)
Columns 49-50.

Allowed speed changes between adjacent links in B-direction
Columns 54-55.

SIGNAL Card

The card name must be given in columns 1-6. This card is mandatory for each traffic signal on an arterial. The SIGNAL card marks the beginning of data for a signal. The following information is provided on this card:

Node identification number (Integer)
Columns 16-20.

A-direction of current or first artery at this signal
Column 25. Range N, S, E, or W. Must not conflict with the cross street A-Direction. Default value is arterial A-direction read from the ARTERY card. In the previous version, fields 23-25 were used to enter sequence number of this signal on the current artery.

A-direction for cross street
Column 30. Range N, S, E, or W. Must not conflict with the above data.

Direction of NEMA 2 movement flow
Column 35. Range N, S, E, or W.

Lost time at this signal
Column 40. Range 3 to 5 seconds. Default: value given on the NETWORK card.

Special Phasing (Character)

Column 45.
M: Metering of signal.
X: Extra Phase.

Cross artery/street name
Columns 62-77 (optional).

VOLUME Card

The units of this turning movement volume data are vehicles per hour (vph).

Northbound: Left volume; Columns 16-20.
Through volume; Columns 21-25.
Right volume; Columns 26-30.

Southbound: Left volume; Columns 31-35.
Through volume; Columns 36-40.
Right volume; Columns 41-45.

Eastbound: Left volume; Columns 46-50.
Through volume; Columns 51-55.
Right volume; Columns 56-60.

Westbound: Left volume; Columns 61-65.
Through volume; Columns 66-70.
Right volume; Columns 71-75.

SATFLOW Card

The unit of this saturation flow data are vehicles per hour green (vphg).

Northbound: Left saturation flow rate; Columns 16-20.
Through saturation flow rate; Columns 21-25.
Right saturation flow rate; Columns 26-30.

Southbound: Left saturation flow rate; Columns 31-35.
Through saturation flow rate; Columns 36-40.
Right saturation flow rate; Columns 41-45.

Eastbound: Left saturation flow rate; Columns 46-50.
Through saturation flow rate; Columns 51-55.
Right saturation flow rate; Columns 56-60.

Westbound: Left saturation flow rate; Columns 61-65.
Through saturation flow rate; Columns 66-70.
Right saturation flow rate; Columns 71-75.

MINGREEN Card

The use can enter this data as seconds or as fractions of the cycle. If the entered number is larger than 1, it is assumed to be in seconds. As such, the program automatically converts the number to fractions of the cycle by using the lower cycle length value supplied by the user. This data ensures that minimum green times will be provided for the corresponding phase.

Northbound: Left minimum green time; Columns 16-20.
Through minimum green time; Columns 21-25.

Southbound: Left minimum green time; Columns 31-35.
Through minimum green time; Columns 36-40.

Eastbound: Left minimum green time; Columns 46-50.
Through minimum green time; Columns 51-55.

Westbound: Left minimum green time; Columns 61-65.
Through minimum green time; Columns 66-70.

SPLITS Card

The green splits can be entered as seconds or as fractions of the cycle. If the number entered is larger than 1, it is assumed to be in seconds. As such, the program automatically converts the number to fractions of the cycle by using the lower cycle length supplied by the user. The splits may be modified to satisfy any minimum green times supplied. The user can specify splits whose sum is less than the cycle length. If this is the case, the program will assume that the additional time is all red for the approaches. By default, this option models signals metering. In addition, this capability can be used to model double cycling, conditional phasing, or an additional approach by entering an X in column 45 of the SIGNAL card. This forces the program to keep all extra phase time together. As of yet, explicit modeling of these features is not complete.

Northbound: Left green split; Columns 16-20.
Through green split; Columns 21-25.

Southbound: Left green split; Columns 31-35.
Through green split; Columns 36-40.

Eastbound: Left green split; Columns 46-50.
Through green split; Columns 51-55.

Westbound: Left green split; Columns 61-65.
Through green split; Columns 66-70.

SPEED Card

The approach speeds are assumed to be in miles per hour or kilometers per hour, depending on the unit system the user selects. This data overrides artery-wide values.

Northbound: Average Approach Speed; Columns 24-25.
Speed Variation; Columns 29-30.

Southbound: Average Approach Speed; Columns 39-40.
Speed Variation; Columns 44-45.

Eastbound: Average Approach Speed; Columns 54-55.
Speed Variation; Columns 59-60.

Westbound: Average Approach Speed; Columns 69-70.
Speed Variation; Columns 74-75.

LENGTH Card

The approach lengths read from this card are assumed to be in feet or meters, depending on the unit system the user selects.

Northbound: Approach Link length; Columns 21-25.

Southbound: Approach Link Length; Columns 36-40.

Eastbound: Approach Link Length; Columns 51-55.

Westbound: Approach Link Length; Columns 66-70.

QUEUE Card

The values of queue clearance times given on this card can be in seconds or fractions of a cycle. If a number read is larger than 1, it is assumed to be in seconds. As such, it is automatically converted to fractions of a cycle using the lower cycle length supplied by the user. When given, the queue clearance times are used to lag the associated arrival time of progression band by this time at the signal.

Northbound: Link Queue Clearance Time; Columns 21-25.

Southbound: Link Queue Clearance Time; Columns 36-40.

Eastbound: Link Queue Clearance Time; Columns 51-55.

Westbound: Link Queue Clearance Time; Columns 66-70.

LEFTPAT Card

This card is used to select a set of left-turn patterns (signal phase sequences) from which PASSR4 is to choose the best pattern. A value of 1 means that the pattern should be analyzed; a value of 0 means that the pattern is not applicable or should be skipped.

Main Artery: Lead-Lag; Column 15.
Lag-Lead; Column 20.
Lead-Lead; Column 25.
Lag-Lag; Column 30.

Cross Street or Artery: Lead-Lag; Column 35.
Lag-Lead; Column 40.
Lead-Lead; Column 45.
Lag-Lag; Column 50.

Overlap option for main street (Integer)

Column 60	Value	0,1	Phasing with overlap.
		2	Split phasing.
		3	Lead-lead or lag-lag without overlap.

Overlap option for cross street (Integer)

Column 70	Value	0,1	Phasing with overlap.
		2	Split phasing.
		3	Lead-lead or lag-lag without overlap.

APPENDIX B
OPTIMIZATION STATUS AND QUICK START FILE

Contents of file *w509.int*, created by using the sample data set named *w509.dat* supplied with PASSER IV, Version 2.1. The first line of each section is given in bold, In addition, the text in italics signifies that these comments are added manually. Chapter IV provides further explanation.

```
10    [number of rows containing bounds]
          0 2  [lower and upper bound for first link]
          0 1
         -1 1
         -1 1
          0 1
          1 2
          1 2
          1 2
          1 1
          0 2  [lower and upper bound for last link]
3     [solution steps]
5     [rows of  m]
1     [rows of n]
1    1        2.5069380000    33.69    90.00 [pass, solution, objective, efficiency, cycle]
1          1  [number of links on artery, values of sum-of-offsets]
4          0 1 1 0
2          0 0
1          0
1          1
1    2        2.8996910000    38.41    90.00
1          1
4          0 1 1 1
2          0 0
1          0
1          1
2    1        2.2238540000    30.98    90.00      [pass, solution, objective, efficiency, cycle]
2          6 6  [number of closed loops in network, values for sum-of-offsets]
2    2        2.8996920000    38.41    90.00
2          7 7
3    1        2.8854810000    38.19    90.00
```