Handbook of Computer Models for Traffic Operations Analysis

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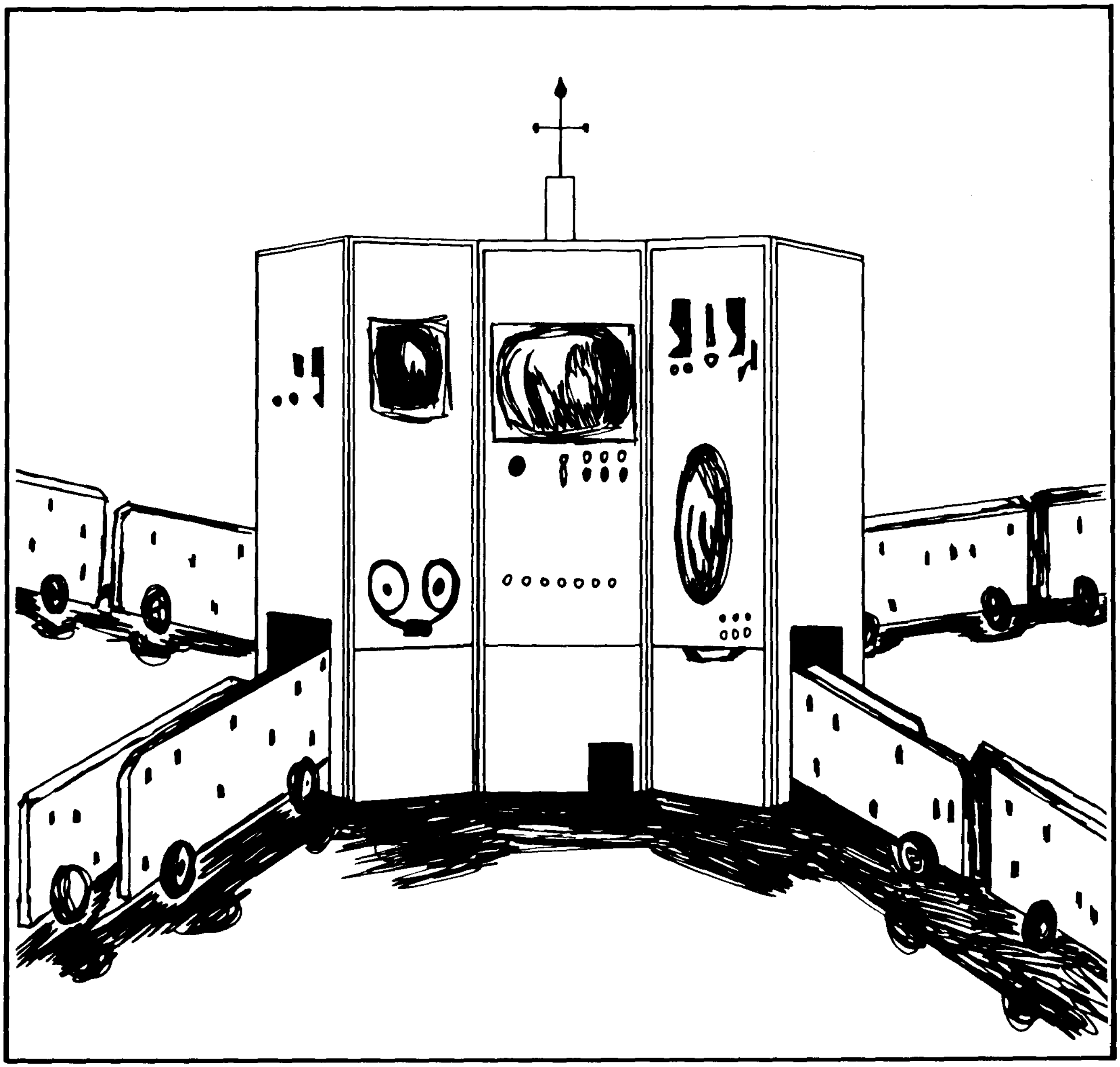

FOREWORD

The use of computer models for analyzing traffic operational problems and evaluating proposed improvements is one of the newest areas of the field of traffic engineering. Consequently, many practicing engineers are not familiar with the concept, use, application and/or the availability of these models. Yet, it is apparent that urban traffic engineers expend a considerable portion of their time in developing and evaluating alternative improvements relative to traffic operational problems, primarily signal systems, and that the use of these models could significantly benefit them.

This Handbook of computer Models for Traffic Operations Analysis has been prepared to inform the practicing traffic engineer of the computer models which are available for developing and evaluating practical, day-to-day, transportation management problems. This Handbook provides sufficient information to permit the reader to understand the practical applications of the more significant models and to select those models which would be most beneficial considering the capability of available personnel and equipment.

To further assist the potential user, a Technical Appendix was prepared which describes over 100 models that have been developed in the past to serve as a guide in selecting other models to assist in unique problems. A tape library has been prepared which includes the ten models described in the Handbook. These models and further information concerning the models discussed in this Handbook can be obtained by writing the Safety and Traffic Implementation Division, FHWA (HRT-20), 6300 Georgetown Pike, Mclean, Virginia 22101 or by contacting Mr. David R.P. Gibson of their staff at (703) 285-2378.

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NOTICE

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Handbook of Computer Models for Traffic Operations Analysis

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CHAPTER 1 - INTRODUCTION

There has been an increasing awareness on the part of the Federal Highway Administration that practicing traffic engineers are not taking advantage of the research and experience gained in the development of computer models to solve many of their transportation management problems. This lack of use is due to many factors, both real and imagined, which practicing traffic engineers associate with the use of computer models.

Many traffic engineers may be reluctant to use computerized tools because of one or more of the following reasons:

1. Unfamiliarity with existing models and their applications,
2. Negative attitude resulting from a belief that computer models will not give practical results,
3. Belief that use of models requires expertise in traffic flow and mathematical theory beyond their knowledge and experience,
4. Difficulty in obtaining the software program and model documentation,
5. Lack of computer hardware to run the models, and/or
6. "Fear" of computers.

PURPOSE OF HANDBOOK

This Handbook has been prepared to inform practicing traffic engineers of available computer models which can be used to solve many transportation management problems. This information is intended to familiarize traffic engineers with the models which have proven to give practical results, that are within their capability to use and are readily available to their organization through the Federal Highway Administration.

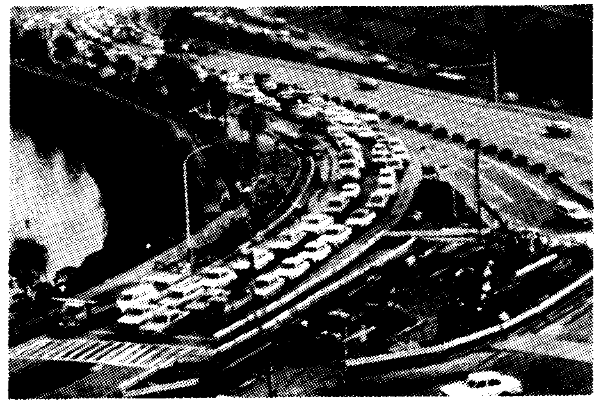

Figure 1. Engineer's Dilemma

The Handbook is intended to familiarize the practicing engineer with computer modeling concepts and considerations in selecting models for their use. The Handbook describes a number of specific models that can assist the engineer in solving a wide range of traffic and transportation management problems. The models described were selected on the basis of past acceptance by practicing traffic engineers; their theoretical validity; practical results; as well as their availability, documentation and maintenance by public agencies. While these models generally represent the current state-of-the-art, there are many other worthwhile models in use or being developed which can serve similar purposes.

BACKGROUND

The use of computer traffic models is one of the newest areas in the field of traffic engineering. In spite of its brief history, there have been significant developments in the use of computer models as analytical tools for evaluating various traffic engineering projects (Ref. 1.1). Unfortunately, most of the published documentation has been limited to theoretical dissertations and/or model validation by research institutions or development of special purpose models used by state and large metropolitan agencies. More recently, articles on the application and use of models to evaluate potential area-wide improvements in a few large metropolitan areas have been published but with little detail on the models used. When reviewed by the practicing engineer it is easy to get the impression that only an army of experts can apply the models to solve problems.

Traditionally there has been a lag between the theoretical development of traffic models and their applications in the field. This lag is due primarily to the need for the "developer" or theorist to look at "why" things happen, while the traffic engineer is concerned more with "what" happens. Thus, a review of literature related to computerized traffic models reveals that the available information is heavily oriented toward basic relationships of traffic flow theory and is written in mathematical terminology which is often confusing to the average reader. Normally, these aspects of model theory and operation are recognized by the traffic engineer as essential to model development, but the practitioner may not readily discern how the model can be applied to help solve a particular problem.

In the past, practicing traffic engineers utilized modeling techniques in one form or another to assist in solving their problems. The early traffic engineer used iconic, or physical, models of a facility to assist in evaluating specific improvements. These were often in the form of scale models, but more frequently were graphic models, such as the time-space diagram. In more recent years, the traffic engineer has used both analog and symbolic models, manually or with a computer, to evaluate effects of implementing improvements. The more widely used models for evaluation are those for capacity analysis, signal timing and traffic assignment.

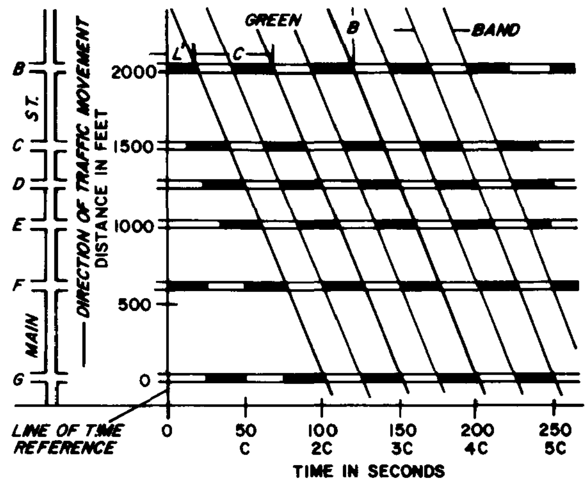

Figure 2. Early Models

Within the last ten years the traffic engineer has found that these traditional techniques cannot provide the insight needed to evaluate the complex problems faced on streets and highways today. No longer can it be said "we need a new highway." Today it is expected, and rightfully so, that all of the techniques available to increase the traffic-carrying capacity of the existing facilities have been exhausted. The potential improvements one must consider range from the traditional solutions of improved signal timing and phasing, interfacing of signals, turn prohibitions, parking prohibitions, exclusive turn lanes, and additional through lanes to more extensive and complex solutions such as a centralized traffic control system, ramp metering, priority lanes and priority treatments for high-occupancy vehicles.

Current techniques used by the practicing traffic engineer can be applied to each of the above control strategies to provide some insight into the advantage of their use. However, increasing traffic demand and its accompanying problems are spreading rapidly throughout most urban areas and are no longer restricted to isolated intersections, arterials and/or the central business districts. Instead the traffic engineer is faced with traffic problems on complex street and freeway networks and does not have the funds for evaluating alternative traffic control policies which could be implemented to solve the problem with traditional techniques. This situation is aggravated by the fact that proposals for local traffic engineering improvements are often subject to funding approval at the state and federal levels. The approval process places the burden on the local traffic engineer to demonstrate that the engineering analyses supporting the proposal are technically sound.

Fortunately, recent developments in traffic computer modeling provide the practicing traffic engineer with the opportunity of evaluating alternative traffic control strategies with much of the same basic information required using traditional methods. In fact, a more comprehensive evaluation of individual improvements and the incremental benefits of more elaborate and expensive solutions may be obtained at little additional cost. In order to use these techniques, the practicing engineer must be familiar with the use and benefits of computer traffic models to a sufficient degree that both the potential benefits, and the confidence in using the techniques for solving day-to-day problems, can be both realized and appreciated. It was with this in mind that the Federal Highway Administration initiated a project to develop the Handbook on Computer Models for Traffic Operations Analysis.

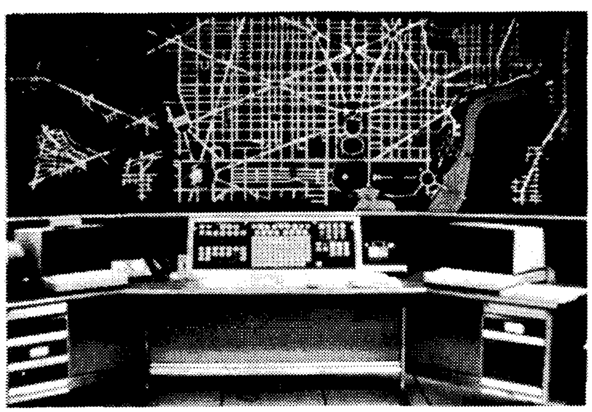

Figure 3. Computer Control System

ORGANIZATION OF HANDBOOK

The next chapter of this Handbook includes a discussion on computer modeling concepts and its use in solving problems. This chapter also describes the various types of computer models based upon modeling techniques and use of a simple example to illustrate the concepts discussed.

The chapter following the one on concepts describes criteria which could be useful in evaluating specific models and the basis for the selection of models included in this Handbook.

A chapter is then devoted to each of the ten (10) models selected for inclusion in the Handbook. Each chapter provided describes model input requirements, internal operational procedures, significant computational algorithms, output reports and other features and considerations in the use of the models. An example application of each model is also included.

The final chapter describes some of the models presently under development and their potential use as well as some general conclusions of model problems and needs that must be addressed in future model development.

REFERENCES

1.1 Gibson, D.R. and Ross, P. "Simulation of Traffic Street Networks" Public Roads, A Journal of Highway Research and Development, September, 1977, Vol. 41, No. 2.

CHAPTER 2 - COMPUTER MODELING CONCEPTS

A model is simply a representation of a real world object or process. Physical models are used to represent objects, structures, etc. Mathematical models are used to represent established relationships which evolve from some process, such as the interaction between speed, flow, and density in a traffic stream. Computer models are, of course, mathematical rather than physical in nature. The use of a mathematical model does not necessarily require a computer; however, models that describe complex relationships or multiple operations are usually easier to incorporate into a computer program than to operate manually.

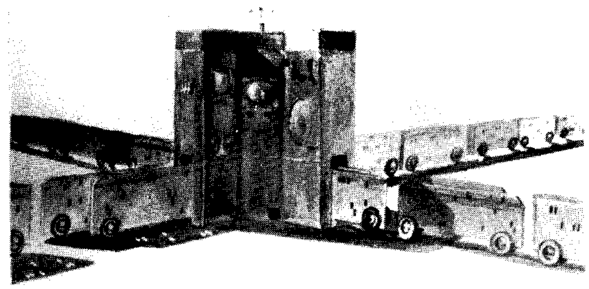

Figure 4. How Does It Work?

APPROACHES TO PROBLEM SOLVING

There are two general approaches to numerical problems in engineering. The first is the experimental, or empirical approach, in which answers to engineering questions are sought by actual measurement, rather than calculation. For example, the traffic carrying capacity of a roadway has been addressed experimentally to determine the effect of such factors as roadway width, parking, etc. The results have been incorporated in the "Highway Capacity Manual" (Ref. 2.1). Many engineering problems can be addressed experimentally. The main advantage of the experimental approach is the credibility resulting from making direct measurements of a specific process under specific conditions. There is no need to rely on assumptions, approximations, or other factors that may reduce confidence in the validity of the solution to a given problem.

The modeling approach, on the other hand, makes use of available information on the process being studied to generate additional information, generally in the form of specific answers to specific questions. The modeling approach, applied to problems of sufficient complexity to warrant the use of a computer program, is the subject of this Handbook.

Compared to the direct measurement approach, computer modeling offers some important benefits in certain areas, especially when applied to complex problems which do not lend themselves to simple experimental solutions.

Specific advantages include:

1. Cost: since it is usually possible to model a complex situation (such as a moon landing) at much lower expense,

2. Safety: since computer specialists are seldom injured in the course of their duties,

3. Speed: since many processes (such as weather patterns) can be simulated at many times their actual speed,

4. Scope: since it is possible using computer modeling to examine hypothetical problems (such as a proposed freeway) or to extend the parameters of a real problem beyond the range of practical experimentation (e.g., future traffic volumes).

5. Controllability: Since it is usually easier to constrain the parameters of a model so that the effects of each parameter may be independently controlled.

All of these advantages are of some interest to the traffic engineer who is concerned with systems that are costly to install, which experience safety problems, and which require data analysis over long time periods, often under hypothetical conditions. These systems also involve complex relationships between variables which defy both analytical methods and field measurements. It is not surprising, therefore, that substantial effort has been put into the development of computer models for use as traffic engineering tools.

There are, however, shortcomings associated with the modeling approach, which have limited its popularity with traffic engineers.

Such specific problems include:

1. Credibility of results: Since the answers obtained through simulation do not evolve from a real world process, but rather through a ficticious approximation of that process.

2. Personnel requirements: Since the use of computerized techniques often assume the need for specialists with a general knowledge of modeling techniques and with detailed knowledge of the process being simulated.

3. Computer requirements: Which often exceed the resources available to the prospective user.

For these reasons, computerized modeling activities have been avoided by many local traffic engineering agencies and have been carried out instead by consultants, universities, and larger governmental agencies. One of the purposes of this Handbook, and the collection of models it represents, is to facilitate the analysis of local traffic operation problems by local practicing traffic engineers.

COMPUTER MODEL APPLICATIONS

Since modeling involves the representation of a real-world process, it naturally follows that its application is predicated on a thorough knowledge of the rules which govern the process. Modeling a process which is not clearly understood to begin with is likely to be a waste of time. This is the first rule which governs when and where to apply computer models.

A second rule suggests that the use of computer models should be subordinate to the use of noncomputerized analytical or experimental techniques. In other words, it should be clearly established that the process does not lend itself to simple analytical methods. It should also be established that, under certain circumstances, modeling is preferable to an experimental approach.

A third rule is also proposed for special cases where decisions may be extremely critical. This would generally apply to large projects where mistakes could be costly in the financial sense, or in terms of the potential for catastrophic system failure. In such cases, simulation techniques may prove to be valuable as a supplement to the more conventional methodology, to give an added degree of confidence to the decision making process.

Some general areas where modeling has been used extensively include:

1. Air and space craft operations, where hypothetical designs and operational situations can be tested in a safer and more economical manner.

2. Power distribution networks where possible modifications to an existing system can be

examined without disturbing the actual operation.

3. Telephone communication systems where different configuration parameters, message control strategies, etc., can be investigated under variable loading conditions.

4. Terminal operation where the handling of passengers and freight can be modeled, to seek more efficient and economical methods.

5. Transportation planning, in which simulated trips can be assigned to a transportation network according to a specified algorithm, to determine the need for, and optimal location of, future transportation facilities.

6. Highway safety, where the characteristics of a highway crash can be simulated using the laws of kinematics and dynamics to predict vehicle paths, extent of damage, etc. For example, the computer generated drawing in Figure 5 shows the simulated paths of two vehicles involved in a sideswipe collision.

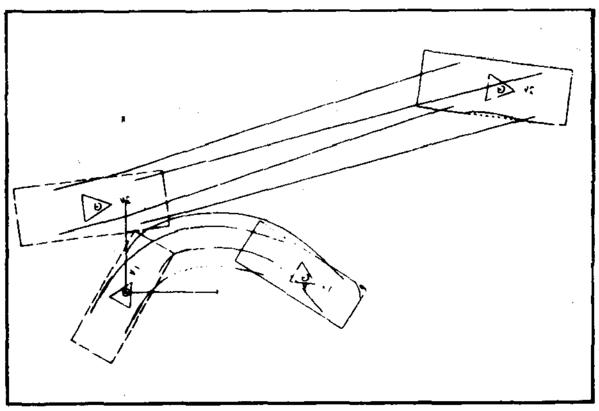

Figure 5. Sample output from the "Smack" program showing a simulated crash between two vehicles.

This Handbook focuses on one particular application of computer modeling; specifically the control of street and highway traffic. This topic is of special interest to the traffic engineer, who holds primary responsibility for the design and operation of traffic control systems. The flow of traffic is a process which is especially well suited to modeling. Past research has produced several well established rules which govern this process, however, many of the rules involve complex relationships which are easily described but are not amenable to simple analytical treatment.

Furthermore, the need to accommodate several independent traffic movements simultaneously complicates the experimental approaches considerably, and strengthens the potential for computer modeling as a problem solving tool.

Computer programs have been developed to deal with several aspects of traffic control. The programs described in this Handbook fall generally into three categories:

1. Intersection operations; including
   - queueing and delay,
   - gap acceptance (stop sign, left turns etc.),
   - signal timing parameters, and
   - effect of geometrics.

2. Street network operations; including
   - optimization of timing,
   - bus priority, and
   - delay and fuel consumption.

3. Freeway corridor operations; including,
   - freeway traffic flow,
   - assignment of demand,
   - ramp merging,
   - effect of geometrics,
   - bus priority,
   - ramp metering, and
   - restricted lanes.

These programs provide an evaluation of a specified physical or operational configuration under chosen operating parameters in terms of certain figures of merit (delay, speeds, fuel consumption, etc.). In some cases, graphical outputs are produced to illus-

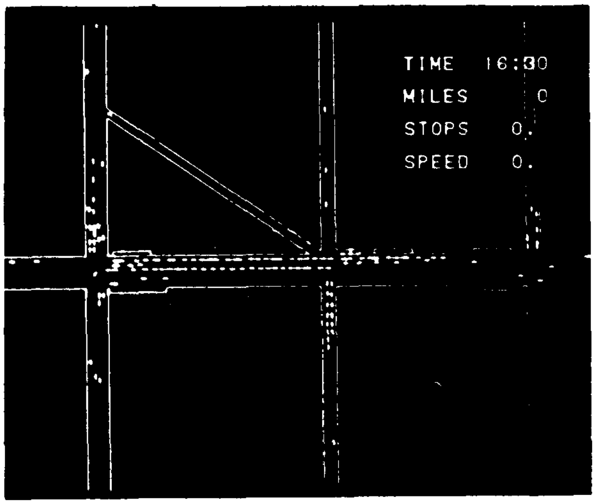

Figure 6. Sample frame from a movie produced by the "NETSIM " program.

trate time variations, or relationships between variables. In other cases, specific design recommendations are derived. In one case (see Figure 6) a motion picture was produced showing the movement of each simulated vehicle in the system as a function of time.

MODEL TYPES

The models represented in this Handbook may be categorized according to several criteria which specify the modeling technique. Most of the computer programs presented in the following chapters make use of several different modeling techniques and can be considered as a family of models incorporated into one package. Some criteria for categorizing models are described as follows:

Computation vs Simulation Models

Computational models involve the application of mathematical equations, to calculate solutions directly. These equations may represent fundamental mathematical truths, they may be derived from basic principles (e.g., trigonometric functions) or they may simply reflect an established relationship between several variables. The case of highway capacity measurement, mentioned previously as an example of the experimental approach to problem solving, also provides an example of a computational model. In this case, the results of the field measurements were incorporated into a model in the form of the "Highway Capacity Manual". While this methodology has been computerized (Ref. 2.1), most capacity calculations are performed manually today.

A simulation model, on the other hand, is a mathematical representation of the sequence of events which comprise a process. In the application of a simulation model the sequence of events is repeated several times to study the outcome. Because of the ability of digital computers to perform repeated calculations at incredible speed, simulation models are usually incorporated into computer programs.

As a simple example, suppose you wanted to determine the probability that out of a group of, say, thirty people, there would be at least two people whose birthdays fell on the same day of the year. You could approach this problem analytically as an exercise in probability. The resulting equations would be more complicated than many people would prefer; however, an answer could be determined without the help of a computer. You could also take an experimental approach by making a frequent nuisance of yourself at public gatherings. With sufficient patience on everyone's part, a solution could be obtained.

Simulation could also be used quite effectively in this problem. Using a computer program, you could assign birthdays randomly to thirty ficticious people (represented by computer memory locations) and then check to see if the same date had been assigned to more than one "person." This process could be repeated a few thousand times in just a few seconds of computer time to produce a believable answer.

The credibility of the answer lies in the fact that the rules of the operation are well established. In this case, it is assumed that the birthdays are indeed randomly distributed. Perhaps they're not. Suppose the group were attending a convention for Capricorns, or maybe a meeting of the Twin's Club. The point is that simulation of a process requires a thorough familiarity with all of the relationships between the variables which effect the process.

Empirical vs Analytical Models

The Highway Capacity Manual is an example of an empirical model. In this case, the basic relationships within the model were arrived at experimentally through extensive field studies. Note that an empirical model is not the same as the "empirical approach" described earlier. The empirical model makes use of results obtained previously using the emperical approach. In some models of both the computational and simulation type, the relationships take the form of analytical equations developed by a purely deductive process.

For example, the number of arrivals during a given period in a traffic stream is frequently assumed to conform to the Poisson distribution. This is an analytical equation in the form,

$$P(x) = \frac{e^{-m} m^{x}}{x!} \qquad (2.1)$$

where $P(x)$ = the probability of x arrivals during a period,
m = the average number of arrivals during the same period.

This relationship is particularly useful in models which must simulate a process in which the number of arrivals fluctuate. For example, consider the operation of a traffic signal in which a different number of vehicles will arrive on each cycle. The Poisson distribution will be used in an example of a simple simulation model discussed at the end of this chapter.

Deterministic vs Stochastic Models

In a deterministic model, the ficticious sequence of events has a completely predictable outcome. For example, a bus passing through a toll plaza may be required to pay a specified fee and to use a specified lane which guarantees precedence over automobile traffic upon entering the facility. The set of rules that govern the passage of a bus through the toll plaza under these circumstances would therefore be described as a deterministic model. Deterministic models, by themselves, do not usually constitute the entire process being simulated, since they offer little potential for problem solving under repeated application. They are therefore more commonly incorporated as sub-models within the overall program structure.

In a stochastic model, the outcome of a given sequence of events is not completely predictable, but depends on something that happens during the course of the process. In the toll plaza example, vehicles may pay a variable fee, depending on their number of axles, and they may be assigned to different lanes depending on whether the driver has the correct change available. They may experience further delay by missing the coin basket or by having to yield right of way to other traffic (buses for example), before entering the facility. The passage of vehicles through a toll plaza under these conditions would therefore be described by a stochastic model, since the outcome of the process depends on a number of events, each of which can be described only in terms of its probability of occurrence.

The credibility of the results generated by the model just described would depend heavily on the assignment of realistic probabilities to the number of axles, and the success with the coin basket. Realistic values would also be required for the delay encountered by yielding right-of-way to other traffic. These delay values could also be either deterministic or stochastic in nature.

The "randomness" inherent in stochastic models is usually derived from a random number generator incorporated into the simulation program. Each time the series of events which make up the process is repeated, the program is asked to supply a new random number. In the toll plaza example, the random number could be used to determine the number of axles on a particular vehicle, whether or not the driver hits the coin basket, etc. The random number, by definition, has an equal probability of falling anywhere between two specified limits (say 1 to 100). For example, if one thousand random numbers between one and one hundred were drawn in sequence, each number should occur approximately ten times, but in no particular order. Thus, if it could be established based on historical information that two thirds of the motorists have the correct change, an individual motorist could be assumed to have the correct change if his assigned random number fell between 1 and 67. Otherwise, he would be assigned by the simulation model to the lane intended for motorists who require change. This concept may be extended to more complex probability functions. More detailed discussions of traffic simulation may be found in References 2.2 and 2.3.

Microscopic vs Macroscopic Models

A process such as the flow of traffic may be simulated either at the microscopic level, in which each vehicle would be treated as a separate unit, or at the macroscopic level, in which the characteristics of the stream as a whole would be examined. The previous example of a single vehicle passing through a toll plaza would be considered as a microscopic model. On the other hand, the operation of the facility served by the toll plaza is more likely to be treated macroscopically, in terms of average speed, flow rate, density etc. In general, microscopic models tend to be more accurate in their description of the process being simulated, but they usually require considerably more input data and computer time for execution. They also tend to be more demanding in terms of the level of detail required in their assumptions and approximations, and this could lead to problems of credibility in the results if they are not properly designed.

Event Scan vs Time Scan Models

A further distinction can be made between models in which the process being analyzed is updated at constant time intervals (e.g., one second) or upon each event which occurs. Time scan models are, in general, easier to develop because the time factor is advanced by a constant increment each time the process is examined. Event scan models, in which the process is updated as each event occurs, are usually more efficient in terms of computer time, since they only update the simulated process in response to a specified event. In the toll plaza example, the position and status of all vehicles could be determined at specified time intervals (time scan), or it could be determined each time a vehicle enters or leaves the plaza (event scan). The choice of techniques is usually based on computer programming considerations.

Optimization vs Evaluation Models

The two main purposes of computer modeling are,

1. Determination of the values of specific design parameters which will optimize the operation (e.g., cycle, splits, sequence and offsets at a traffic signal or a signal network),

2. Evaluation of the operation as a "system" with specified design parameters in terms of measures of effectiveness. (e.g., delay, stops, fuel consumption, etc.)

Simulation models do not, by themselves, have any inherent optimization capabilities. They simply reproduce the process as faithfully as possible and accumulate the results. To obtain an optimal solution using simulation, it is necessary to apply the model repetitively using different design parameters. The set of design parameters that yields the best results should be chosen as the optimal solution. Simulation is therefore best suited to the comparision of a small number of widely differing strategies. Examples of simulation models which do not optimize by themselves are NETSIM (described in Chapter 11), TEXAS (described in Chapter 5), and PRIFRE (described in Chapter 12).

Optimization models seek the best solution automatically. They may or may not provide the required degree of evaluation although they often contain realistic simulation models, such as TRANSYT-7F and SIGOP III (described in Chapters 9 and 10).

The following optimization techniques are commonly used in computer modeling of traffic operations:

Analytical techniques involve an equation, or set of equations, which are solved to yield the answer directly. An example of an analytical optimization is found in Webster's method (Ref. 2.4) for determining the "ideal" cycle length of an isolated signalized intersection according to the equation:

$$C_o = \frac{1.5 L + 5}{1-Y} \qquad (2.2)$$

where C_o = the optimal cycle for minimum delay,

L = the total lost time per cycle due to starting and stopping of traffic movements, and

Y = the proportion of the total green time required to accommodate all of the traffic.

This relationship was originally developed by a combination of analytical, experimental and simulation techniques and is used extensively in modeling of traffic signal operations. It is used, for example, by the Signal Operations Analysis Package (SOAP) described in Chapter 4 of this Handbook. Notice that Webster's optimal cycle length equation does not evaluate the delay. It simply indicates the cycle length at which minimum delay will supposedly be experienced. In fact, however, most simulation models would suggest a different cycle length.

Exhaustive search techniques require that all of the possible outcomes of a process be evaluated to determine the desired outcome. This is also known as the "brute force" technique since it is conceptually simple but requires considerable computer time. An example of an exhaustive search may be found in the pattern selection optimizations of the PASSER II and PASSER III programs discussed in Chapters 6 and 7, respectively. These programs choose the best phasing patterns for each of the signals in a system by examining all of the permissible alternatives and choosing the alternative which provides the best performance.

Hill climbing techniques also involve a search for the optimal value. In this case, however, the search is not exhaustive for the parameter(s) being optimized. A methodical evaluation of successive input values is performed until the general area of the optimal result is located. An intensive search is then conducted in this area until the optimal result is determined to the required degree of precision. The TRANSYT-7F and SIGOP III models described in Chapters 9 and 10 use this technique to optimize several operating parameters for a traffic signal network.

Iterative approximation methods are used in some problems which cannot be solved analytically because the solution contains one of the variables upon which it is based. In this case, a solution is assumed and then calculated using a given value of the variable. Corrections are made and the process is repeated until the assumed and calculated value of the solution fall within an acceptable tolerance. This technique is used in the Signal Operation Analysis Package to determine the cycle length required to accommodate a minimum green time requirement which exceeds the green time required by the traffic volume on a particular approach. Both the hill climbing and iterative approximation techniques can be termed "heuristic" techniques, since the action taken on any given step of the process depends on the results of the previous step.

Mathematical programming techniques such as linear programming, integer programming or dynamic programming are used to optimize, in a formal way, the allocation of resources, such as metering rates on an entrance ramp. In this case, an objective function, such as total volume accommodated by all of the entrance ramps, is maximized subject to constraints such as freeway bottleneck capacities, etc. The FREQ3CP model described in Chapter 13 uses a linear programming model for this purpose.

STEPS IN COMPUTER MODELING

Generally speaking, the solution of an engineering problem by computer modeling will proceed as follows:

1. Identify and describe the problem to be solved.

2. Describe the system or process in terms of,

   o the inputs
   o the outputs
   o the physical configuration, and
   o the rules of operation.

3. Establish the suitability of computer modeling to the investigation of the problem, i.e., could the problem be solved better by experimental techniques or manual analysis.

4. Identify the specific measures of effectiveness by which alternative solutions will be evaluated.

5. Develop the model. If models have already been developed, this step will simply involve the choice of the most appropriate model.

6. Validate the model (if developing a new model) or calibrate the model (if an existing model is chosen) to ensure credibility of results.

7. Apply the model repetitively under the desired range of operating parameters to generate the desired result. This is referred to as "fine tuning" the model.

8. Interpret the results and formulate conclusions and recommendations.

A simple example should be helpful in illustrating the concepts presented in this chapter. Suppose that a left turn movement takes place at a traffic signal on a protected interval (and no other interval). Further, suppose that the signal operates on a 60 second cycle with 13 seconds per cycle of green time allowed to permit four vehicles per cycle to turn left (based on 2.5 seconds per vehicle plus 3 seconds lost time). The turning volume is 180 vehicles per hour, which means that, on the average, only three vehicles per cycle will arrive at the intersection. The actual number of arrivals will vary, naturally, from cycle to cycle, and it can be assumed that the arrival pattern conforms to the Poisson distribution discussed previously.

Let's assume one is interested in answering the following questions:

1. On what proportion of the cycles will all of the arriving left turns be accommodated?

2. What will be the average delay to each left turning vehicle?

3. How many vehicles must a left turn storage bay be able to accommodate to ensure that no overflow takes place on at least 95% of the cycles?

The problem is simple enough to approach by manual analysis or experimentally. It can, however, eliminate the experimental treatment because of the hypothetical nature of the location.

The Simulation Model

In developing a simulation model, one must first decide whether to treat the process microscopically or macroscopically. A microscopic treatment would determine (based on the average headway of 20 seconds) the arrival and departure time of each vehicle, whereas a macroscopic treatment would determine (based on an average arrival rate of three vehicles per 60 second cycle), how many total arrivals took place on a particular cycle. The microscopic approach would naturally be more precise, but the macroscopic approach would be much easier to implement. For this example the macroscopic treatment should be adequate.

The process could then be modeled by the following series of steps:

1. Determine, for the current cycle, how many left turning vehicles arrived, based on a random number applied to a Poisson distribution with a mean arrival rate of three vehicles per cycle.
2. Add these new arrivals to any residual queue from the previous cycle. This will determine, for the current cycle, the storage requirement of the left turn bay.
3. Reduce the queue by four vehicles (the number of left turns accommodated per phase).
4. If no vehicles remain in the queue, treat this cycle as a "satisfied" cycle. Otherwise, keep track of the residual queue to be incremented during the next cycle.
5. Calculate the total vehicular delay for the cycle by multiplying the average number of vehicles in the queue by the cycle length.
6. Proceed to the next cycle and repeat steps 1 thru 5.

The results of a simple computer program developed to simulate this process are presented in Figure 7. In this case the model was applied repetitively for three thousand consecutive cycles, representing 50 hours of real-time operation. The program took approximately one hour to develop and required about three seconds of computer time to exe-

RESULTS OF LEFT TURN TRAFFIC SIMULATION

CYCLE NO.	RANDOM NO.	ARRIVALS	MAXIMUM QUEUE FREQUENCY TABLE 0	1	2	3	4	5	6	7	8	9	10+	SATISFIED CYCLES	DELAY (MINUTES)	TOTAL VEHICLES
1	0.7459	4	0	0	0	0	1	0	0	0	0	0	0	1	2	4
2	0.7315	4	0	0	0	0	2	0	0	0	0	0	0	2	4	8
3	0.8008	4	0	0	0	0	3	0	0	0	0	0	0	3	6	12
4	0.5963	3	0	0	0	1	3	0	0	0	0	0	0	4	7	15
5	0.4957	3	0	0	0	2	3	0	0	0	0	0	0	5	8	18
6	0.9829	7	0	0	0	2	3	0	0	1	0	0	0	5	11	25
7	0.5608	3	0	0	0	2	3	0	1	1	0	0	0	5	15	28
8	0.8939	5	0	0	0	2	3	0	1	2	0	0	0	5	19	33
9	0.4414	3	[illegible]	0	0	2	3	0	2	2	0	0	0	5	23	36
10	[illegible]	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	2	2	0	1	0	5	28	43
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	5	33	43
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5	[illegible]	47
[illegible]	[illegible]	[illegible]	107	343	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8878
2990	0.0970	1	107	343	514	596	502	361	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8879
2991	0.0557	1	107	344	514	596	502	361	228	145	102	51	41	2063	[illegible]	8880
2992	0.8356	5	107	344	514	596	502	362	228	145	102	51	41	2063	5895	8885
2993	0.6374	3	107	344	514	596	503	362	228	145	102	51	41	2064	5897	8888
2994	0.6795	4	107	344	514	596	504	362	228	145	102	51	41	2065	5899	8892
2995	0.4652	3	107	344	514	597	504	362	228	145	102	51	41	2066	5900	8895
2996	0.0505	1	107	345	514	597	504	362	228	145	102	51	41	2067	5900	8896
2997	0.2411	2	107	345	515	597	504	362	228	145	102	51	41	2068	5901	8898
2998	0.3675	2	107	345	516	597	504	362	228	145	102	51	41	2069	5902	8900
2999	0.1601	1	107	346	516	597	504	362	228	145	102	51	41	2070	5902	8901
3000	0.0279	0	108	346	516	597	504	362	228	145	102	51	41	2071	5902	8901

Figure 7. Simulation Model Output showing results of left turn traffic simulation

cute. The following values are summarized in the computer output shown in Figure 7:

1. Cycle No. - Only the first few cycles and the last few cycles of operation are shown in Figure 3.

2. Random No. - The number chosen by the random number generator for determining the number of arrivals on the cycle (in this case numbers between zero and one).

3. Arrivals - The number of arrivals determined by the application of the random number to the Poisson distribution.

4. Maximum Queue Frequency Table (11 Columns) - This table shows the cumulative number of simulated cycles in which the maximum queue reached the indicated number of vehicles (0 thru 10+).

5. Satisfied Cycles - The cumulative number of cycles in which the entire left turn demand (residual queue and new arrivals) was accommodated.

6. Total Vehicles - The cumulative number of left turning vehicles processed by the system. Note that a total of 8901 vehicles were processed during the 3000 cycles. This amounts to an average of 2.967 vehicles per cycle which falls within approximately 1% of the specified nominal arrival rate of three vehicles per cycle.

Returning now to our three specified questions:

1. Proportion of satisfied cycles.
   Figure 7 shows that 2071 of the 3000 total cycles were satisfied, indicating a satisfaction rate of 69%.

2. Average delay.
   Figure 7 shows that the 8901 vehicles processed incurred a total delay of 5902 vehicle-minutes. This amounts to approximately 40 seconds per vehicle.

3. Maximum storage requirements.
   To accommodate the maximum queue on 95% of the cycles, we can tolerate overflow on only 5% of the 3000 cycles, or a total of 150 cycles. Figure 7 indicates that the maximum queue exceeds seven vehicles on 145 cycles. However, a six vehicle queue would be exceeded on 228 cycles, which would violate the maximum failure rate. Therefore, storage for seven vehicles would be needed to satisfy the specified requirements.

An Analytical Solution

Given an average arrival of three vehicles per cycle, and a capacity of four vehicles per cycle, we can determine the probability that four or fewer vehicles will arrive on any cycle to estimate the proportion of cycles which will accommodate all left turns.

Probability of Zero Arrivals $$P(0) = \frac{e^{-3}3^0}{0!} = .050$$

One Arrival $$P(1) = \frac{e^{-3}3^1}{1!} = .149$$

Two Arrivals $$P(2) = \frac{e^{-3}3^2}{2!} = .224$$

Three Arrivals $$P(3) = \frac{e^{-3}3^3}{3!} = .224$$

Four Arrivals $$P(4) = \frac{e^{-3}3^4}{4!} = .168$$

Thus for four or less arrivals $P(\leq 4) = .815$

So, by the analytical solution, the number of arrivals will not exceed the capacity on 81.5% of the cycles. The corresponding value computed by the simulation program was only 69%. Why the difference? The simulation program, by monitoring the process on a cycle by cycle basis, was able to keep track of the residual queue following cycles on which all arrivals were not accommodated. A substantially more complicated analytical model would be required to describe this process as realistically as the simple simulation model.

The average delay can be estimated by Webster's method (Ref. 2.3) by the formula.

$$d = .9 \left[\frac{c(1-\lambda)^2}{2(1-\lambda\chi)} + \frac{\chi^2}{2q(1-\chi)} \right] \qquad (2.3)$$

where C = cycle length = 60 seconds

q = volume = 0.05 vehicles per second

$$\lambda = \frac{\text{green time - lost time}}{\text{cycle}}$$

$$= \frac{13-3}{60} = .167$$

$$\chi = \text{Degree of Saturation} = \frac{q}{\lambda s} \qquad (2.4)$$

where s = saturation = $\frac{1}{2.5}$ =

.4 vehicles per sec.

$$\text{therefore } \chi = \frac{q}{\lambda s} = \frac{.05}{.167 \times .4} = .749$$

from which the calculated delay is 41.68 seconds per vehicle or,

.695	minutes per vehicle
X 8901	vehicles processed
6,186	vehicles-minutes of delay,

This value differs by about 5% from the value of 5,902 vehicle-minutes calculated by the simulation program. This should be considered as a reasonably close agreement. The analytical method, being substantially simpler, would probably be preferable in this case.

The problem of the maximum queue length would be extremely difficult to solve analytically. This would require a stochastic queuing model, the development of which would tax the capabilities of most traffic engineers, therefore, no analytical solution will be proposed for this example.

This chapter has served as an introduction to the concepts and general approaches to computer modeling. The next chapter discusses the selection of computerized models contained in this Handbook.

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CHAPTER 3 - HANDBOOK DEVELOPMENT

Once the practicing traffic engineer decides that the use of a computer model may be the most practical method of developing and evaluating solutions to a traffic management problem one is faced with the decision of what model, or models, to use. Review of available literature would indicate a myriad of models which have been developed or used in the past. Unless one has maintained a reference file, considerable time and effort will be required just to identify available models. Even if a list is available, additional time and effort will be required to obtain model descriptions, and user documentation to evaluate and select appropriate models.

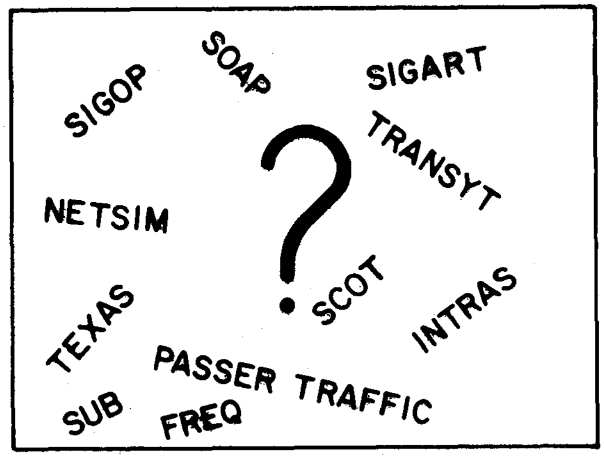


Figure 8. Which Models to Choose?

As part of the development of this Handbook an extensive literature research and review was conducted in order to identify existing models and to prepare a synopsis of each from available documentation. The result of this work (Ref. 3.1) included brief abstracts of over 500 references and a synopsis of over 100 models.

An evaluation was made of the relative capabilities and requirements, as well as the potential merits and shortcomings of the traffic analysis models. Based upon this evaluation ten (10) models were selected for inclusion in this Handbook.

The following portions of this Handbook describe the general criteria utilized to evaluate the models. A brief discussion of typical traffic management problems by location type and a listing of models which were reviewed as possible candidates for use are provided as well as the basis of selecting the models for inclusion in this Handbook.

MODEL EVALUATION CRITERIA

The selection of a model for use in developing and evaluating traffic management problems is a critical first step. All to frequently models are selected because of their availability at the potential user's location or because of the familiarity of the user with a model. As a result models are often used which may not represent the state-of-the-art, resulting in an invalid representation of traffic flow and selection of improvements which later prove costly or ineffective.

The following section suggests criteria which the potential model user should consider in evaluating and selecting models for particular problems.

Adequacy of Model Documentation

The most basic requirement in evaluating and selecting a computer model for use in traffic operations analysis is the adequacy of model documentation. Only with this information can the user determine the characteristics of the model and evaluate its potential use for the problem at hand. These documents should include the following:

<u>User Manual</u> - This document provides information on the functional areas of applications,

general information on its computational methodology, input requirements and coding procedures as well as examples of output data and their interpretation.

Programmer's Manual - This document describes the computer program, computer requirements, implementation procedures, program concepts and structure as well as descriptions of subroutines, error messages and other useful information for the installation and operation of the program.

Model Development Documentation - This document describes the background on development of the model, the theoretical basis of the model, the computational methodology and details on model validation.

With the above information at hand the potential user should be able to determine the availability and usefulness of the model. Review of the literature should clearly demonstrate that the model is fully operational and debugged and that the credibility of the output has been previously established. There should be sufficient information included to permit the assessment of other criteria.

Application to Typical Problems

Most of the models for traffic operations analysis have been developed to address specific geometric configurations and traffic control features. Therefore, potential users must select which model, or group of models, best fit their needs in evaluating their typical traffic management problems. In evaluating the applicability of available models the following should be considered.

Functional Applications - The question here is, "does the model do the right job?" In other words, what areas are covered and what are omitted. This requires that the user have a reasonable idea of the type of analysis that will have to be carried out. Normally this is determined based upon whether one is trying to identify an existing problem, developing alternative solutions and/or evaluating alternatives. The extent and complexity of the problem and the ramifications of the solution will determine the level of detail required for the modeling process.

Configurational Limitations - While a particular model may be functionally applicable, there may be simplifying assumptions or other constraints which limit the geometrics, size of system, control measures, etc. that the model will accommodate. Such restrictions usually simplify the input data coding and reduce the computer memory and time requirements; however, they can also limit the usefulness of the model.

Reasonableness of Results

For a model to be useful to the traffic engineer the output must produce credible results consistent with available data. In other words, the traffic engineer must be confident that decisions based upon the results of the model, when implemented, will obtain similar results in the field. To insure that the model will produce reasonable results, consideration should be given to the following:

Theoretical Validity - The question here is, "How well does the model represent the real world?". Part of this question can be answered by review of the computational methodology employed. Although the practicing engineer may not be able to conduct an in-depth evaluation of the theoretical basis for the model, the computational methodology should be reviewed to determine with some degree of confidence that it represents the state-of-the-art.

Field Validation - To further insure that the model does produce "real world" results it is important that the model developers have conducted field studies that substantiated the reasonableness of the results. Careful attention should be given to conditions under which the model was tested and range of results.

Calibration Requirements - The validity of the results is frequently a function of the amount of calibration required on the model. Models requiring extensive calibration to produce accurate results must be examined critically by the user to assure that the resources are available to obtain the required data, since certain operating parameters may require field studies that are not normally obtained or are difficult to perform.

Sensitivity - Some assumptions and approximations are made by most analysis models which affect the results to varying degrees. A high degree of sensitivity to the assumptions and approximations is clearly undesirable in any model. This is especially important where absolute values of the measures of effectiveness are required. However, it is of lesser importance if the model will be used primarily for relative comparison of alternatives.

Utility of Output

An equally important consideration is the utility of the output obtained. Does the output provide results that are useful in the form they are printed out or does it require considerable interpretation? The purpose of a traffic operations model is to provide the user with decision making information. Computer programs often demonstrate their capability to produce substantially more information than people have time to absorb. Therefore, users should carefully assess the character and extent of the output of a particular model that would be run routinely. In assessing the utility of the output the potential user should consider the following:

Input Listing and Editing - Considerable time and effort can be saved when a listing of input data is automatically produced as the first printout. This listing of input data should include an edit of coded values, as well as some logic edit, with written error messages as necessary. Too often data are coded, the model is executed and the results indicate a normal execution, but upon further assessment of results it is obvious that the input data were coded or punched incorrectly.

Measures of Effectiveness (MOE's) - Many measures of effectiveness can be calculated and demonstrated to be numerically correct. To be useful, however, some relationship must be established between these numerical values and the traffic engineering decisions which the analysis is supposed to support. The ideal measures of effectiveness for evaluating traffic operation performance should be:

- o Understandable (with a minimum of explanation) by the administrator who must make decisions regarding public works programs,
- o Defined in a manner consistent with traffic engineering terminology,
- o Addressed to the problem which the traffic engineer is trying to solve,
- o Convertible to economic terms, and
- o Summable, along with other MOE's, to produce a single "bottom line" figure for evaluation.

The MOE's that are used should also be comprehensive. For traffic operations purposes sufficient measures of effectiveness should be provided for assessment of delay, stops, safety, environmental factors and general comfort. These measures should be self explanatory or guidance in their interpretation should be found in the user's manual.

Optimization Capabilities - Some models are capable of self optimization. Others simply evaluate a given scheme proposed by the user in terms of a set of measures of effectiveness. A third group have no real optimization capability, but will evaluate a wide range of parameters specified by the user and provide a summary of the results for manual interpretation. The degree of self optimization required by the user will depend upon the level of traffic engineering capabilities available to generate the inputs and interpret the outputs. A highly desirable feature when considering models with self-optimization features is the ability to run an "existing" condition as a base for evaluating the optimum solution.

Graphical Output Supplements - Several traffic analysis models produce graphical output supplements (time-space diagrams, etc.) which are useful both in the interpretation of the outputs and in reducing the manual effort often devoted to preparing drawings for recordkeeping purposes. Graphical outputs are provided in a variety of forms, the most common being a line printer representation, using alphanumeric characters and, less frequently, a true plot using peripheral plotting equipment.

Cost Effectiveness

One of the principal concerns to the practicing traffic engineer is the cost effectiveness of using computer models (which naturally includes the choice of models). For agencies that expend considerable manual efforts in evaluating traffic management problems, the selective use of computer models can result in more effective use of human resources at little additional cost. On the other hand, agencies that have not expended much on this type of effort in the past, but now find they need to increase this effort, should consider benefits of a computer model to increase the effectiveness of their personnel with minimal increase in operating costs. In considering the cost effectiveness of traffic operation analysis models consideration should be given to the following:

Data Collection - All traffic engineering analysis procedures, whether manual or automatic, require some form of input data. However, the automated procedures, being more powerful than the manual techniques, frequently have an enormous appetite for data. The user should carefully evaluate the data required by a particular model and seriously consider their ability to provide the required data prior to a decision to use a particular model.

Input Deck Structure - A user-oriented model will have an input data deck structure which is uncomplicated (i.e. easy to learn), flexible, and capable of executing multiple runs with minor input changes between runs. Generally, a user oriented deck structure tends to produce fewer errors, thus decreasing turnaround time. Therefore, the importance of a user oriented structure depends largely on the source of computer support. If, for example, computer services are supplied commercially from a distant city, the consequences of an input data error are far more severe than the case where the computer is located in the user's office.

Personnel Training and Use - The user must carefully examine the level of technical support available for implementing and using a particular model. As the complexity of the model increases the support requirements in terms of both program operation and interpretation increase. Some additional training, or perhaps additional personnel, may be required to effectively operate and use some models.

Computer Requirements and Cost - The user must compare the requirements of the model with the available computer resources. This includes consideration of program language, core requirements and peripheral equipment (i.e., plotting equipment, etc.). If adequate computer facilities are not available "in house" the user should not immediately eliminate or omit a model. Often large scale computer support may be obtained from other government agencies or from commercial suppliers of computer services. An excellent source of computer service for government agencies is often found at universities and colleges. Another possibility, where an agency has adequate software support but minimum hardware facilities, is modification of specific models to adapt them to their own computers. However, careful review of the work required will be necessary to determine if this is cost effective.

External Processing Requirements - If an analysis model is tailored to the user's specific application, no external processing should be required. In many cases, however, the application will differ slightly from the original concept, or a general purpose model will be applied to a specific application. In either situation some pre-processing of the input data may be needed, or manual tabulations of the output data may be required for interpretation. The amount of external processing should therefore be examined from the point of view of the quantity of data and level of judgement required.

Life Expectancy

To obtain, install and become familiar with a particular model can require considerable time and effort. Therefore, it is important to select models that are expected to have a reasonable life expectancy. In selecting models, consideration should be given to the following factors.

Maintenance by Public Agency - A major hedge against obsolescence is the assurance of maintenance of the software by a public agency. This ensures that the most current version of the model, incorporating both corrections to previous versions and refinements of computational logic will be available at all times.

Potential for Improvement - The advancing state-of-the-art, as well as changes in user requirements, suggest that future improvements may be desirable in any model which is implemented. Models which are amenable to change are therefore generally more useful than those which are not. The potential for improvement depends largely on the complexity of the program structure and the level of documentation available.

Potential for Obsolescence - Current research and development programs of the Federal Highway Administration and other agencies are constantly advancing the state-of-the-art in traffic operations analysis. This creates some potential for obsolescence in existing models. This could be an important factor, especially where an extensive user effort would be required to implement a particular model.

SELECTION OF MODELS

In selecting models for inclusion in this handbook consideration was given to selecting illustrative models which would be responsive to the typical problems faced by practicing urban traffic engineers. The problems could vary from intersection signal timing and phasing, to interconnection of signals along an arterial or within a network, as well as lane operation and vehicle usage at an intersection, along arterials and freeways. To meet these varying requirements, it was felt that the models would best be evaluated and selected by grouping them based upon the geometric configuration they were primarily designed to model. These include:

- o Intersections
- o Arterials
- o Arterial Networks
- o Freeways
- o Transportation Corridors

The following sections describe the typical traffic management problems faced by traffic engineers at each of these locations, identify the models considered and the basis for selection of models included within this Handbook.

Figure 9. Intersection Problem

Intersection Models

In the United States today there are over 240,000 signalized intersections with more being installed each day. To the drivers of vehicles, these signalized intersections can either aid them on a trip or become an obstacle that delays their free movement. In the minds of these drivers, how efficient their signals are controlled depends largely on their perception of how well each works to his benefit. Thus, the efficient operation of signalized intersections is a matter of increasing concern to both the motorist and the traffic engineer.

Current traffic signalization design procedures do not permit a truly comprehensive design due to the largely trial-and-error process required. Frequently, the experience of the designer is heavily weighted in the ultimate design, and many factors, such as phasing patterns, hourly volume patterns, etc., are not considered adequately in developing the signal control strategy.

In addition, many solutions to intersection problems require geometric improvements. Traffic engineers can assess benefits to be gained by adding additional thru lanes, separate turn lanes and/or lengthening storage lanes. However, the benefits to be gained from widening existing lanes, improving turning radius, etc., is subject to considerable judgement and open to debate.

Researchers, as well as practicing traffic engineers, over the last two decades have expended considerable effort to develop computer models that provide a more objective and quantifiable methodology for developing and assessing proposed improvements. A review of existing literature resulted in the identification of 26 models which could be used to develop and/or evaluate traffic performance at intersections. Table 1 summarizes the models that were reviewed.

Many of these models are outdated or have limited practical applications. However, two of the models, SOAP and TEXAS, have recently been released, thus they represent the latest state-of-the-art and can be useful to practicing traffic engineers.

SOAP, Signal Operations Analysis Package, was developed by the University of Florida for the Florida Department of Transportation and FHWA and provides the user with a valuable tool for examining and evaluating a wide range of intersection signal design alternatives. SOAP is an optimization model which determines solutions for optimal cycle lengths, splits, phasing patterns and left-turn configurations for three or four-legged intersections.

TEXAS, Traffic EXperimental and Analytical Simulations, was developed by the University of Texas for the Texas Department of Highways and Public Transportation and provides the user with the ability to evaluate existing and proposed intersection designs, both geometric and traffic operations. TEXAS is a simulation model which provides the user with quantifiable effects of changes in roadway geometry, driver and vehicle characteristics, flow conditions, intersection control, lane control and signal timing plans upon traffic operations.

Because these two models are maintained by public agencies and future enhancements are expected without significant changes in input or output format, they were selected for inclusion in the Handbook. Availability of these two models would provide the user with a wide range of evaluation opportunities for individual intersections.

Arterial Models

On most arterial highways serving the urbanized areas of the United States, traffic congestion has severely restricted the flow of traffic to, through, and from major employment centers. New freeway construction has provided some relief, but has had only a slight impact on decreasing congestion in most locations. This method of increased travel capacity is being suppressed in most cities today.

Due to ever increasing right-of-way and environmental problems, construction cost and other difficulties involved in highway construction, the existing arterial streets must continue to serve as the major distributors of traffic for the urbanized areas. Therefore, it is essential that traffic engineers use their knowledge and expertise to obtain maximum capacity and efficiency from these existing streets.

Table 1 - Summary of Intersection Models

Number	Name	Date	Application	Modeling Approach	Program Language	Computer
I-1	TEXAS	1977	Traffic Performance	Mic., Det., TS, Sim.	Fortran IV	CDC 6600 IBM 370
I-2	SOAP	1977	Signal Timing (Cycle, splits & phasing)	Mac., Det., TS, Opt.	Fortran IV	IBM 360/ * 370
I-3	SIGCAP	1977	Signal Intersection Capacity	Mac., Det., TS, Opt.	Fortran	IBM 360/ 370
I-4	SPLIT	1976	Signal Timing (Splits only)	Mac., Det., TS, Opt.	Fortran	IBM 360 CDC 74
I-5	CYCLE	1976	Signal Timing (Cycle only)	Mac., Det., TS, Opt.	Fortran	IBM 360 CDC 74
I-6	HARPST	1975	Pedestrian Effects	Mac., Det., TS, Sim.	GPSS	IBM
I-7	UTCS-IS	1973	Traffic Performance	Mic., Stoc., Sim.	Fortran IV	IBM 360
I-8	BLY	1973	Bus Priority Lanes	Mic., Sim.	Fortran	Unknown
I-9	SIGSET	1973	Signal Timing (Cycle & Splits)	Mac., Det., TS, Opt.	Fortran	IBM 360/ 370
I-10	BRADFORD	1968	Gap Acceptance	Mic., Stoc., TS, Sim.	ALGOL	ICL 1909
I-11	TEC	1968	Traffic Performance	Mic., Det., TS, Sim.	GPSS	IBM 7094 IBM 360
I-12	JONES	1968	Left Turn Storage	Mic., Stoc., TS, Sim.	Fortran	IBM 1130
I-13	DARE	1968	Advisory Speed Signals	Mic., Det., TS, Sim.	GPSS	IBM 360
I-14	WRIGHT	1967	Stop Control Delays	Mic., Stoc., TS, Sim.	ALGOL (Ext.)	Unknown
I-15	BOTTGER	1965	Four Way Stop	Mic., TS, Sim.	Unknown	Unknown
I-16	MILLER	1965	Effect of Turns	Mic., Stoc., Sim.	Unknown	Unknown
I-17	NCHRP	1964	Traffic Performance	Mic., Stoc., TS, Sim.	Fortran II, FAP	IBM 1094
I-18	AUSTRAL-IAN	1964	Capacity and Controls	Mic., Stoc., TS, Sim.	Fortran	IBM 7090
I-19	BLEYL	1964	Traffic Performance	Mic., Stoc., TS, Sim.	Fortran II	IBM 7094
I-20	EVANS	1963	Queueing at Stop Signs	Mic., Stoc., TS, Sim.	Unknown	IBM 7090
I-21	AITKEN	1963	Queueing at "T" Junction	Sim.	Unknown	Ferrenti Sirius
I-22	KELL	1962	Vehicular Delay	Mic., Stoc., TS, Sim.	FAP	IBM 701& 7094
I-23	LEWIS	1962	Traffic Control	Mic., Stoc., TS, Sim.	Fortran II/FAP	IBM 7094
I-24	NPL	1962	Traffic Performance	Mac, Det., Sim.	Unknown	Ferrenti Pegasus
I-25	CHEUNG		Delay	Mac., Det., TS, Sim.	Fortran	ICL 1907
I-26	GOODE	1956	Delay	Mic., Det., TS, Sim.	Unknown	MIOAC IBM 704

Abbreviations: Mic. - Microscopic; Det. - Deterministic; TS - Time Scan; Sim. - Simulation; Mac. - Macroscopic; Stoc. - Stochastic; ES - Event Scan; Opt. - Optimization

*Also available in hand-held calculator and micro computer versions.

Figure 10. Congested Arterials

Traffic engineers have a wide range of improvements that can be considered to increase the traffic-carrying capability of urban arterial streets. Among the first looked at are usually traffic control measures, such as improved signal phasing and timing, coordination of signals, removal of curb parking, etc., due to their lower cost. The next level of improvement can include minor geometric improvements, such as construction of separate turn lanes or pull-out lanes for buses or minor widening of short segments of streets. Systems for coordinating traffic signals along arterial highways to provide continuous movement of traffic have also been a commonly used traffic control strategy for many years.

Over the years, computer programs to determine the "optimal" offset and timing have been developed and used by practicing traffic engineers. More recently, programs have been developed which assist traffic engineers in developing a more nearly optimum signal system for the modern traffic controllers which provide multi-phase and multi-split capabilities. Other models have been developed which evaluate bus operations, intersection operations and vehicle performance along arterials, both urban and rural.

Table 2 summarizes the programs identified as arterial models only. Other models in the succeeding section on network also have applications for a single arterial. Review of these models indicates that several models, particularly the signal optimization models, have widespread usage in the urban traffic engineering field (PASSER II, PASSER III, SIGPROG, SIGART and LITTLE/MORGAN). However, PASSER II & III are the more recent models, represent current state-of-the-art and, most importantly, are maintained by a public agency. Therefore, PASSER II & III were chosen for inclusion in the Handbook.

PASSER II, Progression Analysis and Signal System Evaluation Routine, version two, was developed at Texas A & M University's Texas Transportation Institute for the Texas Highway Department and provides the user with a valuable tool for determining optimal splits, phases and offsets. PASSER III, a specialized version for diamond interchange signalization, may be used for either an isolated interchange or along a frontage road system.

A special purpose model, SUB (Simulation of Urban Buses), has been developed by FHWA and presents an evaluation of the benefits of bus stop locations (nearside, farside or midblock) as well as physical characteristics (protected or unprotected lanes). Because of the increased interest in bus operations within our urban areas this model was also included in the Handbook to provide transit operators with a tool for evaluating bus lane use and bus stop operations. It is expected that the characteristics of the SUB model will eventually be incorporated into TRAF (see Chapter 14).

The Maxband model was not included since it is still under development by MIT under contract to FHWA. When this model has been fully developed and tested within the next few years it should be a valid model for consideration for use since it will be maintained by FHWA.

Table 2 - Summary of Arterial Models

Number	Name	Date	Application	Modeling Approach	Program Language	Computer
A-0	MAXBAND	UD	Signal Progression	Mac., Det., TS, OPT.	Fortran IV	IBM 370
A-1	TWOMIC-2CL	1980	Two-Lane Rural Roads	Mic., Stoc., TS, Sim.	Fortran IV	CDC 6400
A-2	MRI	1980	Traffic Flow in Mts.	Mic., Stoc., TS, Opt.	Fortran IV /Assembly	CDC 6900
A-3	NO STOP 1	1979	Signal Progression	Mac., Det., TS, Opt.	Fortran IV	IBM 360
A-4	PASSER II	1978	Signal Progression	Mac., Det., TS, Opt.	Fortran IV	IBM 360/ 370
A-5	PASSER III	1976	Signal Timing Diamond Ramps	Mac., Det., TS, Opt.	ANSI/ Fortran IV	IBM 360/ 370
A-6	SIMTOL	1976	Grades & Trucks	Mic., Stoc., TS, Sim.	Fortran IV	CDC 6400
A-7	SUB	1973	Urban Bus Operations	Mic., Stoc., ES, (buses), TS (others)	Fortran IV	IBM 360/ 370
A-8	NCSU	1973	Passing Sight Distance Requirement	Mac., Det., TS, Opt.	Fortran IV	Unknown
A-9	YU/VANDYKE	1973	Parking Effects on Capacity	Mic., Det., Sim.	Unknown	Unknown
A-10	VECELLIO	1973	Platoon Dispersion	Mac., Det., Sim.	GPSS	IBM 360/ 165
A-11	TSUMB	1971	Intersection Operations	Mic., Stoc., Sim.	Machine Code	Elliott 920 NB
A-12	MACCLEN-AHAN	1969	Vehicle Lengths	Mic., Det., TS, Sim.	Fortran IV	Unknown
A-13	DELAY/ DIFFERENCE	1969	Signal Progression	Mac., Det., TS, Sim.	Fortran IV	IBM 7094
A-14	SIGPROG	1967	Signal Progression	Mac., Det., TS, Opt.	Fortran	IBM 360
A-15	FIRL	1967	Passing Maneuvers	Mic., Det., TS, Sim.	Fortran IV	IBM 360
A-16	WARNSHIUS	1967	Traffic Flow - Rural Roads	Mic., Det., TS, Sim.	Fortran IV	IBM 7094
A-17	SIGART	1965	Signal Progression	Mac., Det., TS, Opt.	Fortran IV	IBM 360 CDC 74
A-18	NEWARK	1965	Car Following Man.	Mic., Stoc., Sim.	Unknown	Unknown
A-19	LITTLE & MORGAN	1964	Signal Progression	Mac., Det., TS, Opt.	Fortran IV	IBM 7094 & 1620
A-20	YARDENI	1964	Signal Progression	Mac., Det., TS, Opt.	Fortran IV	IBM 7090 & 7040
A-21	FISHER	1964	Lateral Restrictions	Mic., Stoc., TS, Sim.	Unknown	IBM 650
A-22	PRETTY	1964	Traffic Flow Signal-ized Arterial	Sim.	Unknown	Unknown
A-23	ARNOLD/ RESZ	1964	Traffic Flow on Two-Lane Roads	Mic., Det., ES, Sim.	Unknown	Unknown
A-24	MANCHESTER	1963	Traffic Performance	Mac, Stoc., TS, Sim.	Atlas Autocode	Atlas ICT
A-25	RHEE	1963	Traffic Control Pol.	Mac., Det., TS, Sim.	Unknown	Unknown
A-26	NBS	1961	Traffic Flow	Mac., Sim.	Assembly	IBM 704

Abbreviations:
Mic. - Microscopic
Det. - Deterministic
TS - Time Scan
Sim. - Simulation
UD. - Under Development
Mac. - Macroscopic
Stoc. - Stochastic
ES - Event Scan
Opt. - Optimization

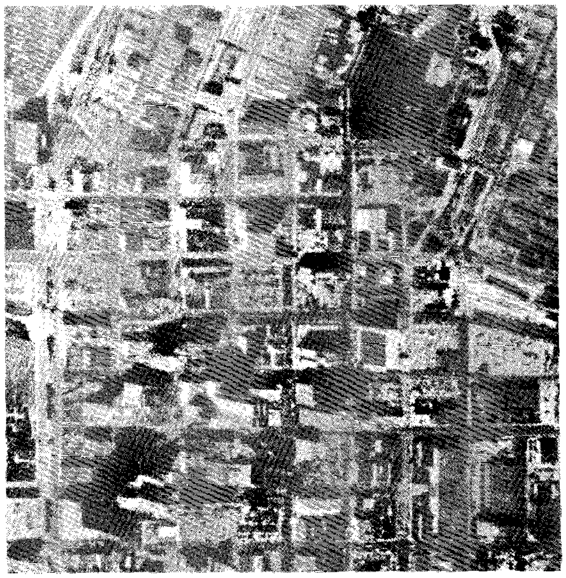


Figure 11. CBD Problems

Arterial Network Models

In most urban areas, streets and highways form an integrated network within the more densely populated areas. This is most noticeable in central business districts where resurgence in reconstruction and consequently travel, within these areas. During the next decade the growth in our urbanized areas is expected to continue to tax our existing highway system, particularly in the CBD.

Unfortunately this modernization of the infrastructure of the downtown areas has frequently not included the physical street system or traffic operations controls. Traffic entering the CBD immediately slows to a crawl due to limited roadway capacity, poorly timed signals, and outmoded operational procedures (on street parking, bus loading and unloading on thru lane, left turning vehicles, etc.).

Such efforts as improved signal timing, arterial signal interconnection, removal of parking, one-way streets or reversible lane operations and other potential improvements must continue to be utilized if maximum use is to be made of our existing arterial network. Other improvements, such as centralized traffic signal systems controlled by computers, provide the opportunity for being more responsive to change in travel demand and increasing the available capacity. These new systems are expensive to implement on a trial and error basis and, therefore, are not looked at as frequently as they should be.

However, recent developments in computer modeling provide the traffic engineer with rather inexpensive methods of developing and evaluating various alternatives in order to select the ones most beneficial to the network as a whole. Most of these models require the same inputs that traffic engineers normally obtain and the models provide an economical method of assessing proposed improvements.

Table 3 summarizes the models that can assist the traffic engineer in analyzing and evaluating alternative network traffic control systems.

One of the most widely used models has been TRANSYT, originally developed in England. This model permits development of optimum signal timing and offsets to minimize travel time (delay) and stops within an interconnected system of signals. Results obtained from the use of TRANSYT have proven to be beneficial after implementation. Recently FHWA enhanced and modified this program as TRANSYT-7F and will maintain this program.

Recently the FHWA has redesigned SIGOP into a new version, SIGOP III, which provides for improved optimization of signal timing with output that permits basic evaluation between alternatives. This model provides for a comprehensive evaluation, including cycle lengths, with measures of effectiveness for both link and the network as a whole. This model will also be maintained by FHWA, and along with TRANSYT-7F, is included in this Handbook. Both represent the latest state-of-the-art and will provide the urban traffic engineer with the opportunity to evaluate the benefits of either model.

Table 3 - Summary of Arterial Network Models

Number	Name	Date	Application	Modeling Approach	Program Language	Computer
N-0	NETFLO	1982	Eval. TSM Strategies	Mac., Stoc, TS, Sim.	Fortran	IBM, CDC, BURROUGH
N-1	TRANSYT-7F	1981	Opt. Signal Timing	Mac., Det., TS, Opt.	Fortran IV	IBM, CDS, BURROUGH, HONEYWELL
N-2	SIGOP III	1980	Opt. Signal Timing	Mac., Det., TS, Opt.	Fortran	CDC 660 IBM 360/370
N-3	TRANSYT-7	1978	Opt. Signal Timing	Mac., Det., TS, Opt.	Fortran IV	ICL 4-70 IBM 360/370
N-4	NETSIM	1977	Evaluate Signal Control Systems	Mic., Stoc, TS, Sim.	Fortran IV	IBM 360/370 CDC 6600
N-5	TRANSYT-6C	1977	Opt. Signal Timing	Mac., Det., TS, Opt.	Fortran	CDC 6600 IBM 360/370
N-6	SIGRID	1977	Opt. Signal Timing	Mac., Det., TS, Opt.	Fortran	CDC 74/172
N-7	TRASOM	1976	Opt. Signal Timing	Mac., Det., TS, Opt.	Fortran IV	Unknown
N-8	BRITISH COMBIN.	1974	Opt. Signal Timing	Mac., Det., TS, Opt.	Fortran IV	IBM 360/50
N-9	MITROP	1974	Opt. Signal Timing	Mac., Det., TS, Opt.	MPSX/MIP	IBM 370/165
N-10	SIGOP I	1974	Opt. Signal Timing	Mac., Det., TS, Opt.	Fortran IV	IBM 370/165
N-11	ERIKSEN	1973	Eval. Bus Movement	Mic., ES, Sim.	Unknown	Unknown
N-12	SIGNET	1972	Eval. Sig. Timing	Mic., Stoc., TS, Opt.	Fortran IV	CDC 6500
N-13	UTS-1	1971	Eval. Traffic Flow	Mis., Stoc., TS, Sim.	Unknown	Unknown
N-14	BIRMING-HAM	1970	Evaluate Signal Timing	Mic., Det., TS, Sim.	Egtran 3	Atlas ICL
N-15	DYNET	1969	Eval. Traffic Flow	Mic., Stoc., TS, Sim.	Fortran	IBM 360
N-16	SAKAI/ NAGAO	1969	Eval. Traffic Flow	Mac., Det., TS, Sim.	Machine Language	Mini-Computer
N-17	SCHALK-WIJK	1968	Eval. Traffic Flow	Mac., Sim.	SimScript	CDC
N-18	LONGLEY	1968	Eval. Traffic Flow	Mic., Det., TS, Sim.	Fortran	Elliott 4100
N-19	MILLER & SCHWARTZ	1966	Eval. Sig. Timing	Mac., Sim.	GPSS	IBM 7094
N-20	VETRAS	1966	Eval. Traffic Flow	Mic., Stoc., TS, Sim.	GPSS	IBM 360
N-21	TRRL	1965	Eval. Sig. Timing	Mac., Stoc., TS, Sim.	Unknown	Ferranti Pegasus
N-22	VTS	1964	Eval. Traffic Flow	Mic., Stoc., TS, Sim.	GPSS/FAP	IBM 7090
N-23	TRANS	1963	Eval. Sig. Timing	Mac., Stoc., TS, Sim.	SAP/FAP	IBM 709
N-24	TRAUTMAN	1954	Eval. Traffic Flow	Mac., Stoc., TS, Sim.	Unknown	SWAC

Abbreviations:
Mic. - Microscopic
Det. - Deterministic
TS - Time Scan
Sim. - Simulation
Mac. - Macroscopic
Stoc. - Stochastic
ES - Event Scan
Opt. - Optimization

Where more sophisticated computer control systems are available for changing signal timings, based upon demand as well as the need to evaluate other operational improvements (removal of parking, dedicated bus lanes, turn prohibits, etc.), the NETSIM simulation model has proven quite useful. This simulation model can be used to evaluate several alternatives which are being considered and provides a basis for a comprehensive analysis and identification of potential problems which could occur that would not show up in other models. This model is maintained by FHWA and is expected to be continually enhanced with little change in basic input coding except for the addition of a interactive input processor for use by engineers having access to CRT's.

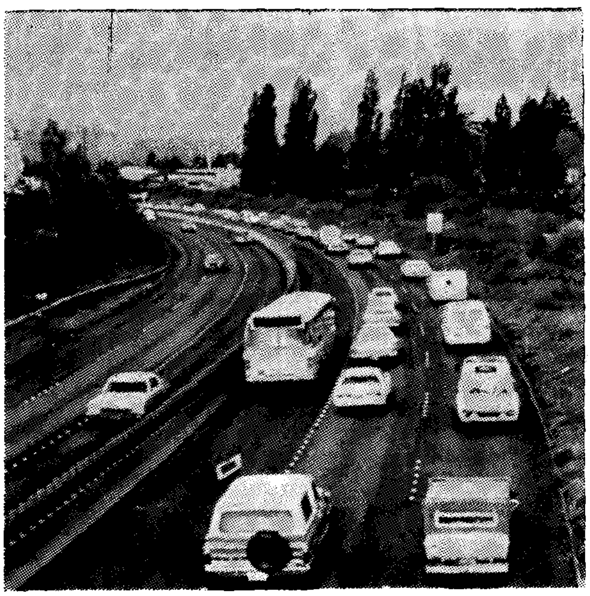


Figure 12. Freeway HOV Lanes.

Freeway Models

In recent years an emphasis has been placed on increasing the capacity, safety and efficiency of our nation's freeways. These limited access highways were built generally during the last two decades to serve existing and future traffic for years to come. However, due to the attractiveness of these facilities, design traffic volumes were often exceeded within several years of their opening.

Today our freeways operate during portions of the day with stop and go traffic and low speeds, much as the parallel arterials they were to replace. This congestion is due to demand in excess of freeway capacity and, frequently, to accident or other incidents affecting traffic conditions.

Since most of the congested freeways are within the urbanized areas, the typical solutions of adding lanes are not feasible, due to right-of-way and construction costs, as well as land use and environment problems. The more economical solutions to these problems have concentrated on encouraging higher vehicle occupancy, controlling the rate of access to the freeway, improving bottlenecks due to weaving or inadequate merging lanes, as well as detection of incidents to permit improved response by traffic control officials.

In the last decade, a number of computer models have been developed to aid the transportation engineer in evaluating alternative traffic control strategies to improve the efficiency of the freeway system. Table 4 summarizes the models that were reviewed.

The most common method of encouraging higher vehicle occupancy has been through the designation of a priority lane reserved exclusively for high-occupancy vehicles (HOV). The model which has been used the most extensively in the past to evaluate the effectiveness of this technique is the PRIFRE model. PRIFRE, a reverse acronym for FREeway PRIority lane model, can be used to evaluate the existing conditions without priority treatment of HOV's and various types of priority treatments.

Another method of improving the level of service of freeways is the use of ramp metering to either control the flow of entering vehicles or provide priority treatment for

Table 4 - Summary of Freeway Models

Number	Name	Date	Application	Modeling Approach	Program Language	Computer
F-0	FREFLO	1979	Evaluate Traffic Flow	Mac., Det., TS, Sim.	Fortran 79	CDC, IBM, BURROUGH, DEC
F-1	FREQ6PL	1978	Evaluate HOV Lanes	Mac., Det., TS, Opt.	ANSI Fortran	CDC/IBM
F-2	FREQ4CP	1976	Develop Optimal Ramp Metering	Mac., Det., TS, Opt.	ANSI Fortran	CDC/IBM
F-3	FREQ3CP	1975	Develop Optimal Ramp Metering	Mac., Det., TS, Opt.	Fortran IV	IBM 360 CDC 6900
F-4	TRAFFIC	1975	Evaluate Incident Detec. Strat.	Mic., Stoc., TS, Sim.	Fortran IV	CDC 6400
F-5	MACK	1974	Eval. Traf. Flow	Mac., Det., TS, Sim.	Fortran	CDC 6400
F-6	PRIFRE	1973	Evaluate HOV Lanes	Mac., Det., TS, Sim.	Fortran IV	CDC 6400 IBM 360
F-7	RAMPCON	1973	Develop Opt. Metering Rates	Mac., Det., TS, Sim.	Fortran	CDC 6400
F-8	SINHA	1973	Evaluate Traffic Flow	Mic., Stoc., TS, Sim.	Fortran IV /Assembly	IBM 360/65
F-9	SDC	1972	Evaluate Traffic Flow	Mic., Stoc., TS, Sim.	Fortran IV	IBM 360/67 UNIVAC 1108
F-10	GEORGIA	1971	Eval. Effects of Trucks	Mic., Stoc., TS, Sim.	Fortran IV /Assembly	IBM 360/ 30 & 50
F-11	CONNECTI-CUT	1970	Evaluate Traffic Flow	Mic., Stoc., TS, Sim.	Fortran IV	UNIVAC 1106
F-12	MIKHALKIN	1970	Eval. Sensor Loc.	Mic., Stoc., TS, Sim.	Fortran IV	IBM 360
F-13	NORTH-WESTERN	1969	Evaluate Lane Changing	Mic., STоc., TS, Sim.	Fortran IV /SPURT	CDC 6400
F-14	TTI - MERGING	1969	Evaluate Ramp Controls	Mic., Stoc., TS, Sim.	Fortran IV	IBM 7094
F-15	MRI	1968	Evaluate Traffic Flow	Mic., Stoc., TS, Sim.	Fortran IV /Assembly	IBM 360/50
F-16	MIESSE	1966	Eval. Ramp Closures	Mic., Stoc., TS, Sim.	Unknown	Unknown
F-17	ARIZONA	1964	Evaluate Ramp Design	Mic., Stoc., TS, Sim.	Fortran & Autocoder	IBM 7072 or 1401
F-18	GERLOUGH	1965	Eval. Traf. Flow	Mic., Stoc., TS, Sim.	Unknown	SWAC

Abbreviations:

Mic. - Microscopic	Mac. - Macroscopic
Det. - Deterministic	Stoc. - Stochastic
TS - Time Scan	ES - Event Scan
Sim. - Simulation	Opt. - Optimization

high occupancy vehicles. The FREQ3CP model has been used frequently to evaluate alternative priority entry control for freeways. The FREQ3CP model can be used to determine the entry control strategy (metering rates and priority cut-off levels) that maximize an objective function such as passenger input or miles of travel.

Although both of these models have been around for a number of years (they are included in the FHWA Transportation Planning "Back Pack" library), they have been included in this Handbook. They have proven to be a valuable tool in evaluating freeway operations.

Both of these models were developed at the Institute of Transportation Studies (ITS) by Dr. Adolph D. May and his associates at the University of California at Berkeley. In recent years Dr. May and his associates have extended FREQ3CP and PRIFRE to include fuel consumption, vehicle emissions and demand response impacts. The more current version of this model, FREQ6PL, undergoing testing as of this writing (as was FREQ6PE) a corridor model discussed in the next section).

It was therefore felt more appropriate to include PRIFRE and FREQ3CP in the Handbook since these models are fully documented and are readily available. For those urban traffic engineers and planners who wish to undertake a more comprehensive evaluation of the effect of ramp metering and freeway HOV lanes it is suggested they contact ITS to determine the availability of their latest programs and documentation.

Transportation Corridor Models

During the last decade, transportation officials concerned with congestion on our freeway systems have looked to solutions which considered the entire system of arterials and freeways serving the transportation corridors. These efforts have been focused not only on increasing freeway capacities and vehicle occupancy but on fuller use of the existing capacity available on parallel facilities, as well as efforts to minimize the travel time and delay for the system as a whole.

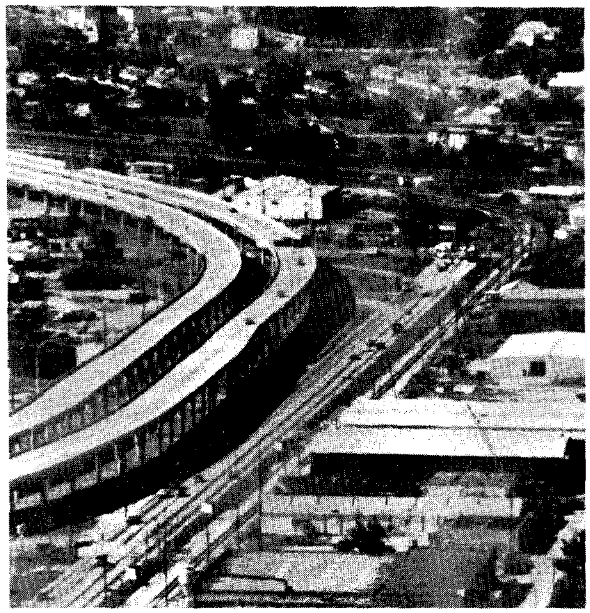


Figure 13. Transportation Corridors

Efforts toward accomplishing this purpose have included preferential treatment for high occupancy vehicles both on the freeway and their entrances to parallel facilities (where additional vehicles would reduce the level of service on the freeway to unacceptable levels) and surveillance of accidents and other incidents in order to implement control strategies for diversion of traffic to alternate routes.

Most of the computer models available for developing and evaluating transportation corridors are recent and are still in the process of development, testing and refinement. Table 5 summarizes those models which were identified and reviewed.

Much active work in model development in this area is being done by the University of California in Berkeley. Existing models (PRIFRE, FREQ, CORQIC and TRANSYT, etc.) were extended and refined to obtain a family of models for use in evaluating TMS-type projects. These five models, FREQ6PL, FREQ6PE, FRESCOT, TRANSYT-6C and SIMTOL provide the capability for investigating demand, supply and control interaction for transportation corridors.

Table 5 - Summary of Transportation Corridor Models

Number	Name	Date	Application	Modeling Approach	Program Language	Computer
T-0	TRAFLO	1982	Evaluate TSM Strategies	Mac., Stoc., TS, Sim.	Fortran 77	CDC/IBM, BURROUGH
T-1	FREQ7	1980	Eval. Ramp Metering, Corridor Analysis & Driver Response	Mac., Det., TS, Opt.	ANSI Fortran	CDC/IBM
T-2	FREQ6PE	1978	Develop Optimal Metering Strategy and Corridor Analysis	Mac., Det., TS, Opt.	ANSI Fortran	CDC/IBM
T-3	FREQ5CP	1977	Eval. Ramp Metering & Corridor Analysis	Mac., Det., TS, Opt.	ANSI Fortran	CDC/IBM
T-4	INTRAS	1977	Eva. Freeway Incidents On Corridor Operations	Mic., Stoc., TS, Sim.	Fortran IV	IBM 370 CDC 7600
T-5	CORQIC	1975	Develop Optimal Controls for Corridor Operations	Mac., Det., TS, Opt.	Fortran IV	CDC 6400
T-6	CORQ	1974	Eva. Traffic Control Strategies within Corridor	Mic., Det., TS, Sim.	Fortran IV	IBM 360
T-7	VPT	1974	Evaluation of Traffic Flow in Freeway Network	Mic., Stoc., TS, Sim.	Fortran IV /COMPASS	CDC 7600
T-8	LIEW	1974	Evaluate Optimal Ramp Control Strategies	Mac., Stoc., TS, Sim.	Unknown	Unknown
T-9	STAR	1974	Evaluate Surveillance and Control Strategies for Route Diversions	Mac., Det., TS, Sim.	Unknown	Unknown
T-10	SCOT	1975	Evaluate Traffic Control Strategies within Corridor	Mic., Stoc., TS, Sim.	Fortran IV	CDC 660 IBM 370 UNIVAC
T-11	FRIOP	1972	Develop Optimal Interchange Configuration	Mac., Det., ES, Opt.	Fortran IV /Assembly	IBM 360
T-12	DAFT	1970	Evaluate Traffic Control Strategies within Corridor	Mac., Stoc., TS, Sim.	Unknown	Unknown
T-13	SDC	1966	Evaluation of Alternative Diamond Inter-Change Configurations	Mac., Stoc., TS, Sim.	Jovial/ Machine	VARIAN 620
T-14	TRANSIM	1966	Evaluation of Traffic Performance in System	Mic./Mac., Stoc./Det. TS, Sim.	Fortran IV	IBM 7090, 7094,1401

Abbreviations:
Mic. - Microscopic Mac. - Macroscopic
Det. - Deterministic Stoc. - Stochastic
TS - Time Scan ES - Event Scan
Sim. - Simulation Opt. - Optimization

Due to limitations of the models that could be included in the Handbook none of these models were included. It is felt comprehensive studies of major transportation corridors are unique and present special circumstances which would require an evaluation of several models to select the most appropriate. It is recommended that users who are interested in studies of this nature contact the University of California to determine availability and applicability of other models.

The FHWA offices of Research and Development are developing a family of traffic simulation models as part of the TRAF Program (Ref. 3.2) which allow the simulation of transportation corridors (See Chapter 14-Future Developments).

METHOD OF PRESENTATION

Each of the ten models which were selected are described in the following chapters. A summary description of the model is provided followed by a discussion on its input requirements, model operation and significant computational algorithms and output reports. Any special features which are available as well as potential applications and limitations are described. This is followed by several example applications of the models and a list of appropriate references.

During the development of the Handbook it was determined that the best method of model evaluation and presentation was to select actual problems faced by urban traffic engineers rather than use problems illustrated in the text of model documentation. By this technique the authors were able to "start from scratch," as would a new user and could evaluate adequacy of model documentation, data collection requirements, coding effort and usefulness of output reports.

In the case of the six models used for intersection, arterial and arterial network the data were obtained from the Central Business District of the City of Tampa, Florida. Within this downtown area is a fairly congested signalized intersection with some unique operational characteristics. This intersection is also part of an arterial serving as a major access to the CBD. This arterial roadway is within an interconnected signal system providing a background cycle for seven actuated signals and one fixed time signal. Presently this arterial is also part of CBD arterial network which includes a system of one-way streets with an additional 50 fixed time signals interconnected and under the same master control as the arterial. The entire downtown system is presently controlled by this master controller with three dial operation.

The other arterial model, PASSER III, is for diamond interchanges. Since no diamond interchanges exist within the CBD an interchange within the adjacent urban area was selected.

For the two freeway models, PRIFRE and FREQ3CP, a section of I-95 in Miami, Florida (Airport expressway to Golden Glades) was used as the example application. This section was previously evaluated by the Florida Department of Transportation and field data was readily available.

As previously indicated, each model is discussed in separate chapters. However, several models have applications at the same type of location. Therefore, to illustrate model applications and to permit comparison between models, the same problem is used frequently in two or more chapters. The first time a problem is used there is a more detailed description of existing conditions. When used in succeeding chapters this detail is omitted and the reader may wish to refer back to the referenced chapters.

AVAILABILITY OF MODELS

The models included within this Handbook provide the urban traffic engineer with a wide range of capabilities to evaluate typical traffic management problems they are faced

Table 6 - Capabilities of Handbook Models

MODEL	LOCATION APPLICATION				
	Intersection	Arterial	Arterial Network	Freeway Lanes	Freeway Ramps
SOAP	OPT				
TEXAS	SIM				
PASSER II	OPT	OPT			
PASSER III		OPT*			
SUB		SIM*			
TRANSYT-7F		OPT	OPT		
SIGOP III		OPT	OPT		
NETSIM	SIM	SIM	SIM		
PRIFRE				SIM	
FREQ3CP					OPT

*Special Application

with today. Table 6 summarizes the capabilities of the models discussed in this Handbook.

Each of the models described in this Handbook has been placed in a Tape Library which is available for purchase at a modest fee. This can be obtained from the Implementation Division of the Federal Highway Administration by completion of the order form on the last page of this Handbook.

The Tape Library includes the computer program for each model and the problems described in this Handbook for use in executing the problem on the user's computer to determine compatibility.

The Technical Appendix that is provided with the tape includes a description of the structure and contents of the tape, instructions for installing and accessing specific programs as well as notes on using and modifying the source code. In addition, a separate chapter is devoted to each model to describe the machine requirements, comments on required Job Control Language (JCL), data coding and input-output requirements. Also there is a discussion on the use of the example problem for executing the programs.

The Tape Library package does not include a User's Manual or Programmer's Manual for each model. These must be obtained from the National Technical Information Service (NTIS). The documents that are available for earlier models are listed in the references at the end of each chapter along with their NTIS number. The documentation that is essential for model application, the User's Manual and frequently a programmer's manual, are indicated by an asterisk.

The Tape Library has been successfully installed and executed on IBM 360/370 equipment and users that have access to this computer system should have no unusual difficulties in using the models. Since all the programs are written in FORTRAN IV, users with other computer systems should be able to install the program on other compatible systems with a minimum of effort (no more than one to two weeks programmer's time).

REFERENCES

3.1 Byrne, A.S., et al., "Handbook of Computer Models for Traffic Operations - Technical Appendix: Summary of Models and References," Technology Sharing Report; FHWA-TS-80, Federal Highway Administration, 1980, 215 pgs.

3.2 "Executive Summary", Integrated Traffic Simulation Model-Phase 1, FHWA-RD-801086.

CHAPTER 4 - SOAP (INTERSECTION OPTIMIZATION MODEL)

In the United States today there are over 240,000 signalized intersections with more being installed each day. To the driver of a vehicle these signalized intersections can either aid them on a trip or become an obstacle which delays their free movement. In the minds of these drivers, how efficient their streets are controlled depends largely on their perception of how well each works to their benefit. Therefore, the efficient operation of signalized intersections is a matter of increasing concern to both the motorist and the traffic engineer.

Current traffic signalization design procedures do not permit a truly comprehensive design due to the largely trial-and-error process which is required. Frequently the experience of the designer is heavily weighted in the ultimate design and many factors, such as phasing patterns, hourly volume patterns, etc., are not considered adequately in developing the signal control strategy.

Clearly, there is a need for a procedure that will allow the traffic signal designer to consider a variety of phasing possibilities and to allow the varying traffic volumes to be considered. In addition, data should be provided to permit the designer to conduct a cost-effectiveness evaluation of alternative traffic control equipment.

With this need in mind, the Florida Department of Transportation and Federal Highway Administration, have recently developed a computer model that provides the user with a valuable tool for examining a wide range of intersection signal design alternatives and selecting the best alternative.

SOAP, which is an acronym for Signal Operations Analysis Package, is a traffic signal controller optimizing tool which enables the user to design the signal timing for any three or four legged intersection. SOAP will determine the optimal cycle length, phasing pattern and left-turn configuration for isolated intersections. The user may preselect

Figure 14. Signalized Intersection

any of the design parameters if he chooses or allow SOAP to determine them by an optimization algorithm. SOAP can analyze present timing as well. Since the model has this dual capability - design and analysis - it can be used as an evaluation tool to compare the relative effectiveness of alternative control strategies.

MODEL DESCRIPTION

The Signal Operations Analysis Package (SOAP) was designed and written by the University of Florida Transportation Research Center (Ref. 4.1-4.5). The program was written in Fortran IV on an IBM 370/165 computer system. The program consists of over eleven thousand card images. Almost one half of these are actual Fortran code with the remaining lines used for program documentation.

This program requires 202 K bytes of computer memory. During the development phase the program has been run using IBM FORTRAN G, H-extended and WATFIV compilers. A version is also available for Burroughs computers. The current program is a stable and reliable version and should be free of errors. The program should be ready to run on most IBM systems with some changes required for other systems.

Execution time will vary considerably depending upon the time periods, type of control and use of progression analysis features. Typically, on the IBM 370/165, an execution time of 2 or 3 seconds may be required. More detailed information of the model program is found in the Programmer's Manual [4.4].

INPUT REQUIREMENTS

The developers of the model have provided a program which can be run with only the normal information gathered by typical traffic engineering agencies. Provisions have been made for the user to modify the default values built into the program to reflect local conditions.

A standardized format for all input data is used to simplify the coding as much as possible and is shown in Figure 15.

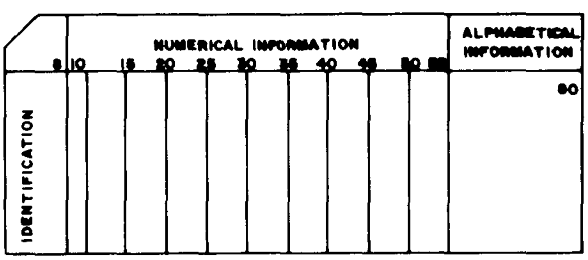


Figure 15. General Card Format

There are three types of inputs which are required. These are:

Type 1 - Instruction cards which tell SOAP what to do,

Type 2 - Parameter cards which tell SOAP how to do it; and

Type 3 - Data cards which supply the input variables for the intersection under study.

Data may be coded and submitted to the computer as a single run or for multiple runs. Figure 16 shows the standard deck stack used for obtaining multiple computer runs.

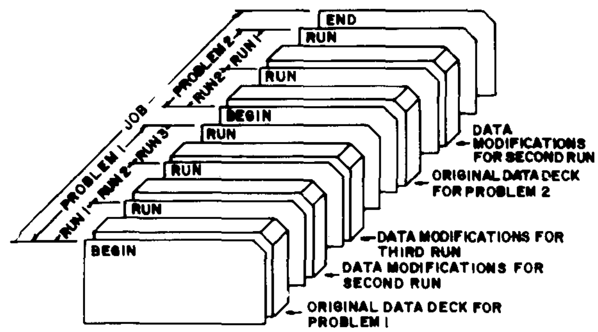


Figure 16. Structure of SOAP Input Data Deck.

SOAP input data may consist of an original data deck for a given intersection with multiple runs for evaluating alternatives. In addition, multiple intersections, or problems, may be included at the user's discretion. Table 7 contains a brief description of each of the input cards and their purpose.

Instruction Cards

It was noted earlier that multiple runs can be accommodated by SOAP. This does not mean that data requirements become overly burdensome. There are three levels of a complete execution:

1. A "job" which is the complete execution;

2. Problems, which are completely separate and independent analyses, but stacked for convenience to avoid multiple job executions; separated by BEGIN cards; and

Table 7 - Input Requirements for SOAP

CARD TYPE	NAME	PURPOSE	DATA REQUIREMENT
Instruction Cards	BEGIN	To begin a new problem	Begin and end time, duration of periods and name of intersection
	RUN	Initiates a run using all data in the input file	Case number and title of this run
	END	To terminate job	None
	COMMENT (optional)	To record user comments	Maximum of 25 characters per card
	TABLE (optional)	To request intermediate output of tables	Table numbers desired
	PLOT (optional)	To obtain printer plots of specified variables	Plot number and number of horizontal and vertical line and spaces between
	COMPARE (optional)	To compare total delay and excess fuel consumption for prior runs	None
	CASE (optional)	To name a case or run	Run (or Case) number and name of this case
	NO WARN (optional)	To suppress printing of warning messages	None
	CHECK (optional)	To have SOAP check all input cards, but not execute	None
Parameter Cards	PATTERN (optional)	To specify signal phasing patterns	Pattern "name" for east-west and north-south direction
	LEFTURN (optional)	To specify protected left turning intervals or number of "sneakers"	Directions for protected turning intervals, number of left turn vehicles released at end of unprotected phases
	CONTROL (optional)	To specify controller operating parameters	Time duration, begin time, dial no. for fixed time control, min. & max. cycle length and all-red period
	LINK (optional)	To examine progression with adjacent intersection	Dial number, average speed, distance, directions, outbound and inbound green split, volume data and degree of saturation at satellite
Data Cards	VOLUME	To input traffic counts	Volume units, duration period, begin time and volume of each movement
	CAPACITY	To input capacity or lanes to calculate	Duration period, begin time, capacities or number of lanes
	HEADWAY (optional)	To input headway data for each approach	Start up time and departure headways for thru and left movements
	EXISTING (optional)	To analyze existing timing (no optimization)	Duration period, begin time, green time for each movement and pattern
	MINGREEN (optional)	To specify minimum phase time for each movement	Minimum phase times for each movement
	TRUCKS (optional)	To adjust volumes to reflect trucks and buses	Duration period, begin time, and % trucks and buses for each movement
	GROWTH (optional)	To input growth factors to update or project old counts	Duration period, begin time, growth factors for each movement
	PCF (optional)	To assign platoon Concentration Factor	Percent of traffic arriving on the red phase for each movement

3. Runs within a problem separated by RUN cards.

The key instruction cards are thus the BEGIN, RUN and END cards. The BEGIN card clears all data arrays and commences a completely new problem. CASE cards may precede a begin card to label conditions (runs) included behind the BEGIN, as may COMMENT cards (which are ignored by SOAP except to echo them in the input report) and the NOWARN card. The CHECK card must precede a BEGIN card to suppress execution.

When a RUN card is encountered, SOAP begins execution and outputs all reports requested prior to the RUN card. It then looks for either another BEGIN card (to start a new problem), a COMPARE CARD (to insure that the previous run is included in the comparison) or an END card to terminate execution. If none of these is encountered (including the card following a COMPARE card) SOAP will begin to accept changes to the current data in preparation for the next run. Thus a typical deck to study, say, four alternatives will have most of the data in the first run, followed by three runs with only minor parameter or data changes.

Parameter Cards

The parameter cards follow a BEGIN card. These four cards (PATTERN, LEFTURN, CONTROL, and LINK) establish the signal patterns, left turn sequence, the controller dial settings, cycle lengths and coordination data. All are optional and SOAP either has default values or will produce the parameters internally. Additionally, the EXISTING data card has parameters similar to the PATTERN card.

With multiple phasing and sequencing, there can be up to eight phases and these may be sequenced in many combinations, or patterns. To understand how to use the PATTERN, LEFTURN and EXISTING cards, it is necessary to know precisely how SOAP interprets several traffic engineering terms, specifically "phase," "pattern," and "sequence."

1. Phase is a unique green display which authorizes only certain movements to occur. Typical phases are shown in Figure 17. For SOAP's purposes the yellows are considered part of the green.

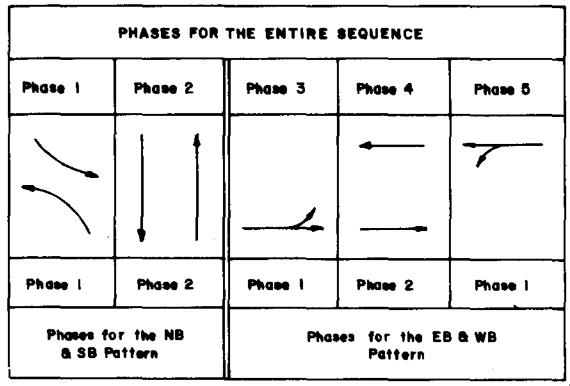


Figure 17. Typical Signal Cycle Showing Phases, Patterns and Sequences

2. Pattern is the combination of phases for the north-south (N-S) and east-west (E-W) directions. For example, in Figure 17, the N-S pattern consists of phases 1 and 2 and the E-W pattern consists of phases 1, 2, and 3, as indicated at the bottom of the figure.

3. Sequence is the complete phasing for the cycle, or phases 1-5 as shown at the top of Figure 17.

To simplify coding of the input cards, a standard terminology for describing phases was developed. The permitted movements are simply named according to their direction, as illustrated in Figure 18. The sequence shown in Figure 17 is thus "LTETW". SOAP does not deal with the entire sequence, however, but in patterns. Thus the N-S "pattern name" is "LT" and the E-W "pattern name" is "ETW". This overcomes the uncertainty about the "T's" since it is now clear which direction is intended. There are a total of eight two-phase patterns and eight three-phase patterns which are permissible, in addition to the "all" patterns, shown at the bottom of Figure 18.

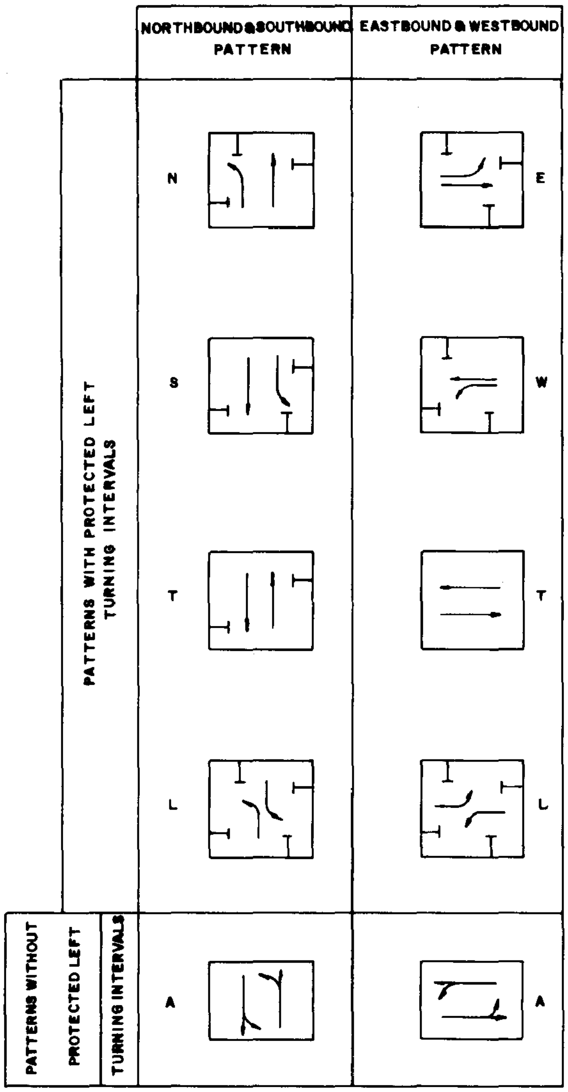


Figure 18. Terminology for Naming Signal Phases By Movement.

Pattern names (used on PATTERN and EXISTING cards) should not be confused with LEFTURN specifications, although they must be consistent.

The LEFTURN card establishes for each left turning movement any protected left turn intervals which are required. It is also possible to specify the minimum number of vehicles on each approach which can be cleared during each cycle.

The CONTROL card establishes the dial number and, time periods, if any, for pretimed operation, the minimum and maximum cycle lengths and the length of any all red period. Up to six dials can be considered. If full-actuation operation is to be evaluated, the dial numbers and time periods are omitted.

Up to four LINK cards can be utilized to examine the effects of progressive movement of traffic through an adjacent signalized intersection. Data which must be coded include vehicle speed, distance, present green time at adjacent intersection, affect and thru volumes. If platoon concentration factors (PCF) are supplied they will override data on the LINK card.

Data Cards

Eight data cards exist, but only two (VOLUME and CAPACITY) are required. The descriptions in Table 7 are self explanatory, but it is important to recall that all data input must always be in the order specified below (see special case of the "standard" data card as illustrated in Figure 19).

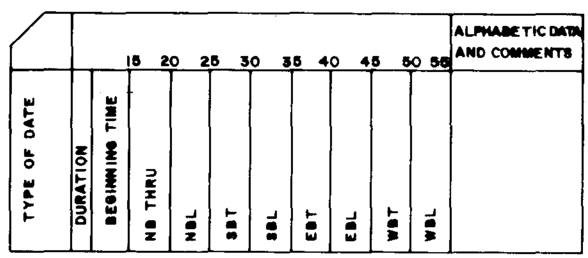


Figure 19. Input Data Card Format As A Special Case of the General Card Format.

The VOLUME Card is necessary to establish the traffic volumes for each of the eight movements. A separate card is necessary for each time interval where a volume change occurs. If data are missing for some intervals, the user has the option to allow the program to estimate the volumes by interpolation of values on each side of the vacant interval(s) or to omit the interval(s).

The CAPACITY Card establishes the (maximum) capacity, or saturation flow per hour of green time, given to each movement. However, the user has the option of coding the number of lanes and the saturation flows will be estimated using the departure headways provided in the HEADWAY Card. The number of lanes should be coded as a decimal number (e.g. 2.1) to permit the user to adjust saturation flows for narrow pavements and other restrictions.

Although the HEADWAY Card is optional, frequent users of SOAP will find it desirable to conduct headway studies for their area. If they are different than the default values of 3.5 seconds for start-up time and 2.2 and 2.5 seconds for thru and left turns departures, respectively, the user will want to adjust these default values and use their values for calculating capacity.

The EXISTING Card is optional but can be used to input existing signal timing. This provides a basis for comparing existing operating characteristics with those expected under optimized conditions. However, this card can only be used for pretimed control.

The MINGREEN Card is also optional but should be used when minimum green times for pedestrian crossing are different than the default values. The default values are 10 seconds for protected left turns and 15 seconds for thru movement for pretimed signals and zero seconds for actuated signals.

The traffic volumes can be adjusted to reflect trucks and buses by use of the TRUCKS Card. The program converts the percent of trucks and buses to equivalent passenger vehicles by multiplying by a factor of 1.6.

The GROWTH Card can be used to update old data or to reflect projected changes in traffic volumes. The user can apply factors to each movement to reflect these changes.

In cases where the signal being examined is part of a coordinated system of intersections, the user can supply this information on the PCF Card as a percent of traffic that arrives on the red phase of each movement. When the "Platoon Concentration Factor" is not supplied, the program assumes random arrivals unless one or more LINK Cards are provided. However, PASSER II or MAXBAND should be used for optimizing (bandwidth) coordination.

OPERATIONAL SUMMARY

SOAP is a complex program in its entirety, however, the more restrictions the user inputs (eg. preselected signal sequences), the fewer the calculations required. The operations and capabilities of SOAP are discussed in this section.

SOAP has three inherent functions:

a) design,

b) analysis, and

c) evaluation.

To accomplish these functions it is necessary to provide inputs mentioned briefly before. To design signal timing it is necessary to configure the intersection and input the appropriate data. SOAP then produces all legitimate phasing patterns. It internally analyzes each pattern and selects the ones which can be executed using the minimum amount of green time. This design is returned to the user.

The next step is dial assignment and timing. A typical controller provides three dials which allow up to three timing patterns to be implemented. SOAP can handle up to six such patterns. The user must decide how many patterns are to be used at a given intersection and assign them to the appropriate dial (control period). If any pattern is unassigned, SOAP will do so, based on the traffic demands. If actuated control is desired, no pattern assignments are made and SOAP makes its computations accordingly.

Cycle length is the most difficult design element to determine. This is a particularly complex problem when several control periods are to be designed. However, SOAP produces these quickly, based on the volumes, capacities and several other parameters. A trial and error optimization procedure is used to find the cycle length which produces the minimum total delay, subject to constraints which govern the amount of queueing which can be tolerated.

Analysis is accomplished by computing the various measures of effectiveness, MOE, which are:

- delay,
- stops,
- excess fuel consumption,
- degree of saturation, and
- left-turn conflicts.

This allows the user to quantify the effects of either the designed control strategy, or if desired, any explicit scheme he wishes to analyze. Evaluation comes in the comparison of several alternative schemes. Comparisons can be produced by SOAP automatically or the user may make them off-line, manually.

COMPUTATIONAL ALGORITHMS

The salient MOE's produced by SOAP were identified above. The computational algorithms to compute these measures are discussed in the following paragraphs.

Delay is calculated using the well accepted Webster's method (Reference 4.6) for unsaturated flow under fixed-timed operations. The Webster model has three components. The delay due to uniform arrivals is expressed as:

$$D_1 = \frac{C(1-\lambda)^2}{2(1-\lambda X)} \qquad (4.1)$$

D_1 = delay due to uniform arrivals (sec/veh),
C = cycle length (sec),
λ = the proportion of green time given to the movement (effective green time/C), and
X = the degree of saturation of the movement (v/c).

The delay due to random arrivals, D_2, is,

$$D_2 = \frac{X^2}{2v(1-X)} \qquad (4.2)$$

where v = volume (veh/sec) and the rest as before.

An adjustment factor, D_3, is,

$$D_3 = -0.65 \frac{C}{v^2}^{1/3[X(2 + 5\lambda)]} \qquad (4.3)$$

which was developed empirically to provide a better mathematical fit to field studies. Webster's delay increases infinitely as the v/c ratio approaches 1.0; therefore Webster's is only practical to use up to v/c = 0.975. For saturations in excess of capacity the following is used:

$$Q_r = T\,(v - \lambda S); \qquad (4.4)$$

where Q_r = no. of vehicles not accommodated during the green
T = time period (sec).
S = Saturation flow (veh/sec) and the rest as before

The queue length at the end of the phase, Q_e, is,

$$Q_e = Q_b + Q_r; \qquad (4.5)$$

where Q_b = queue length at the beginning of the period.

Given these values the total delay, D, is,

$$D = \frac{T}{2}(Q_b + Q_e) \tag{4.6}$$

For the region where saturation is between 0.975 and 1.0 no model existed. Since the region is small, the assumption that delay is constant was used, which was the Webster's delay at v/c = 0.975, or 2 minutes, whichever was less.

For actuated control, no reliable delay model existed and this problem is extremely complex. The approach used in SOAP was to modify Webster's model. The actuated control strategy is assumed to:

a) Distribute the available green time in proportion to the demand on the critical approaches, and

b) To minimize "wasted" time by terminating each green interval as soon as the queue has been served.

This approximation simulates a "well timed" actuated controller. To achieve the results calculated by SOAP, it is therefore necessary to avoid excessively long initial and extension intervals.

The cycle length calculated by SOAP uses the Webster's method also. For fixed time operation the optimal cycle length, C_o, is,

$$C_o = \frac{1.5 + 5}{1 - Y} \tag{4.7}$$

where L = sum of all lost time due to starting and stopping critical movements, and
Y = overall degree of saturation (i.e. the proportion of green time required for the movement of traffic).

For actuated control the "cycle length" is the average cycle length which ensures all excess time is dissipated in the starting and stopping process, or 1 - Y. Therefore, the average cycle length, C_a, is simply 1.1 L/(1-Y). In the low to moderate demand range, C_a will always be lower than C_o and the difference is slack time necessary to provide for the stochastic variation in demand.

As the intersection approaches saturation, actuated control approaches fixed time control, or C_a C_o = C_{max}. The estimate of delay must account for the various sources of delay as expressed in Webster's component models. For reasons too lengthy to discuss here, the cycle length used in the first (e.g. 6.1) and second (e.g. 6.2) terms are as follows:

	First Term	Second Term
Fixed Time	C_o	C_o
Actuated	C_a	C_{max}

The proportion of vehicles required to stop, P_s, is equal to the number of vehicles joining the queue while it is still discharging, all divided by the number of arrivals per cycle, or:

$$P_s = \frac{rs}{C(s-v)} \tag{4.8}$$

where r = length of red (sec.),
s = saturation flow during green (veh/sec) and the rest as before.

Excess fuel consumption is computed from the percentage of stops as follows:

$$E_s = \alpha v P_s, \tag{4.9}$$

where E_s = gallons of fuel consumed due to stops (gal/hr),
α = fuel consumption rate (gal/stop),
v = volume (veh/hr), and
P_s = percent of stops.

The excess fuel consumption due to delay, E_d, is:

$$E_d = \beta\ v\ d/3600, \tag{4.10}$$

where β = fuel consumption rate per veh-hr of idling,
d = average vehicle delay (sec/veh),

and of course total consumption, E, is the sum or E_s and E_d.

The fuel consumption rates, α and β are based on studies by Claffy (Reference 4.7).

The v/c ratio is a reflection of the degree of saturation of the intersection. For an individual approach the degree of saturation, X, is found by:

$$X = \frac{v}{\lambda S} = \frac{v}{s} \qquad (4.11)$$

as previously defined.

Left-turn conflicts occur when left turns are permissive, or not exclusively protected. The measure of effectiveness is the number of left turns which cannot be accommodated safely. Since protected left turns have no conflicts, none are computed. When the turning vehicles may cross traffic there must be sufficient gaps in the oncoming traffic. An effective left-turning saturation flow based on Tanner's model (Reference 4.8) which relates opposing flow to left turning flow is used. Given the opposing flow, the left turn saturation flow is taken from a curve and compared to the left turn demand. Any "excess" demand is the number of left turn conflicts. It is recognized that many left turns are made at the beginning or end of the red; thus the left turn conflicts are not necessarily denied their turn, but it is felt that this MOE would indicate when (and where) enough excess left-turn maneuvers may occur that remedial action might be warranted.

OUTPUT REPORTS

There are six types of outputs available from SOAP. Each of these provide useful information to the user.

Input Summary

The input data is echoed prior to execution in a list similar to the one shown in Figure 20. Where appropriate, messages are included so the user can verify that the action taken

```
   1    |BEGIN            0700 1800    15                          ASHLEY DR. E KENNEDY BLVD|
   2    |CASE      1                                               OPTIMAL DIAL & TIMING    |
   3    |TABLE               22    23    39                                                 |
   4    |PLOT      1                                                                        |
   5    |PLOT      5                                                                        |
   6    |LEFTURN                2.0                                      WE                 |
   7    |CONTROL  2 0700     1   60   120                          DIAL = 1 SEED            |
*** 309 *** ALL RED PERIOD ASSUMED NOT TO EXIST
   8    |CONTROL  4 0900     2   60   120                          DIAL = 2 SEED            |
*** 309 *** ALL RED PERIOD ASSUMED NOT TO EXIST
   9    |CONTROL  2 1600     3   60   120                          DIAL = 3 SEED            |
*** 309 *** ALL RED PERIOD ASSUMED NOT TO EXIST
  10    |HEADWAY      3.5  1.9  2.5  1.9    0  2.5  2.2  2.5    0 FIELD MEASUREMENTS        |
*** 302 *** DEFAULT VALUE USED FOR SOUTHBOUND LEFT  HEADWAY
*** 302 *** DEFAULT VALUE USED FOR WESTBOUND LEFT   HEADWAY
  11    |MINGREEN            15    0   15    0   24   24   15   15                          |
*** 303 *** MINIMUM GREEN VALUE FOR NORTHBOUND LEFT  IS ZERO
*** 303 *** MINIMUM GREEN VALUE FOR SOUTHBOUND LEFT  IS ZERO
  12    |VOLUME  15 0700    39    0  128    0    0   56   42    1                           |

  41    |VOLUME  15 0730   127   10  286    0    0  127  227   14                           |
  42    |VOLUME  15 1730    96    5  224    0    0  109  176   15                           |
  43    |VOLUME  15 1745    89    7  213    0    0   79  116   10                           |
  44    |CAPACITY 9 0700  2.0  1.0  3.2    0    0  1.8  2.6    1 LANE EQUIV.                |
*** 305 *** NORTHBOUND THRU  CAPACITY WILL BE ESTIMATED USING DEPARTURE HEADWAYS
*** 305 *** NORTHBOUND LEFT  CAPACITY WILL BE ESTIMATED USING DEPARTURE HEADWAYS
*** 305 *** SOUTHBOUND THRU  CAPACITY WILL BE ESTIMATED USING DEPARTURE HEADWAYS
*** 304 *** SOUTHBOUND LEFT  MOVEMENT ASSUMED NOT TO EXIST
*** 304 *** EASTBOUND THRU   MOVEMENT ASSUMED NOT TO EXIST
*** 305 *** EASTBOUND LEFT   CAPACITY WILL BE ESTIMATED USING DEPARTURE HEADWAYS
*** 305 *** WESTBOUND THRU   CAPACITY WILL BE ESTIMATED USING DEPARTURE HEADWAYS

*** 305 *** WESTBOUND THRU   CAPACITY WILL BE ESTIMATED USING DEPARTURE HEADWAYS
*** 305 *** WESTBOUND LEFT   CAPACITY WILL BE ESTIMATED USING DEPARTURE HEADWAYS
  46    |PCF      11 0700 .265 .265 .350                  417 .417 PCF FOR SB EST           |
*** 311 *** PCF VALUE NOT SPECIFIED FOR SOUTHBOUND LEFT .  ISOLATED OPERATION ASSUMED.
*** 311 *** PCF VALUE NOT SPECIFIED FOR EASTBOUND THRU  .  ISOLATED OPERATION ASSUMED.
*** 311 *** PCF VALUE NOT SPECIFIED FOR EASTBOUND LEFT  .  ISOLATED OPERATION ASSUMED.
  47    |RUN       1                                                                        |
```

Figure 20. Listing of SOAP Input Data

by SOAP was as intended. The liberal use of the comment card will assist the user in recalling the basis for the input data.

MOE Report

For each run a table of the numerical results of the current run is output. An example is shown in Figure 21. General and control strategy information is found above the table.

Within the table are the current values of the MOE, namely:

1. Delay in vehicle-hours,
2. Percent saturation (v/c),
3. Maximum queue length in vehicles,
4. Percentage of stops,
5. Excess fuel consumed (due to stops and delays) in gallons, and
6. Left-turn conflicts.

All but the last are given separately for the thru and left-turn movements for the four directions.

Below this is a summary of items 1 (also in average seconds/vehicle), 2, 5 and 6 for the entire intersection. To the right of the summary is the phasing diagram. The entries in the phasing diagram correlate with Figure 18 as follows:

N = North	A = Green
S = South	T = Thru
E = East	L = Left
W = West	

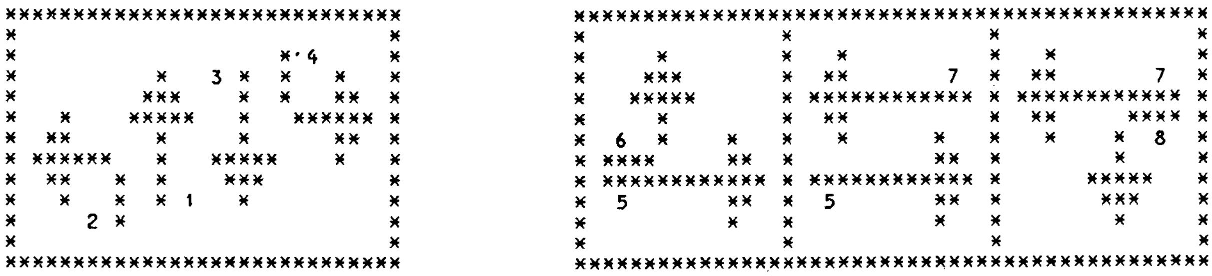
```
SIGNAL OPERATION FOR: ASHLEY DR. E KENNEDY BLVD

2 DIAL CONTROLLER:

ANALYSIS PERIOD:  700. TO 1800.          PHASING:   1 PHASE NS,   2 PHASE EW.

LEFT TURNS - NORTH: NONE,  SOUTH: NONE,  EAST: REST,  WEST: REST.
                                         NORTH        SOUTH        EAST         WEST
*****************************************************************************************
*                             *            *            *            *            *
*      DELAY TO THRU (VEH-HRS) *        6.  *       22.  *        0.  *       31.  *
*      DELAY TO LEFT (VEH-HRS) *        1.  *        0.  *       23.  *        1.  *
*                             *            *            *            *            *
*      % SATURATION THRU       *       28.  *       46.  *        0.  *       69.  *
*      % SATURATION LEFT       *       29.  *        0.  *       50.  *        9.  *
*                             *            *            *            *            *
*      MAX QUEUE TO THRU (VEH) *       11.  *       19.  *        0.  *       18.  *
*      MAX QUEUE TO LEFT (VEH) *        1.  *        0.  *       12.  *        1.  *
*                             *            *            *            *            *
*      % STOPS TO THRU         *       34.  *       52.  *        0.  *       74.  *
*      % STOPS TO LEFT         *       36.  *        0.  *       84.  *       44.  *
*                             *            *            *            *            *
*      EXCESS FUEL THRU (GAL)  *       13.  *       50.  *        0.  *       59.  *
*      EXCESS FUEL LEFT (GAL)  *        2.  *        0.  *       43.  *        2.  *
*                             *            *            *            *            *
*      LEFT TURN CONFLICTS     *        0.  *        0.  *        0.  *        0.  *
*                             *            *            *            *            *
*****************************************************************************************
*                      *      *            *            *            *            *
*     SUMMARY          * PH 1*   GREEN    *   GREEN    *            *            *
*                      * PH 2*            *            *            * LEFT THRU  *
*SECONDS PER VEH    16. * PH 3*            *            * LEFT THRU  *            *
*TOTAL VEH-HRS      84. * PH 4*            *            *            *            *
*CRITICAL V/C       75. * PH 5*            *            *            *            *
*EXCESS FUEL(GAL)  167. * PH 6*            *            *            *            *
*TURN CONFLICTS      0. *      *            *            *            *            *
*****************************************************************************************
```

Figure 21. MOE Report Form SOAP



OPPOSITE ROTATION EQUALLY ACCEPTABLE   OPPOSITE ROTATION EQUALLY ACCEPTABLE

Figure 22. SOAP Phasing Diagram Output

Design Recommendations

SOAP develops recommended designs based on optimal flow as constrained by input parameters. There are two types of outputs for recommended designs.

1. Phasing Patterns. When protected left turns are specified for one or more approaches, it is necessary to choose the optimal phase patterns from several alternatives. SOAP determines the best two and three phase patterns for both the N-S and E-W directions. Each of the four possible phase combinations which may result from these choices is analyzed as a separate design configuration so the user may compare the MOE. A sample phasing diagram is shown in Figure 22. The phase sequence in each pattern is indicated as either:

   a. User specified,

   b. Determined by analysis of progression characteristics, or

   c. Unimportant (i.e. opposite phase sequence equally acceptable).

2. Timing Design. Each design configuration must be optimized in terms of cycle length, splits and patterns before the MOE can be calculated. The result of the optimization process is produced in a table such as Figure 23. For each analysis period, the table includes dial number, cycle length and splits. Above the table is general information and control strategy specifications. The "PATTERN" entries indicate the possible sequences resulting from the choices available and are interpreted exactly as discussed in the previous Section. In this example the patterns are:

   a. North-south thru and left movements,

   b. East thru and left movements,

   c. East and west thru movements, and

   d. West thru and left movements.

The phasing diagram at the top of the table indicates the particular phase sequencing for this alternative (e.g. the NS, WE, and EW).

When the control is actuated, an asterisk (*) will appear in the DIAL column and the cycle length and splits are average for each period. The controller should be timed accordingly to be "well timed."

SIGNAL OPERATION FOR: ASHLEY DR. E KENNEDY BLVD

2 DIAL CONTROLLER:

PHASING: 1 PHASE NS, 2 PHASE EW. PATTERN: A NS, WE EW.

LOST TIME PER PHASE: 3.5, TOTAL LOST TIME: 10.5

LEFT TURNS - NORTH: NONE, SOUTH: NONE, EAST: REST, WEST: REST.

MOVEMENTS		PATTERN PHASES PH 1	PH 2	PH 3	PH 4	PH 5	PH 6
NORTHBOUND	THRU	XXXX					
	LEFT	XXXX					
SOUTHBOUND	THRU	XXXX					
	LEFT	XXXX					
EASTBOUND	THRU			XXXX			
	LEFT			XXXX			
WESTBOUND	THRU		XXXX				
	LEFT		XXXX				

TIME FROM	TO	DIAL	CYCLE	PERCENT OF CYCLE TO EACH PHASE PH 1	PH 2	PH 3	PH 4	PH 5	PH 6
700	715	1	70.0	29.3	24.6	28.1	18.0	0.0	0.0
715	730	1	70.0	29.3	24.6	28.2	17.9	0.0	0.0
730	745	1	70.0	30.1	25.3	28.9	15.8	0.0	0.0
745	800	1	70.0	30.2	25.4	29.0	15.4	0.0	0.0
800	815	1	70.0	30.3	25.5	29.1	15.1	0.0	0.0
815	830	1	70.0	30.1	25.3	28.9	15.7	0.0	0.0
1730	1745	2	90.0	31.6	25.9	28.8	13.7	0.0	0.0
1745	1800	2	90.0	32.0	26.1	29.0	12.9	0.0	0.0

Figure 23. SOAP Timing Report

TABLE NO. 22
CRITICAL VC FOR EACH PHASE

CRITY	TIME	PHASE 1	PHASE 2	PHASE 3	PHASE 4	PHASE 5	PHASE 6
1	700	0.084	0.120	0.0	0.069	0.0	0.0
2	715	0.142	0.211	0.022	0.114	0.0	0.0
3	730	0.187	0.253	0.012	0.150	0.0	0.0
4	745	0.314	0.236	0.090	0.119	0.0	0.0
5	800	0.234	0.247	0.078	0.147	0.0	0.0
6	815	0.352	0.205	0.109	0.108	0.0	0.0
41	1700	0.288	0.228	0.117	0.117	0.0	0.0
42	1715	0.300	0.217	0.090	0.128	0.0	0.0
43	1730	0.188	0.259	0.016	0.153	0.0	0.0
44	1745	0.197	0.241	0.0	0.139	0.0	0.0

Figure 24. Typical SOAP Intermediate Report

Intermediate Calculations Reports

Usually the MOE table and recommendations will be sufficient for the engineer's use. On the other hand, there may be a need to have more detailed information as the analysis progresses. The TABLE and PLOT commands are instruction cards which enable the user to call for outputs of many tables (or plots) which are maintained by SOAP.

Table options include printouts of forty-two different types of tables which indicate either basic parameters (trucks and bus factors, minimum green time, capacities, etc.) or operational measures (v/c ratios, degree of saturation, average delay by period, etc). Figure 24 illustrates one of these tables.

Plot options graphically portray a comparison of two different statistics. Presently, eight plots are available and show such comparisons as cycle length versus period, delay or volumes per period and excess fuel consumption by period. Figure 25 shows an example of one plot.

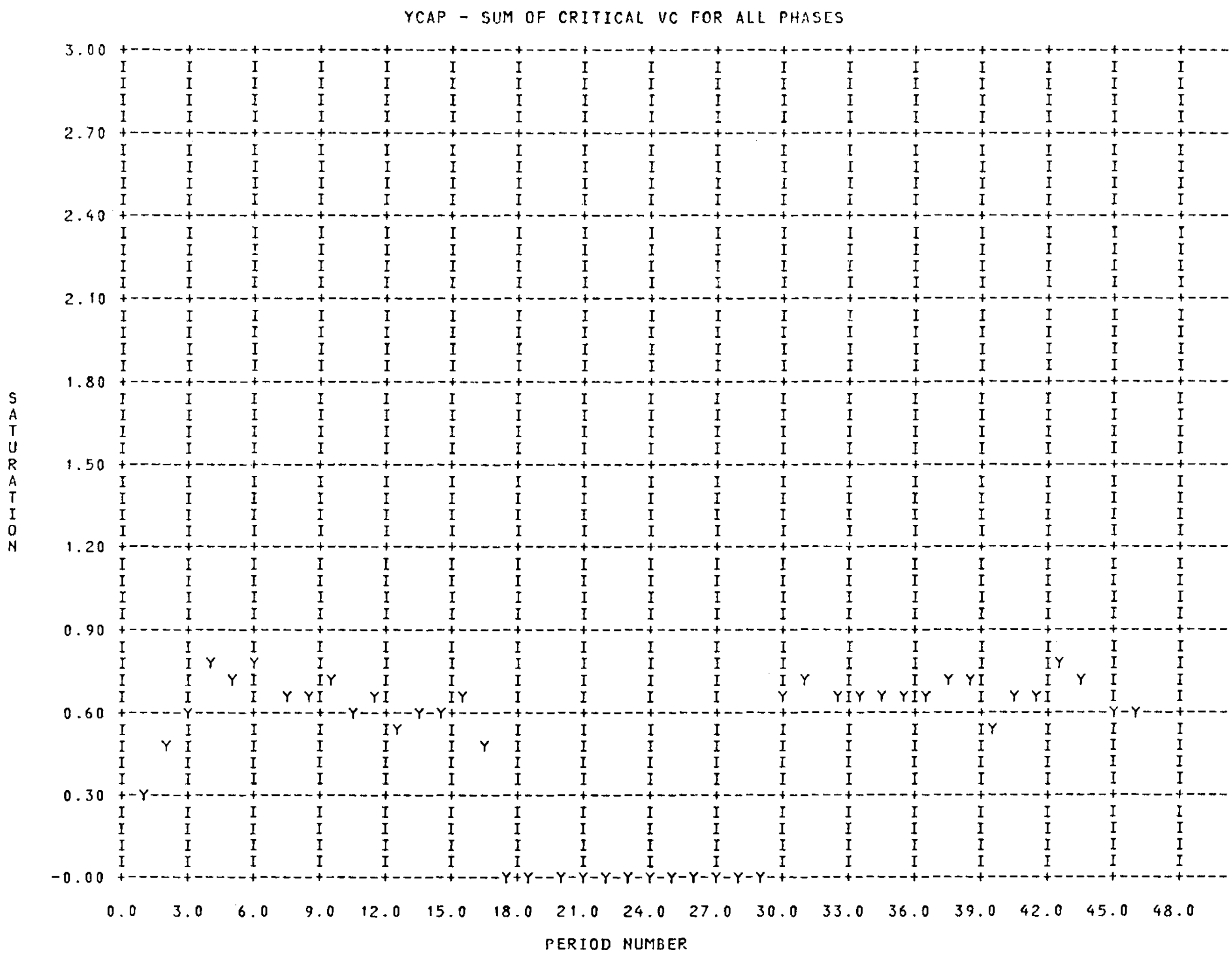


Figure 25. Example SOAP Graphical Output

SYSTEM SUMMARY SHEET

SYSTEM ALTERNATIVES SUMMARY

PROB #	RUN	INTERSECTION	TOTAL DELAY #1	TOTAL DELAY #2	TOTAL DELAY #3	TOTAL DELAY #4	EXCESS FUEL #1	EXCESS FUEL #2	EXCESS FUEL #3	EXCESS FUEL #4
1	1	ASHLEY DR. E KENNEDY BLVD	127.1				237.6			
1	2	ASHLEY DR. E KENNEDY BLVD	84.0				167.0			

COMPARISON OF CASE SYSTEMS

CASE #	CASE NAME	TOTAL DELAY	EXCESS FUEL
1	EXIST OPERS(MIN.DATA)	127.14	237.61
2	EXIST OPERS.(ACT.HDWY)	84.00	167.00

Figure 26. SOAP Comparison Summary Reports

Comparison Summaries

SOAP may be used to examine several different control strategies at an intersection. Each alternative may generate up to four MOE tables depending on the choice of phasing patterns to handle left turns. To facilitate the comparison of these alternatives, the user may request a separate summary of MOE's following a series of runs. Figure 26 illustrates the comparison summary, which includes delay and excess fuel consumption. The columns labeled "#1" through "#4" represent the different phasing patterns which were examined.

A second table gives the comparison of the "best" case designs. The output is obtained by including a COMPARE card in the input deck (after the last RUN card which is to be included). Cases can be labeled by including CASE card(s) in the deck.

Diagnostic Messages

SOAP contains an extensive library of messages to inform the user of fatal errors in the inputs; to alert the user to potential, but non-fatal, errors; and to advise the users of actions taken by SOAP, such as the use of default values in lieu of data which were not input. There are four (4) levels of messages, as follows:

1. 100 level - fatal messages which must be corrected before SOAP can execute. Examples are unrecognizable card name or missing required cards or data, time periods out of range, inconsistency in pattern names and left-turn specifications and incorrect parameters, to name a few. There are a total of 32 errors at this level.

2. 200 level - warnings that the user may wish to reconsider some aspect of his inputs.

   Examples are that unrealistic queues occurred (perhaps due to use of default headways), missing volumes (which SOAP had to estimate), unassigned analysis periods, etc. There are 17 of these messages.

3. 300 level - simply informing the user that SOAP took some action as a result, usually, of omitted data cards. Examples are advisement that a particular default value was used, a particular movement was assumed not to exist or that parameters for a satellite signal were assumed to be the same as the subject signal. There are 19 of these messages.

4. 400 level - these are high level messages that will not generally occur except when the user is highly proficient with SOAP and is getting into the program itself. To generate this level of messages, one must use the Programmer's Manual (Reference 4.4) in lieu of the User's Manual (Reference 4.3).

The placement of messages generally occurs in the input report at the location where SOAP had to make a decision, see Figure 20. Once an input deck has been edited and tested to the user's satisfaction, and the messages are no longer required, the NOWARN card may be placed in the next job to suppress printing of the messages (at levels 200-400). Fatal error messages (level 100) are naturally always printed.

ADDITIONAL FEATURES

The SOAP options are extensive in terms of the design, configuration and control strategies which can be analyzed or optimized. In a previous section all the options were identified, but to summarize, the following options are available in SOAP (these are not mutually exclusive).

1. Analysis vs. design.
2. Existing preset timing vs. optimization.
3. Pretimed vs. actuated.
4. Protected vs. unprotected left-turns.
5. Isolated runs vs. multiple runs with comparison.
6. Preset vs. optimal phase sequencing.
7. Preset vs. optimal dial assignments.
8. Numerous input data vs. default options.
9. Isolated vs. coordinated control.
10. Data check without execution.

The coordinated control function, g, is based on the delay-difference in offset (Reference 4.8). It is not truly an interconnected arterial design capability, but only estimates the effect of adjacent coordinated signals on the subject signal (i.e. platooned arrivals). Chapter 6 dicusses PASSER II, (80), which is an arterial progression design model and Chapter 9 discusses TRANSYT-7F, which is a system optimization model. It would seem logical to combine these to obtain total system optimization. Such a model package may soon be available from the FHWA, called the "Arterial Analysis Package," or the AAP. The AAP is being developed for FHWA by the University of Florida Transportation Research Center and PRC-Voorhees.

APPLICATIONS AND LIMITATIONS

As stated earlier, SOAP can be used to design and/or analyze any standard traffic control strategy for either pretimed or actuated operations. As such, it is limited primarily in the same areas which the controller itself is limited. The analysis and optimization is clearly based on mathematical approximations of the real world and therefore necessarily cannot take into account any extraordinary or erratic human behavior.

SOAP cannot duplicate fully the logic of intelligent controllers with microprocessor "brains" which can be programmed to be extremely responsive to traffic in real time. For instance, the combining of right turns with thru traffic in SOAP presents some problems with accurate estimation of capacity. This is not a severe limitation, however, since the very function of these sophisticated controllers is to optimize on a real time basis, but SOAP is a very powerful and realistic off-line design tool for the practicing signal design engineer.

EXAMPLE APPLICATION

To illustrate the capabilities and use of SOAP, an existing signalized intersection which is in operation in the downtown area of Tampa, Florida, was selected as an example application. The following describes the intersection location and the use of the SOAP model to evaluate existing signal operation.

Problem Description

An aerial photograph of the example intersection is shown on Figure 27. This intersection, Ashley Drive and Kennedy Boulevard, is located at the southwest boundary of Tampa's CBD. Kennedy Boulevard is one of the major access routes into the CBD from the west while Ashley Drive is the major access route from the Interstate Highway to the north connecting with the suburban areas.

Kennedy Boulevard enters the CBD from the west over the Hillsborough River and is a two-way four-lane highway with a fifth left turn lane. However, beginning at Ashley Drive, Kennedy Boulevard is a one-way street serving only westbound traffic. Traffic approaching from the west wishing to continue east must turn right at Ashley Drive and make a left turn on Jackson Street which is the eastbound one-way street pair with Kennedy Boulevard.

Ashley Drive is a two-way highway with three lanes in each direction divided by a 30 foot landscaped median. Ashley Drive to the south of Jackson Street continues as a four-lane undivided roadway.

The intersection is presently controlled by a five phase, full-actuated controller. However, at the present time it is under computer supervision with a background cycle. Pedestrian push buttons are provided with concurrent pedestrian timing. Thus it operates as if it was pretimed.

Even though the intersection is four-way, arterial movements are prohibited due to the one-way approach on Kennedy Boulevard. On the north approach two through lanes are present with a separate lane for right turns while on the south approach two through lanes are available with a separate lane for left turns. The west approach provides two lanes for left turning vehicles and one lane for right turns. On the one-way east approach two through lanes are provided with separate lanes for both the left turns and the right turns. In Florida, right turns on red are permitted.

This intersection handles the largest number of vehicles of all intersections within the CBD. Although considerable study has gone into the present design, it is desired to determine if present signal phasing and timing is at its optimum.

Analysis of Existing Conditions

The first step in the use of the SOAP model is to code the input data for existing conditions and analyze the results of the SOAP output. The purpose of this is two-fold. One is the need to obtain data on existing conditions as a basis for evaluating alternatives. The second is to obtain model results in order to evaluate the credibility of the results.

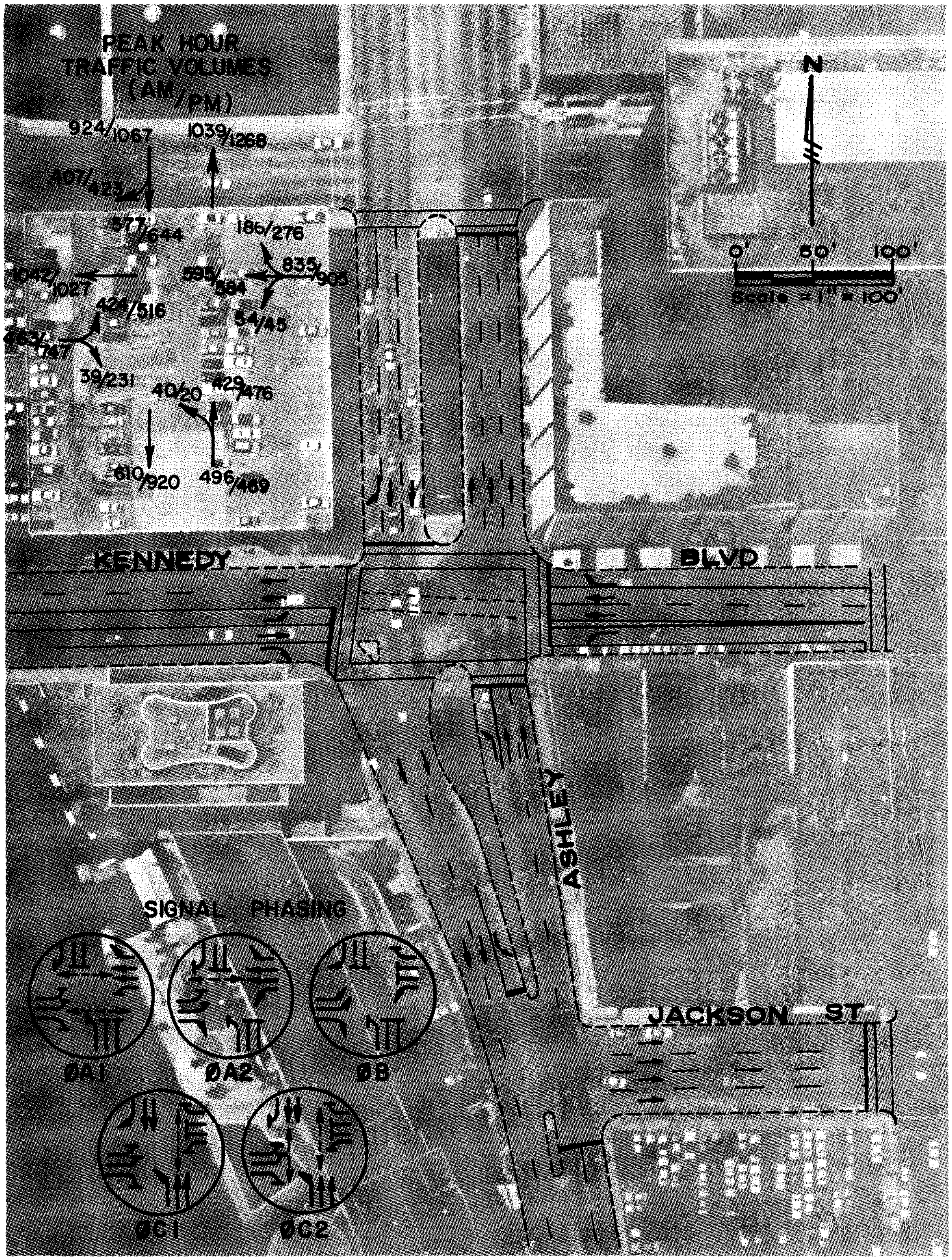


Figure 27. Intersection Configuration For Example Problem.

The minimum data required to use SOAP are lane geometry and turning movements. In addition, information on signal timing is required to evaluate existing traffic operations. Normally these data are available in the maintaining agency's files.

For this location a 1"=20' intersection plan was available showing existing geometric, pavement markings and signs. A signal operating plan was also available as well as a current record of actual controller settings. Recent 15 minute turning movement counts for the period 7:00 AM to 11:00 AM and 2:00 PM to 6:00 PM were also available. Figure 27 illustrates the lane geometric and summarizes the pertinent operating conditions.

In order to evaluate the model's ability to represent actual traffic operations it was decided to conduct limited field studies to determine if the model should be calibrated to ensure the credibility of results. The two areas which most affect these results are headways and platoon concentration factors.

An agency which makes frequent use of SOAP would, over a period of time, obtain average headway values for their community. However, in cases of unusual geometrics, or where a high number of left or right turns are made from the through lanes, special studies may be required. For this location 15 minute observations were made on each approach during the AM and PM traffic period to determine average headways.

Under normal conditions the SOAP model assumes isolated signal operation and vehicle arrivals are assumed to be random. However, in this case the signal is part of a signal system and it would be expected that vehicles would arrive more uniformly. For this location the percent of vehicles arriving during the red interval on the east and south approach were obtained during a one-half hour period at mid-morning. In actual practice a separate study should have been done for each dial. An estimate was made for the north approach and random arrivals were assumed for the west approach since the signal to the west operates as an isolated actuated signal.

Figure 28 shows the coded input data for existing conditions under two cases. Case number 1 uses minimum input data (traffic volumes, capacity, in terms of lanes, and existing signal operation). Case number 2 modifies the default values for headways and establishes platoon concentration factors for three approaches. A total of 51 lines of code are used with 32 of these lines for traffic movements.

For the Case 1 (Min. Data) four intermediate tables and two plots were requested. The left turn card was used to specify that northbound left turns could be permissible, but that east and west bound left turns must be protected movements only. The control cards specify that Dial 1 operates from 7:00 AM for 9 hours with a 70 second cycle and that Dial 2 operates from 4:00 PM (1600) for 2 hours with a 90 second cycle. Turning movements counts were coded by 15 minute periods from 7:00 to 11:00 AM and from 2:00 PM to 6:00 PM.

Capacity is coded in lanes. Notice that capacity is coded for two time periods in order to reflect the increase in capacity on two approaches (southbound thru and westbound thru) during the PM peak hour due to the difference in right turns. Since a separate lane is reserved exclusively for right turns on these approaches, the capacity could have been reduced to two thru lanes and the right turning traffic removed from the thru counts. However, one case (westbound right turn) required more time than the thru lanes and it was necessary to reflect the need for this time. In the other case (southbound right turn) the right turn could occur during an overlap period and the number of lanes have been increased to reflect the lesser time required to accommodate through traffic. No HEADWAY card was coded, therefore the capacity will be based upon default values.

In order to reflect existing phasing and splits, the existing card was used to specify for east dial the phase sequence ("A" for all north and south movements at one time, "W" for westbound thru and left at one time and "E" for eastbound thru and left at one time) and their green times. Although the signal

PAGE 1 OF 3

ARTERIAL: Ashley Drive CROSS STREET Kennedy Blvd. CITY Tampa DATE 6/8/81
CONDITION: Existing CODED BY: ASB

TRAFFIC MOVEMENTS →			NBT	NBL	SBT	SBL	EBT	EBL	WBT	WBL	
DATA FIELD	A	B	1	2	3	4	5	6	7	8	C
IDENTIFICATION	NUMERICAL INFORMATION										OTHER INFORMATION
BEGIN			0700	1800							ASHLEY DR. & KENNEDY BLVD
CASE	1										EXIST. ØPERS (MIN. DATA)
TABLE			22	23	39	44					
PLØT	1										
PLØT	2										
LEFTURN											A WE
CØNTRØL	9	0700	1	70	70						
CØNTRØL	2	1600	2	90	90						
VØLUME	15	0700	39	0	128	0	0	56	42	1	
VØLUME	15	0715	49	0	215	0	0	57	127	9	
VØLUME	15	0730	79	0	283	0	0	88	152	6	
VØLUME	15	0745	116	4	356	0	0	108	196	3	
VØLUME	15	0800	81	8	240	0	0	133	211	5	
VØLUME	15	0815	118	7	341	0	0	102	203	15	
VØLUME	15	0830	114	5	270	0	0	113	150	12	
VØLUME	15	0845	79	4	259	0	0	111	149	6	
VØLUME	15	0900	70	13	229	0	0	98	188	7	
VØLUME	15	0915	67	4	195	0	0	103	157	10	
VØLUME	15	0930	47	7	157	0	0	108	203	6	
VØLUME	15	0945	73	6	196	0	0	89	137	8	
VØLUME	15	1000	70	10	166	0	0	101	162	5	
VØLUME	15	1015	46	8	151	0	0	97	177	6	
VØLUME	15	1030	68	12	144	0	0	109	202	5	
VØLUME	15	1045	50	6	142	0	0	80	119	5	
VØLUME	15	1400	77	7	208	0	0	49	90	5	
VØLUME	15	1415	68	8	260	0	0	149	198	7	
VØLUME	15	1430	52	12	195	0	0	95	141	6	
VØLUME	15	1445	88	3	178	0	0	119	145	5	
VØLUME	15	1500	89	9	222	0	0	114	165	13	
VØLUME	15	1515	83	8	211	0	0	107	156	5	
VØLUME	15	1530	93	8	183	0	0	142	201	7	
VØLUME	15	1545	80	10	225	0	0	108	189	5	
VØLUME	15	1600	102	14	224	0	0	136	216	15	
VØLUME	15	1615	98	7	154	0	0	120	180	9	
VØLUME	15	1630	91	8	250	0	0	140	192	10	
VØLUME	15	1645	100	8	253	0	0	141	197	11	
VØLUME	15	1700	158	10	278	0	0	168	244	10	
VØLUME	15	1715	127	10	286	0	0	127	227	14	
VØLUME	15	1730	96	5	224	0	0	109	176	15	
VØLUME	15	1745	89	7	213	0	0	79	116	10	
CAPACITY	9	0700	2.0	1.0	3.2	0	0	1.8	2.6	1	LANE EQUIV.
CAPACITY	2	1600	2.0	1.0	3.3	0	0	1.8	2.9	1	LANE EQUIV
EXISTING	9	0700	25	25	25	0	0	24	21	21	A WE
EXISTING	2	1600	33	33	33	0	0	24	27	27	A WE
RUN	1										
CASE	2										EXIST. ØPERS. (ACT. HDWY)
HEADWAY		3.5	1.9	2.5	1.9	0	0	2.2	2.0	2.5	FIELD MEASUREMENTS
PCF	11	0700	.265	.265	.350				.417	.417	PCF FØR SB ESTIMATED
RUN	2										
CØMPARE											ALL CASES
END											

Figure 28. Example SOAP Input Data For Existing Conditions.

controller operates as a semi-actuated signal with a background cycle, the splits were coded assuming each phase extended to its maximum extension, thus acting as a fixed time signal.

Notice that it was necessary to code the signal operation as a three phase signal. In actual practice the minor movements on Phase A (westbound left turns and eastbound right turns) delayed to provide additional pedestrian clearance time for the south approach. Phase C also cut short the same movement (right turns southbound and left turns northbound) to provide additional pedestrian clearance time. Both of these phases (A2 & C2) only operate when actuated by pedestrians. Since the SOAP model does not evaluate pedestrian actuation, it is necessary to provide minimum pedestrian clearance that are for A1 and C1.

In order to more accurately reflect actual conditions, a second case was coded. A HEADWAY card and PCF card were coded using data obtained from the field. Notice that it was not necessary to recode the previous cards. Since a BEGIN card was not placed after run 1 the computer reads in the HEADWAY card and the PCF card (which changes the default values used in Run 1 to those specified) and again executes the run using all the previous input data. In order to obtain a comparison of the results between Case 1 and Case 2 a COMPARE card was included just prior to the END card. Figure 29 illustrates the output from this computer run, including both cases.

Examination of the results of the output for each case shows how the modification of default headways and the use of PCF factors affect the vehicle operation on each approach. This is best illustrated from a comparison of the MOE reports which reflect the changes that occur due to these modifications.

The most obvious change is in the percent of vehicles stopping north and southbound. In Case 1, which assumed random arrivals, 77% of the northbound thru traffic and 64% of the southbound thru traffic stopped. Not very good when you consider that the system attempts to maximize progression along the north-south route. However, Case 2, which adjusts vehicle arrivals from a random pattern to the observed pattern reduces the percent stops to 34% and 52% respectively. Notice for eastbound traffic (left turn) the percent stops remained virtually the same, 86% versus 84%.

The change due to modification in headways is more difficult to see. However, one indication is in the percent of saturation flow for each approach. Since the green time is the same for both cases the change in percent saturation flow is due solely to the change in the time required between vehicles. For instance, this was decreased for northbound thru from 2.2 seconds (default) to 1.9 and the percent saturation flow decreased from 32% to 28%. On the other hand, headways for westbound through was increased from 2.2 to 2.5 seconds and the percent saturation flow increased from 61% to 69%.

Based upon a comparison of the results, it appears that Case 2 conditions more accurately reflect existing operation. Therefore these conditions should be used in the evaluation of alternatives. If one wishes to further verify the reasonableness of results, additional field studies could be conducted to obtain information on vehicle hours of delay and percent vehicle stopping for each approach using techniques developed as part of a research project for FHWA (Ref. 4.10).

Define and Analyze Alternatives

Now that input data required to obtain reasonable results has been identified it is now possible to use SOAP to determine alternate signal timing schemes and associated measures of effectiveness. These alternate schemes can then be compared with existing signal timing to determine if an improvement can be obtained. Figure 30 illustrates the

```
*****************************************************************************************************
  VERSION:  1.01          S O A P    P R O G R A M         RELEASE:  1.04 - APR  10, 1978 (MRL)

  CARD #                          CARD FILE LIST            UNIVERSITY OF FLORIDA
*****************************************************************************************************

         1    |BEGIN            0700 1800    15                             ASHLEY DR. E KENNEDY BLVD|
         2    |CASE      1                                                  EXIST . OPERS(MIN.DATA)  |
         3    |TABLE              22    23    39    44                                               |
         4    |PLOT      1                                                                           |
         5    |PLOT      5                                                                           |
         6    |LEFTURN                                                      A     WE                 |
         7    |CONTROL   9 0700     1    70    70                                                    |
     *** 309 *** ALL RED PERIOD ASSUMED NOT  TO EXIST
         8    |CONTROL   2 1600     2    90    90                                                    |
     *** 309 *** ALL RED PERIOD ASSUMED NOT  TO EXIST
         9    |VOLUME   15 0700    39     0   128     0     0    56    42     1                      |
        10    |VOLUME   15 0715    49     0   215     0     0    57   127     9                      |
        11    |VOLUME   15 0730    79     0   283     0     0    88   152     6                      |
        12    |VOLUME   15 0745   116     4   356     0     0   108   196     3                      |
        13    |VOLUME   15 0800    81     8   240     0     0   133   211     5                      |
        14    |VOLUME   15 0815   118     7   341     0     0   102   203    15                      |
        15    |VOLUME   15 0830   114     5   270     0     0   113   150    12                      |
        16    |VOLUME   15 0845    79     4   259     0     0   111   149     6                      |
        17    |VOLUME   15 0900    70    13   229     0     0    98   188     7                      |
        18    |VOLUME   15 0915    67     4   195     0     0   103   157    10                      |
        19    |VOLUME   15 0930    47     7   157     0     0   108   203     6                      |
        20    |VOLUME   15 0945    73     6   196     0     0    89   137     8                      |
        21    |VOLUME   15 1000    70    10   166     0     0   101   162     5                      |
        22    |VOLUME   15 1015    46     8   151     0     0    97   177     6                      |
        23    |VOLUME   15 1030    68    12   144     0     0   109   202     5                      |
        24    |VOLUME   15 1045    50     6   142     0     0    80   119     5                      |
        25    |VOLUME   15 1400    77     7   208     0     0    49    90     5                      |
        26    |VOLUME   15 1415    68     8   260     0     0   149   198     7                      |
        27    |VOLUME   15 1430    52    12   195     0     0    95   141     6                      |
        28    |VOLUME   15 1445    88     3   178     0     0   119   145     5                      |
        29    |VOLUME   15 1500    89     9   222     0     0   114   165    13                      |
        30    |VOLUME   15 1515    83     8   211     0     0   107   156     5                      |
        31    |VOLUME   15 1530    93     8   183     0     0   142   201     7                      |
        32    |VOLUME   15 1545    80    10   225     0     0   108   189     5                      |
        33    |VOLUME   15 1600   102    14   224     0     0   136   216    15                      |
        34    |VOLUME   15 1615    98     7   154     0     0   120   180     4                      |
        35    |VOLUME   15 1630    91     8   250     0     0   140   192    10                      |
        36    |VOLUME   15 1645   100     8   253     0     0   141   197    11                      |
        37    |VOLUME   15 1700   158    10   278     0     0   168   244    10                      |
        38    |VOLUME   15 1715   127    10   286     0     0   127   227    14                      |
        39    |VOLUME   15 1730    96     5   224     0     0   109   176    15                      |
        40    |VOLUME   15 1745    89     7   213     0     0    79   116    10                      |
        41    |CAPACITY 9 0700   2.0   1.0   3.2     0     0   1.8   2.6     1 LANE EQUIV.          |
     *** 305 *** NORTHBOUND THRU   CAPACITY WILL BE ESTIMATED USING DEPARTURE HEADWAYS
     *** 305 *** NORTHBOUND LEFT   CAPACITY WILL BE ESTIMATED USING DEPARTURE HEADWAYS
     *** 305 *** SOUTHBOUND THRU   CAPACITY WILL BE ESTIMATED USING DEPARTURE HEADWAYS
     *** 304 *** SOUTHBOUND LEFT   MOVEMENT ASSUMED NOT TO EXIST
     *** 304 *** EASTBOUND THRU    MOVEMENT ASSUMED NOT TO EXIST
     *** 305 *** EASTBOUND LEFT    CAPACITY WILL BE ESTIMATED USING DEPARTURE HEADWAYS
     *** 305 *** WESTBOUND THRU    CAPACITY WILL BE ESTIMATED USING DEPARTURE HEADWAYS
     *** 305 *** WESTBOUND LEFT    CAPACITY WILL BE ESTIMATED USING DEPARTURE HEADWAYS
        42    |CAPACITY 2 1600   2.0   1.0   3.3     0     0   1.8   2.9     1 LANE EQUIV.          |
     *** 305 *** NORTHBOUND THRU   CAPACITY WILL BE ESTIMATED USING DEPARTURE HEADWAYS
     *** 305 *** NORTHBOUND LEFT   CAPACITY WILL BE ESTIMATED USING DEPARTURE HEADWAYS
     *** 305 *** SOUTHBOUND THRU   CAPACITY WILL BE ESTIMATED USING DEPARTURE HEADWAYS
     *** 304 *** SOUTHBOUND LEFT   MOVEMENT ASSUMED NOT TO EXIST
     *** 304 *** EASTBOUND THRU    MOVEMENT ASSUMED NOT TO EXIST
     *** 305 *** EASTBOUND LEFT    CAPACITY WILL BE ESTIMATED USING DEPARTURE HEADWAYS
     *** 305 *** WESTBOUND THRU    CAPACITY WILL BE ESTIMATED USING DEPARTURE HEADWAYS
     *** 305 *** WESTBOUND LEFT    CAPACITY WILL BE ESTIMATED USING DEPARTURE HEADWAYS
        43    |EXISTING 9 0700    25     0    25     0    24    24    21   21A     WE                |
     *** 310 *** NORTHBOUND LEFT   BOUND GREEN TIME ASSUMED TO BE ZERO
     *** 310 *** SOUTHBOUND LEFT   BOUND GREEN TIME ASSUMED TO BE ZERO
        44    |EXISTING 2 1600    33     0    33     0    30    30    27   27A     WE                |
     *** 310 *** NORTHBOUND LEFT   BOUND GREEN TIME ASSUMED TO BE ZERO
     *** 310 *** SOUTHBOUND LEFT   BOUND GREEN TIME ASSUMED TO BE ZERO
        45    |RUN       1                                                                           |
```

Figure 29. Example SOAP Output For Existing Conditions.

ANALYSIS OF TRAFFIC SIGNAL OPERATION

PROBLEM # 1 ASHLEY DR. E KENNEDY BLVD RUN # 1

*** 212 *** THE FOLLOWING MOVEMENTS WERE UNASSIGNED FOR THIS RUN:

MOVEMENT # 4 SOUTHBOUND LEFT
MOVEMENT # 5 EASTBOUND THRU

*** 211 *** THE FOLLOWING PERIODS WERE UNASSIGNED FOR THIS RUN:

1100., 1115., 1130., 1145., 1200., 1215., 1230., 1245.,
1300., 1315., 1330., 1345.,

*** 213 *** THE FOLLOWING UNASSIGNED PERIODS HAD DIALS ASSIGNED TO THEM:

1100., 1115., 1130., 1145., 1200., 1215., 1230., 1245.,
1300., 1315., 1330., 1345.,

1 PHASE NS VS 2 PHASE EW

PATTERN # 1 (A) PATTERN # 3 (WE) ASHLEY DR. E KENNEDY BLVD

TABLE NO. 22
CRITICAL VC FOR EACH PHASE

CRITY	TIME	PHASE 1	PHASE 2	PHASE 3	PHASE 4	PHASE 5	PHASE 6
1	700	0.098	0.039	0.086	0.0	0.0	0.0
2	715	0.164	0.119	0.088	0.0	0.0	0.0
3	730	0.216	0.143	0.136	0.0	0.0	0.0
4	745	0.351	0.184	0.167	0.0	0.0	0.0
5	800	0.259	0.198	0.205	0.0	0.0	0.0
6	815	0.387	0.191	0.157	0.0	0.0	0.0
7	830	0.259	0.141	0.174	0.0	0.0	0.0
8	845	0.239	0.140	0.171	0.0	0.0	0.0
9	900	0.294	0.177	0.151	0.0	0.0	0.0
10	915	0.181	0.148	0.159	0.0	0.0	0.0
11	930	0.165	0.191	0.167	0.0	0.0	0.0
12	945	0.198	0.129	0.137	0.0	0.0	0.0
13	1000	0.194	0.152	0.156	0.0	0.0	0.0
14	1015	0.165	0.166	0.150	0.0	0.0	0.0
15	1030	0.182	0.190	0.168	0.0	0.0	0.0
16	1045	0.144	0.112	0.123	0.0	0.0	0.0
29	1400	0.219	0.085	0.076	0.0	0.0	0.0
30	1415	0.280	0.186	0.230	0.0	0.0	0.0
31	1430	0.246	0.133	0.147	0.0	0.0	0.0
32	1445	0.158	0.136	0.184	0.0	0.0	0.0
33	1500	0.250	0.155	0.176	0.0	0.0	0.0
34	1515	0.230	0.147	0.165	0.0	0.0	0.0
35	1530	0.199	0.189	0.219	0.0	0.0	0.0
36	1545	0.262	0.178	0.167	0.0	0.0	0.0
37	1600	0.292	0.182	0.210	0.0	0.0	0.0
38	1615	0.158	0.152	0.185	0.0	0.0	0.0
39	1630	0.264	0.162	0.216	0.0	0.0	0.0
40	1645	0.267	0.166	0.218	0.0	0.0	0.0
41	1700	0.316	0.206	0.259	0.0	0.0	0.0
42	1715	0.329	0.191	0.196	0.0	0.0	0.0
43	1730	0.211	0.148	0.168	0.0	0.0	0.0
44	1745	0.219	0.098	0.122	0.0	0.0	0.0

TABLE NO. 23

Figure 29 (Cont'd). Example SOAP Output For Existing Conditions.

SUM OF CRITICAL VC FOR ALL PHASES

YCAP	TIME	TOTAL
1	700	0.224
2	715	0.372
3	730	0.495
4	745	0.702
5	800	0.663
6	815	0.736
7	830	0.575
8	845	0.550
9	900	0.622
10	915	0.488
11	930	0.522
12	945	0.464
13	1000	0.502
14	1015	0.481
15	1030	0.540
16	1045	0.379
29	1400	0.379
30	1415	0.696
31	1430	0.525
32	1445	0.478
33	1500	0.581
34	1515	0.542
35	1530	0.607
36	1545	0.606
37	1600	0.684
38	1615	0.495
39	1630	0.642
40	1645	0.651
41	1700	0.781
42	1715	0.716
43	1730	0.527
44	1745	0.438

YCAP - SUM OF CRITICAL VC FOR ALL PHASES

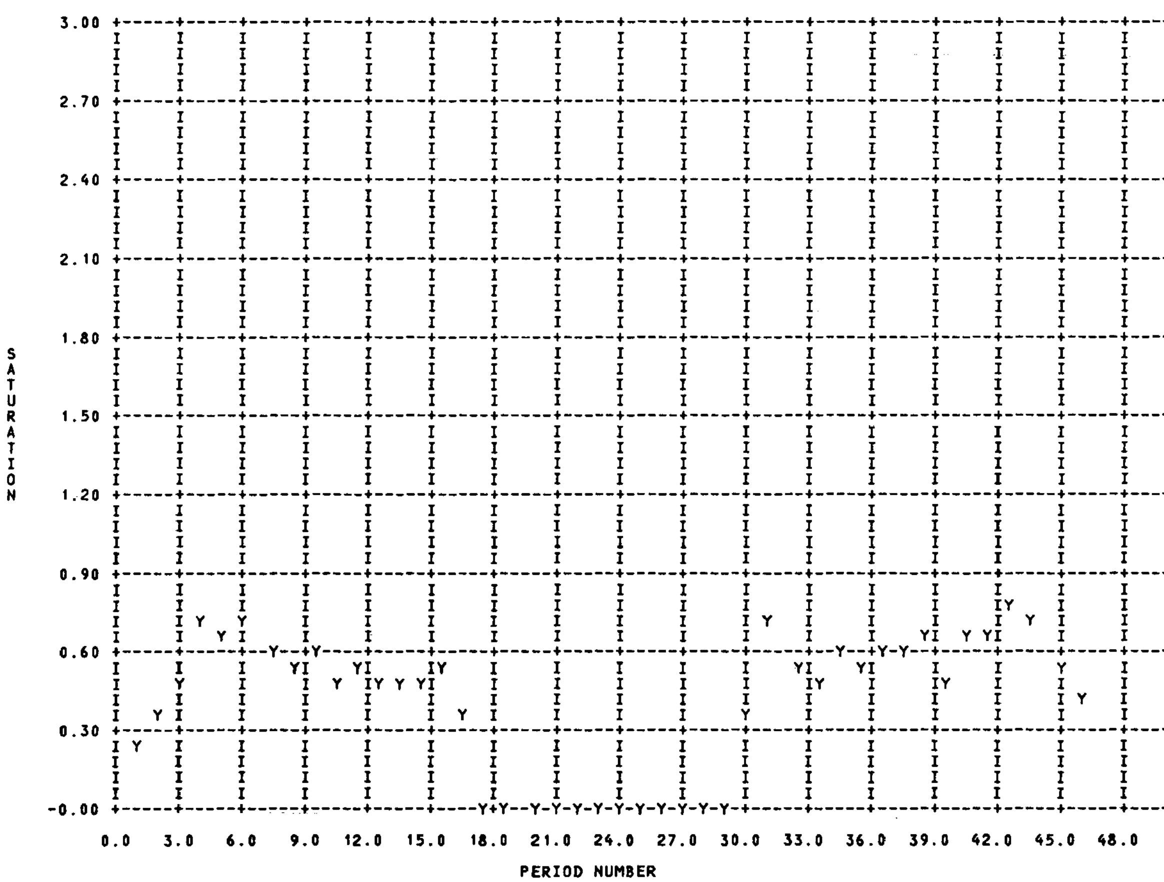
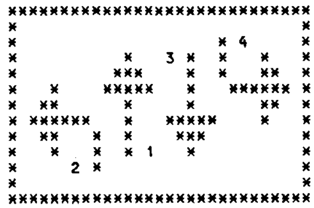
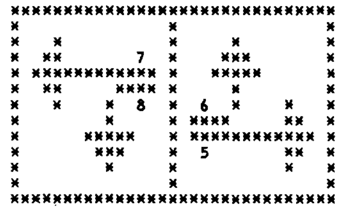


Figure 29 (Cont'd). Example SOAP Output For Existing Conditions.



ROTATION BASED ON USER CHOICE



ROTATION BASED ON USER CHOICE

TABLE NO. 39
TOTAL DELAY PER APPROACH (VEHICLE HOURS PER 15 MINUTE PERIOD)

DEL	TIME	1 - NBT	2 - NBL	3 - SBT	4 - SBL	5 - EBT	6 - EBL	7 - WBT	8 - WBL
1	700	0.180	0.0	0.630	0.0	0.0	0.291	0.226	0.005
2	715	0.231	0.0	1.183	0.0	0.0	0.297	0.787	0.048
3	730	0.395	0.0	1.762	0.0	0.0	0.507	0.995	0.032
4	745	0.631	0.133	2.962	0.0	0.0	0.675	1.478	0.016
5	800	0.406	0.079	1.374	0.0	0.0	0.956	1.718	0.026
6	815	0.645	0.233	2.578	0.0	0.0	0.621	1.582	0.084
7	830	0.617	0.047	1.634	0.0	0.0	0.723	0.978	0.066
8	845	0.395	0.032	1.534	0.0	0.0	0.704	0.969	0.032
9	900	0.343	0.178	1.287	0.0	0.0	0.587	1.372	0.037
10	915	0.327	0.025	1.042	0.0	0.0	0.630	1.041	0.054
11	930	0.221	0.041	0.799	0.0	0.0	0.675	1.582	0.032
12	945	0.360	0.041	1.049	0.0	0.0	0.515	0.867	0.043
13	1000	0.343	0.067	0.854	0.0	0.0	0.612	1.089	0.026
14	1015	0.215	0.047	0.763	0.0	0.0	0.579	1.243	0.032
15	1030	0.332	0.076	0.721	0.0	0.0	0.685	1.566	0.026
16	1045	0.236	0.033	0.710	0.0	0.0	0.448	0.726	0.026
29	1400	0.383	0.053	1.132	0.0	0.0	0.250	0.521	0.026
30	1415	0.332	0.094	1.543	0.0	0.0	1.227	1.506	0.037
31	1430	0.246	0.109	1.042	0.0	0.0	0.562	0.900	0.032
32	1445	0.448	0.017	0.930	0.0	0.0	0.786	0.934	0.026
33	1500	0.454	0.084	1.234	0.0	0.0	0.733	1.118	0.072
34	1515	0.418	0.065	1.154	0.0	0.0	0.666	1.032	0.026
35	1530	0.479	0.055	0.962	0.0	0.0	1.094	1.551	0.037
36	1545	0.400	0.102	1.257	0.0	0.0	0.675	1.385	0.026
37	1600	0.646	0.211	1.485	0.0	0.0	1.227	1.900	0.105
38	1615	0.616	0.051	0.944	0.0	0.0	0.994	1.466	0.026
39	1630	0.564	0.096	1.714	0.0	0.0	1.297	1.600	0.068
40	1645	0.631	0.098	1.742	0.0	0.0	1.315	1.659	0.075
41	1700	1.141	0.199	1.984	0.0	0.0	2.138	2.343	0.068
42	1715	0.848	0.243	2.067	0.0	0.0	1.089	2.058	0.097
43	1730	0.601	0.044	1.485	0.0	0.0	0.861	1.423	0.105
44	1745	0.549	0.065	1.394	0.0	0.0	0.563	0.856	0.068

TOTAL INTERSECTION DELAY BY PERIOD

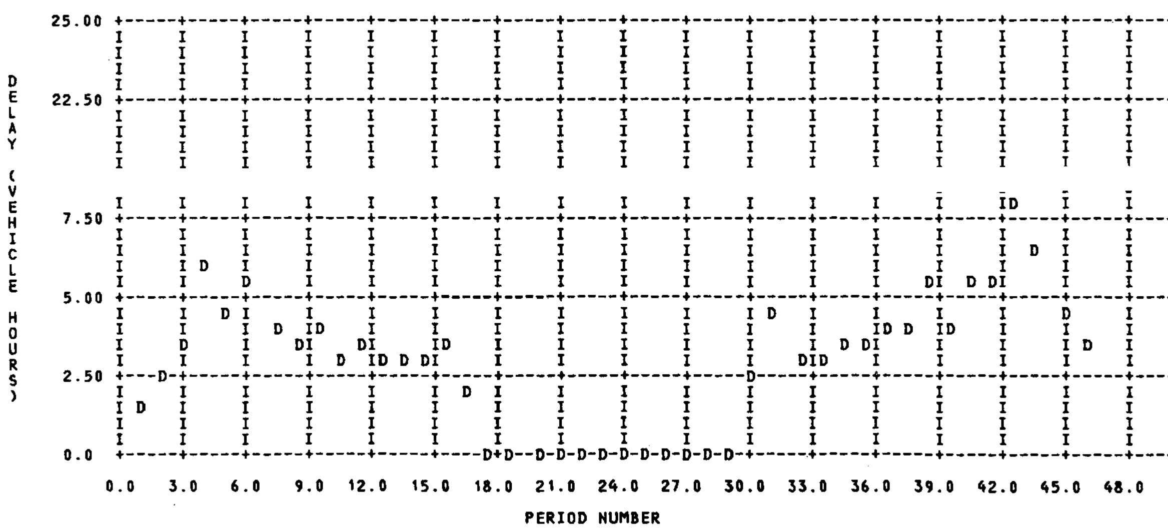


Figure 29 (Cont'd). Example SOAP Output For Existing Conditions.

TABLE NO. 44
CALCULATED PROPORTION OF VEHICLES STOPED

STOP	TIME	1 - NBT	2 - NBL	3 - SBT	4 - SBL	5 - EBT	6 - EBL	7 - WBT	8 - WBL
1	700	0.728	0.726	0.768	0.0	0.0	0.774	0.781	0.752
2	715	0.737	0.782	0.829	0.0	0.0	0.775	0.852	0.769
3	730	0.767	0.827	0.884	0.0	0.0	0.818	0.875	0.763
4	745	0.807	0.949	0.952	0.0	0.0	0.849	0.919	0.756
5	800	0.769	0.864	0.848	0.0	0.0	0.890	0.936	0.761
6	815	0.810	0.990	0.937	0.0	0.0	0.839	0.927	0.783
7	830	0.805	0.864	0.873	0.0	0.0	0.857	0.873	0.776
8	845	0.767	0.845	0.864	0.0	0.0	0.853	0.872	0.763
9	900	0.758	0.898	0.840	0.0	0.0	0.833	0.911	0.765
10	915	0.755	0.795	0.814	0.0	0.0	0.841	0.880	0.771
11	930	0.735	0.780	0.787	0.0	0.0	0.849	0.927	0.763
12	945	0.761	0.809	0.815	0.0	0.0	0.820	0.861	0.767
13	1000	0.758	0.805	0.793	0.0	0.0	0.838	0.885	0.761
14	1015	0.734	0.779	0.783	0.0	0.0	0.832	0.900	0.763
15	1030	0.756	0.793	0.778	0.0	0.0	0.850	0.926	0.761
16	1045	0.738	0.762	0.777	0.0	0.0	0.807	0.844	0.761
29	1400	0.765	0.827	0.824	0.0	0.0	0.765	0.819	0.761
30	1415	0.756	0.884	0.865	0.0	0.0	0.918	0.922	0.765
31	1430	0.740	0.852	0.814	0.0	0.0	0.829	0.865	0.763
32	1445	0.776	0.775	0.802	0.0	0.0	0.866	0.868	0.761
33	1500	0.777	0.856	0.834	0.0	0.0	0.858	0.888	0.778
34	1515	0.771	0.838	0.826	0.0	0.0	0.847	0.879	0.761
35	1530	0.782	0.810	0.805	0.0	0.0	0.906	0.925	0.765
36	1545	0.768	0.867	0.837	0.0	0.0	0.849	0.912	0.761
37	1600	0.768	0.892	0.806	0.0	0.0	0.893	0.903	0.771
38	1615	0.764	0.768	0.759	0.0	0.0	0.866	0.871	0.747
39	1630	0.756	0.865	0.825	0.0	0.0	0.900	0.882	0.760
40	1645	0.766	0.868	0.827	0.0	0.0	0.902	0.886	0.762
41	1700	0.833	0.916	0.847	0.0	0.0	0.952	0.930	0.760
42	1715	0.796	0.929	0.853	0.0	0.0	0.878	0.914	0.769
43	1730	0.762	0.817	0.806	0.0	0.0	0.848	0.868	0.771
44	1745	0.754	0.823	0.798	0.0	0.0	0.804	0.819	0.760

SIGNAL OPERATION FOR: ASHLEY DR. E KENNEDY BLVD

2 DIAL CONTROLLER:

PHASING: 1 PHASE NS, 2 PHASE EW. PATTERN: A NS, WE EW.

LOST TIME PER PHASE: 3.5, TOTAL LOST TIME: 10.5

LEFT TURNS - NORTH: NONE, SOUTH: NONE, EAST: REST, WEST: REST.

MOVEMENTS		PATTERN PHASES PH 1	PH 2	PH 3	PH 4	PH 5	PH 6
NORTHBOUND	THRU	XXXX					
	LEFT	XXXX					
SOUTHBOUND	THRU	XXXX					
	LEFT	XXXX					
EASTBOUND	THRU			XXXX			
	LEFT			XXXX			
WESTBOUND	THRU		XXXX				
	LEFT		XXXX				

TIME FROM	TO	DIAL	CYCLE	PERCENT OF CYCLE TO EACH PHASE PH 1	PH 2	PH 3	PH 4	PH 5	PH 6
700	715	1	70.0	35.7	30.0	34.3	0.0	0.0	0.0
715	730	1	70.0	35.7	30.0	34.3	0.0	0.0	0.0
730	745	1	70.0	35.7	30.0	34.3	0.0	0.0	0.0
745	800	1	70.0	35.7	30.0	34.3	0.0	0.0	0.0
800	815	1	70.0	35.7	30.0	34.3	0.0	0.0	0.0
815	830	1	70.0	35.7	30.0	34.3	0.0	0.0	0.0
830	845	1	70.0	35.7	30.0	34.3	0.0	0.0	0.0
845	900	1	70.0	35.7	30.0	34.3	0.0	0.0	0.0
900	915	1	70.0	35.7	30.0	34.3	0.0	0.0	0.0
915	930	1	70.0	35.7	30.0	34.3	0.0	0.0	0.0
930	945	1	70.0	35.7	30.0	34.3	0.0	0.0	0.0
945	1000	1	70.0	35.7	30.0	34.3	0.0	0.0	0.0
1000	1015	1	70.0	35.7	30.0	34.3	0.0	0.0	0.0
1545	1600	1	70.0	35.7	30.0	34.3	0.0	0.0	0.0
1600	1615	2	90.0	36.7	30.0	33.3	0.0	0.0	0.0
1615	1630	2	90.0	36.7	30.0	33.3	0.0	0.0	0.0
1630	1645	2	90.0	36.7	30.0	33.3	0.0	0.0	0.0
1645	1700	2	90.0	36.7	30.0	33.3	0.0	0.0	0.0
1700	1715	2	90.0	36.7	30.0	33.3	0.0	0.0	0.0
1715	1730	2	90.0	36.7	30.0	33.3	0.0	0.0	0.0
1730	1745	2	90.0	36.7	30.0	33.3	0.0	0.0	0.0
1745	1800	2	90.0	36.7	30.0	33.3	0.0	0.0	0.0

Figure 29 (Cont'd). Example SOAP Output For Existing Conditions.

```
SIGNAL OPERATION FOR: ASHLEY DR. E KENNEDY BLVD

2 DIAL CONTROLLER:

ANALYSIS PERIOD:  700. TO 1800.          PHASING:   1 PHASE NS,   2 PHASE EW.

LEFT TURNS - NORTH: NONE,  SOUTH: NONE,  EAST: REST,  WEST: REST.

                                 NORTH        SOUTH        EAST         WEST
******************************************************************************
*                            *            *            *            *            *
*     DELAY TO THRU (VEH-HRS) *       15.  *       43.  *        0.  *       40.  *
*     DELAY TO LEFT (VEH-HRS) *        3.  *        0.  *       25.  *        1.  *
*                            *            *            *            *            *
*     % SATURATION THRU       *       32.  *       53.  *        0.  *       61.  *
*     % SATURATION LEFT       *       32.  *        0.  *       57.  *        9.  *
*                            *            *            *            *            *
*     MAX QUEUE TO THRU (VEH) *       11.  *       19.  *        0.  *       18.  *
*     MAX QUEUE TO LEFT (VEH) *        1.  *        0.  *       12.  *        1.  *
*                            *            *            *            *            *
*     % STOPS TO THRU         *       77.  *       84.  *        0.  *       89.  *
*     % STOPS TO LEFT         *       85.  *        0.  *       86.  *       77.  *
*                            *            *            *            *            *
*     EXCESS FUEL THRU (GAL)  *       29.  *       85.  *        0.  *       73.  *
*     EXCESS FUEL LEFT (GAL)  *        4.  *        0.  *       45.  *        3.  *
*                            *            *            *            *            *
*     LEFT TURN CONFLICTS     *        0.  *        0.  *        0.  *        0.  *
*                            *            *            *            *            *
******************************************************************************
*                       *    *            *            *            *            *
*    SUMMARY            * PH 1*   GREEN    *   GREEN    *            *            *
*                       * PH 2*            *            *            * LEFT THRU  *
*SECONDS PER VEH    24. * PH 3*            *            * LEFT THRU  *            *
*TOTAL VEH-HRS     127. * PH 4*            *            *            *            *
*CRITICAL V/C       78. * PH 5*            *            *            *            *
*EXCESS FUEL(GAL)  238. * PH 6*            *            *            *            *
*TURN CONFLICTS      0. *    *            *            *            *            *
******************************************************************************

*****************************************************************************************
 VERSION:  1.01                         S O A P     P R O G R A M

 CARD #                                          CARD FILE LIST
*****************************************************************************************

  46    |CASE     2                                               EXIST. OPERS.(ACT.HDWY)  |
  47    |HEADWAY      3.5  1.9  2.5  1.9    0    0  2.2  2.5  2.5 FIELD MEASUREMENTS       |
*** 302 *** DEFAULT VALUE USED FOR SOUTHBOUND LEFT  HEADWAY
*** 302 *** DEFAULT VALUE USED FOR EASTBOUND THRU   HEADWAY
  48    |PCF       11 0700 .265 .265 .350                .417 .417 PCF FOR SB ESTIMATED   |
*** 311 *** PCF VALUE NOT SPECIFIED FOR SOUTHBOUND LEFT .  ISOLATED OPERATION ASSUMED.
*** 311 *** PCF VALUE NOT SPECIFIED FOR EASTBOUND THRU  .  ISOLATED OPERATION ASSUMED.
*** 311 *** PCF VALUE NOT SPECIFIED FOR EASTBOUND LEFT  .  ISOLATED OPERATION ASSUMED.
  49    |RUN      2                                                                         |

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

                                       ANALYSIS OF TRAFFIC SIGNAL OPERATION

      PROBLEM # 1          ASHLEY DR. E KENNEDY BLVD          RUN # 2

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


*** 212 *** THE FOLLOWING MOVEMENTS WERE UNASSIGNED FOR THIS RUN:

                  MOVEMENT #  4   SOUTHBOUND LEFT
                  MOVEMENT #  5   EASTBOUND THRU

*** 211 *** THE FOLLOWING PERIODS WERE UNASSIGNED FOR THIS RUN:

                    1100., 1115., 1130., 1145., 1200., 1215., 1230., 1245.,
                    1300., 1315., 1330., 1345.,
```

Figure 29 (Cont'd). Example SOAP Output For Existing Conditions.

Table No. 22
CRITICAL VC FOR EACH PHASE

TABLE NO. 23
SUM OF CRITICAL VC FOR ALL PHASES

YCAF - SUM OF CRITICAL VC FOR ALL PHASES

TABLE NO. 39
TOTAL DELAY PER APPROACH (VEHICLE HOURS PER 15 MINUTE PERIOD)

TOTAL INTERSECTION DELAY BY PERIOD

Tables & Plots Omitted for case 2

SIGNAL OPERATION FOR: ASHLEY DR. E KENNEDY BLVD

2 DIAL CONTROLLER:

PHASING: 1 PHASE NS, 2 PHASE EW. PATTERN: A NS, WE EW.

LOST TIME PER PHASE: 3.5, TOTAL LOST TIME: 10.5

LEFT TURNS - NORTH: NONE, SOUTH: NONE, EAST: REST, WEST: REST.

MOVEMENTS		PATTERN PHASES					
		PH 1	PH 2	PH 3	PH 4	PH 5	PH 6
NORTHBOUND	THRU	XXXX					
	LEFT	XXXX					
SOUTHBOUND	THRU	XXXX					
	LEFT	XXXX					
EASTBOUND	THRU			XXXX			
	LEFT			XXXX			
WESTBOUND	THRU		XXXX				
	LEFT		XXXX				

TIME		DIAL	CYCLE	PERCENT OF CYCLE TO EACH PHASE					
FROM	TO			PH 1	PH 2	PH 3	PH 4	PH 5	PH 6
700	715	1	70.0	35.7	30.0	34.3	0.0	0.0	0.0
715	730	1	70.0	35.7	30.0	34.3	0.0	0.0	0.0
730	745	1	70.0	35.7	30.0	34.3	0.0	0.0	0.0
745	800	1	70.0	35.7	30.0	34.3	0.0	0.0	0.0
800	815	1	70.0	35.7	30.0	34.3	0.0	0.0	0.0
1730	1745	2	90.0	36.7	30.0	33.3	0.0	0.0	0.0
1745	1800	2	90.0	36.7	30.0	33.3	0.0	0.0	0.0

Figure 29 (Cont'd). Example SOAP Output For Existing Conditions.

```
*****************************        *******************************
*                           *        *              *              *
*                    * 4    *        *   *          *      *       *
*          *    3 *  *   *  *        *  **       7  *     ***      *
*         ***     *  *   ** *        * *********** *    *****      *
*  *     *****    *   ***** *        *  **      **** *      *      *
* **       *      *      ** *        *   *    *  8  *  6  *    *   *
* *****    *    *****    *  *        *        *     * ****    **   *
*  **   *  *     ***        *        *      *****   * *********** *
*   *   *  * 1    *         *        *       ***    *  5      **   *
*     2 *                   *        *        *     *          *   *
*                           *        *              *              *
*****************************        *******************************
```

ROTATION BASED ON USER CHOICE

ROTATION BASED ON USER CHOICE

Same as Case 1

SIGNAL OPERATION FOR: ASHLEY DR. E KENNEDY BLVD

2 DIAL CONTROLLER:

ANALYSIS PERIOD: 700. TO 1800. PHASING: 1 PHASE NS, 2 PHASE EW.

LEFT TURNS - NORTH: NONE, SOUTH: NONE, EAST: REST, WEST: REST.

	NORTH	SOUTH	EAST	WEST
DELAY TO THRU (VEH-HRS)	6.	22.	0.	31.
DELAY TO LEFT (VEH-HRS)	1.	0.	23.	1.
% SATURATION THRU	28.	46.	0.	69.
% SATURATION LEFT	29.	0.	50.	9.
MAX QUEUE TO THRU (VEH)	11.	19.	0.	18.
MAX QUEUE TO LEFT (VEH)	1.	0.	12.	1.
% STOPS TO THRU	34.	52.	0.	74.
% STOPS TO LEFT	36.	0.	84.	44.
EXCESS FUEL THRU (GAL)	13.	50.	0.	59.
EXCESS FUEL LEFT (GAL)	2.	0.	43.	2.
LEFT TURN CONFLICTS	0.	0.	0.	0.

SUMMARY			NORTH	SOUTH	EAST	WEST
		PH 1	GREEN	GREEN		
		PH 2				LEFT THRU
SECONDS PER VEH	16.	PH 3			LEFT THRU	
TOTAL VEH-HRS	84.	PH 4				
CRITICAL V/C	75.	PH 5				
EXCESS FUEL(GAL)	167.	PH 6				
TURN CONFLICTS	0.					

Figure 29 (Cont'd). Example SOAP Output For Existing Conditions.

```
VERSION:  1.01                 S O A P   P R O G R A M          RELEASE:  1.04 - APR  10, 1978 (MRL)
CARD #                             CARD FILE LIST               UNIVERSITY OF FLORIDA

 50    |COMPARE                                      ALL CASES               |
```

SYSTEM SUMMARY SHEET

SYSTEM ALTERNATIVES SUMMARY

PROB	RUN	INTERSECTION	TOTAL DELAY # 1	TOTAL DELAY # 2	TOTAL DELAY # 3	TOTAL DELAY # 4	EXCESS FUEL # 1	EXCESS FUEL # 2	EXCESS FUEL # 3	EXCESS FUEL # 4
1	1	ASHLEY DR. E KENNEDY BLVD	127.1				237.6			
1	2	ASHLEY DR. E KENNEDY BLVD	84.0				167.0			

COMPARISON OF CASE SYSTEMS

CASE #	CASE NAME	TOTAL DELAY	EXCESS FUEL
1	EXIST . OPERS(MIN.DATA)	127.14	237.61
2	EXIST. OPERS.(ACT.HDWY)	84.00	167.00

```
VERSION:  1.01                 S O A P   P R O G R A M          RELEASE:  1.04 - APR  10, 1978 (MRL)
CARD #                             CARD FILE LIST               UNIVERSITY OF FLORIDA

 51    |END                                                                  |

        ************************ NORMAL SOAP TERMINATION ************************
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Figure 29 (Cont'd). Example SOAP Output For Existing Conditions.

input data required for the SOAP model to define and analyze various alternatives.

One alternative which may result in improved traffic flow is to look at the potential benefits of a three dial system. Typically the AM peak traffic hour has different demand characteristics than off-peak traffic and the addition of a third dial could result in improved operations. At the same time it would also be desirable to see if a different cycle length would result in improved operation at this intersection. Therefore one alternative (Case I) is to determine optimal three dial operation and cycle length under fixed time control.

In order for the SOAP model to define and analyze a three-dial operation the user must include a separate control card for each dial. Each dial must be assigned a different number. For each control card the minimum and maximum cycle length to be evaluated must be defined. The user has the option to establish the time each dial goes into effect and the minimum length of time it will remain in operation. In the example this was specified since the intersection is part of a signal system. However, the user could leave the time in length unspecified and the model will determine which dial and cycle length is best for each time period.

Figure 31 illustrates the timing and MOE reports for the two best variations of signal operations under three-dial control. One solution is for a three-phase pattern which uses a 75 second cycle for the AM peak period, 60 second cycle for off peak and 70 second cycle for the PM peak period. The second solution is for four phase operation. Both the AM and PM periods have the same cycle length, 75 seconds, but the splits are different. There is little difference in the the MOE's, however, the three phase operation is slightly better.

A second alternative which could be looked at would be design of the signal under full actuated operation. To evaluate this alternative, it is only necessary to add a new control card under Case 2. No time or cycle length restriction were included (other than minimum green time for pedestrian clearance and model default value for maximum cycle length). Figure 32 illustrates the timing and MOE reports for the two alternative phasing schemes.

As with Case 1, the two phasing patterns determined to be practical were the three phase and four phase operations. Again, there is little difference in the MOE's for these alternatives. Even the cycle length only reduced slightly, from a minimum of 67 seconds to a maximum of 88.7 seconds.

Evaluation of Results

A comparative analysis between alternatives is an optional report from the SOAP model. Figure 33 illustrates this comparison table for the example problem.

Case 1, the optimum three dial operation has virtually the same values for the two MOE's total delay and excess fuel. This should not be unexpected in this case since the present timing has been established through field observation over a number of years. In fact, this can be taken partially as a demonstration of the model's ability to estimate optimum MOE's attainable.

Case 2, full actuation, is slightly better than the fixed time operation. However, it is not possible to attain this level due to the fact that the signal is part of a signal system and the platoon concentration factor (PCF) assumed that the subject signal would have the same cycle length as the system. Obviously, operating this signal independently of the system would result in considerable variation in the PCF. Therefore, the MOE's are higher than would realistically be achieved under full-actuation.

In summary, the evaluation of the results of SOAP indicate that little improvement can be obtained on the existing two dial operation.

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ARTERIAL: Ashley Drive CROSS STREET Kennedy Blvd CITY Tampa DATE 6/10/81

CONDITION: Alternative Designs 1) 3-dial FT; 2) Full Act.; 3) Existing CODED BY: ASB

DATA FIELD / IDENTIFICATION	A	B	1 NBT	2 NBL	3 SBT	4 SBL	5 EBT	6 EBL	7 WBT	8 WBL	C OTHER INFORMATION
BEGIN			0700	1800	15						ASHLEY DR. & KENNEDY BLVD
CASE	1										OPTIMAL DIAL & TIMING
TABLE			22	23	39						
PLOT	1										
PLOT	5										
LEFTURN				2.0							WE
CONTROL	2	0700	1	60	120						DIAL = 1 SEED
CONTROL	4	0900	2	60	120						DIAL = 2 SEED
CONTROL	2	1600	3	60	120						DIAL = 3 SEED
HEADWAY		3.5	1.9	2.5	1.9	0	0	2.2	2.0	2.5	FIELD MEASUREMENTS
MINGREEN			15	0	15	0	24	24	15	15	
VOLUME	15	0700	39	0	128	0	0	56	42	1	
VOLUME	15	0715	49	0	215	0	0	57	127	9	
VOLUME	15	0730	79	0	283	0	0	88	152	6	
VOLUME	15	0745	116	4	356	0	0	108	196	3	
VOLUME	15	0800	81	8	240	0	0	133	211	5	
VOLUME	15	0815	118	7	341	0	0	102	203	15	
VOLUME	15	0830	114	5	270	0	0	113	150	12	
VOLUME	15	0845	79	4	259	0	0	111	149	6	
VOLUME	15	0900	70	13	229	0	0	98	188	7	
VOLUME	15	0915	67	9	195	0	0	103	157	10	
VOLUME	15	0930	47	7	157	0	0	108	203	6	
VOLUME	15	0945	73	6	196	0	0	89	137	8	
VOLUME	15	1000	70	10	166	0	0	101	162	5	
VOLUME	15	1015	46	8	151	0	0	97	177	6	
VOLUME	15	1030	68	12	144	0	0	109	202	5	
VOLUME	15	1045	50	6	142	0	0	80	119	5	
VOLUME	15	1400	77	7	208			49	90	5	
VOLUME	15	1415	68	8	260			149	198	7	
VOLUME	15	1430	52	12	195			95	141	6	
VOLUME	15	1445	88	3	178			119	145	5	
VOLUME	15	1500	89	9	222			114	165	13	
VOLUME	15	1515	93	8	211			107	156	5	
VOLUME	15	1530	93	8	183			142	201	7	
VOLUME	15	1545	80	10	225			108	189	5	
VOLUME	15	1600	102	14	224			136	216	15	
VOLUME	15	1615	98	7	154			120	180	4	
VOLUME	15	1630	91	8	250			140	192	10	
VOLUME	15	1645	100	8	253			141	197	11	
VOLUME	15	1700	158	10	278			168	244	14	
VOLUME	15	1715	127	10	286			127	227	14	
VOLUME	15	1730	96	5	224			109	176	15	
VOLUME	15	1745	89	7	213	0	0	79	116	10	
CAPACITY	9	0700	2.0	1.0	3.2	0	0	1.8	2.6	1	LANE EQUIV.
CAPACITY	2	1600	2.0	1.0	3.3	0	0	1.8	2.9	1	LANE EQUIV.
PCF	11	0700	.265	.265	.350				.417	.417	PCF FOR SB EST
RUN	1										
CASE	2										FULL ACTUATION
CONTROL											FULL ACT
RUN	2										
CASE	3										EXIST. OPERS. (ACT. HDWY)
CONTROL	9	0700	1	70	70						
CONTROL	2	1600	2	90	90						
EXISTING	9	0700	25	25	25	0	24	24	21	21	A WE
EXISTING	2	1600	33	25	33	0	30	30	27	27	A WE
RUN	3										
COMPARE											ALL CASES
END											

Figure 30. Example SOAP Input Data for Alternative Designs

SIGNAL OPERATION FOR: ASHLEY DR. E KENNEDY BLVD

3 DIAL CONTROLLER:

PHASING: 1 PHASE NS, 3 PHASE EW. PATTERN: A NS, ETW EW.

LOST TIME PER PHASE: 3.5, TOTAL LOST TIME: 10.5

LEFT TURNS - NORTH: NONE, SOUTH: NONE, EAST: REST, WEST: REST.

MOVEMENTS		PATTERN PHASES PH 1	PH 2	PH 3	PH 4	PH 5	PH 6
NORTHBOUND	THRU	XXXX					
	LEFT	XXXX					
SOUTHBOUND	THRU	XXXX					
	LEFT	XXXX					
EASTBOUND	THRU		XXXX	XXXX			
	LEFT		XXXX				
WESTBOUND	THRU			XXXX	XXXX		
	LEFT				XXXX		

TIME FROM	TO	DIAL	CYCLE	PERCENT OF CYCLE TO EACH PHASE PH 1	PH 2	PH 3	PH 4	PH 5	PH 6
700	715	1	75.0	36.0	36.6	7.2	20.2	0.0	0.0
715	730	1	75.0	36.0	36.6	7.2	20.2	0.0	0.0
730	745	1	75.0	36.0	36.6	7.2	20.2	0.0	0.0
745	800	1	75.0	36.0	36.6	7.2	20.2	0.0	0.0
800	815	1	75.0	36.0	36.6	7.2	20.2	0.0	0.0
815	830	1	75.0	36.0	36.6	7.2	20.2	0.0	0.0
830	845	1	75.0	36.0	36.6	7.2	20.2	0.0	0.0
845	900	1	75.0	36.0	36.6	7.2	20.2	0.0	0.0
900	915	2	70.0	29.9	41.0	6.2	22.9	0.0	0.0
915	930	2	70.0	29.9	41.0	6.2	22.9	0.0	0.0
930	945	2	70.0	29.9	41.0	6.2	22.9	0.0	0.0
945	1000	2	70.0	29.9	41.0	6.2	22.9	0.0	0.0
1000	1015	2	70.0	29.9	41.0	6.2	22.9	0.0	0.0
1015	1030	2	70.0	29.9	41.0	6.2	22.9	0.0	0.0
1030	1045	2	70.0	29.9	41.0	6.2	22.9	0.0	0.0
1045	1100	2	70.0	29.9	41.0	6.2	22.9	0.0	0.0
1400	1415	1	75.0	36.0	36.6	7.2	20.2	0.0	0.0
1415	1430	3	75.0	34.8	36.2	8.3	20.7	0.0	0.0
1430	1445	2	70.0	29.9	41.0	6.2	22.9	0.0	0.0
1445	1500	2	70.0	29.9	41.0	6.2	22.9	0.0	0.0
1500	1515	3	75.0	34.8	36.2	8.3	20.7	0.0	0.0
1515	1530	2	70.0	29.9	41.0	6.2	22.9	0.0	0.0
1530	1545	3	75.0	34.8	36.2	8.3	20.7	0.0	0.0
1545	1600	3	75.0	34.8	36.2	8.3	20.7	0.0	0.0
1600	1615	3	75.0	34.8	36.2	8.3	20.7	0.0	0.0
1615	1630	3	75.0	34.8	36.2	8.3	20.7	0.0	0.0
1630	1645	3	75.0	34.8	36.2	8.3	20.7	0.0	0.0
1645	1700	3	75.0	34.8	36.2	8.3	20.7	0.0	0.0
1700	1715	3	75.0	34.8	36.2	8.3	20.7	0.0	0.0
1715	1730	3	75.0	34.8	36.2	8.3	20.7	0.0	0.0
1730	1745	3	75.0	34.8	36.2	8.3	20.7	0.0	0.0
1745	1800	3	75.0	34.8	36.2	8.3	20.7	0.0	0.0

SIGNAL OPERATION FOR: ASHLEY DR. E KENNEDY BLVD

3 DIAL CONTROLLER:

ANALYSIS PERIOD: 700. TO 1800. PHASING: 1 PHASE NS, 3 PHASE EW.

LEFT TURNS - NORTH: NONE, SOUTH: NONE, EAST: REST, WEST: REST.

	NORTH	SOUTH	EAST	WEST
DELAY TO THRU (VEH-HRS)	6.	22.	0.	35.
DELAY TO LEFT (VEH-HRS)	3.	0.	20.	1.
% SATURATION THRU	30.	50.	0.	72.
% SATURATION LEFT	42.	0.	45.	12.
MAX QUEUE TO THRU (VEH)	9.	20.	0.	15.
MAX QUEUE TO LEFT (VEH)	1.	0.	10.	1.
% STOPS TO THRU	35.	54.	0.	76.
% STOPS TO LEFT	46.	0.	80.	46.
EXCESS FUEL THRU (GAL)	13.	51.	0.	62.
EXCESS FUEL LEFT (GAL)	3.	0.	39.	2.
LEFT TURN CONFLICTS	1.	0.	0.	0.

SUMMARY			NORTH	SOUTH	EAST	WEST
		PH 1	GREEN	GREEN		
		PH 2			LEFT THRU	
SECONDS PER VEH	16.	PH 3			THRU	THRU
TOTAL VEH-HRS	87.	PH 4				LEFT THRU
CRITICAL V/C	77.	PH 5				
EXCESS FUEL(GAL)	170.	PH 6				
TURN CONFLICTS	1.					

SIGNAL OPERATION FOR: ASHLEY DR. E KENNEDY BLVD

3 DIAL CONTROLLER:

PHASING: 1 PHASE NS, 2 PHASE EW. PATTERN: A NS, EW EW.

LOST TIME PER PHASE: 3.5, TOTAL LOST TIME: 10.5

LEFT TURNS - NORTH: NONE, SOUTH: NONE, EAST: REST, WEST: REST.

MOVEMENTS		PATTERN PHASES PH 1	PH 2	PH 3	PH 4	PH 5	PH 6
NORTHBOUND	THRU	XXXX					
	LEFT	XXXX					
SOUTHBOUND	THRU	XXXX					
	LEFT	XXXX					
EASTBOUND	THRU		XXXX				
	LEFT		XXXX				
WESTBOUND	THRU			XXXX			
	LEFT			XXXX			

TIME FROM	TO	DIAL	CYCLE	PERCENT OF CYCLE TO EACH PHASE PH 1	PH 2	PH 3	PH 4	PH 5	PH 6
700	715	1	75.0	36.0	36.6	27.4	0.0	0.0	0.0
715	730	1	75.0	36.0	36.6	27.4	0.0	0.0	0.0
730	745	1	75.0	36.0	36.6	27.4	0.0	0.0	0.0
745	800	1	75.0	36.0	36.6	27.4	0.0	0.0	0.0
800	815	1	75.0	36.0	36.6	27.4	0.0	0.0	0.0
815	830	1	75.0	36.0	36.6	27.4	0.0	0.0	0.0
830	845	1	75.0	36.0	36.6	27.4	0.0	0.0	0.0
845	900	1	75.0	36.0	36.6	27.4	0.0	0.0	0.0
900	915	2	60.0	29.9	41.0	29.1	0.0	0.0	0.0
915	930	2	60.0	29.9	41.0	29.1	0.0	0.0	0.0
930	945	2	60.0	29.9	41.0	29.1	0.0	0.0	0.0
945	1000	2	60.0	29.9	41.0	29.1	0.0	0.0	0.0
1000	1015	2	60.0	29.9	41.0	29.1	0.0	0.0	0.0
1015	1030	2	60.0	29.9	41.0	29.1	0.0	0.0	0.0
1030	1045	2	60.0	29.9	41.0	29.1	0.0	0.0	0.0
1045	1100	2	60.0	29.9	41.0	29.1	0.0	0.0	0.0
1400	1415	1	75.0	36.0	36.6	27.4	0.0	0.0	0.0
1415	1430	3	70.0	34.8	36.2	28.9	0.0	0.0	0.0
1430	1445	2	60.0	29.9	41.0	29.1	0.0	0.0	0.0
1445	1500	2	60.0	29.9	41.0	29.1	0.0	0.0	0.0
1500	1515	3	70.0	34.8	36.2	28.9	0.0	0.0	0.0
1515	1530	2	60.0	29.9	41.0	29.1	0.0	0.0	0.0
1530	1545	3	70.0	34.8	36.2	28.9	0.0	0.0	0.0
1545	1600	3	70.0	34.8	36.2	28.9	0.0	0.0	0.0
1600	1615	3	70.0	34.8	36.2	28.9	0.0	0.0	0.0
1615	1630	3	70.0	34.8	36.2	28.9	0.0	0.0	0.0
1630	1645	3	70.0	34.8	36.2	28.9	0.0	0.0	0.0
1645	1700	3	70.0	34.8	36.2	28.9	0.0	0.0	0.0
1700	1715	3	70.0	34.8	36.2	28.9	0.0	0.0	0.0
1715	1730	3	70.0	34.8	36.2	28.9	0.0	0.0	0.0
1730	1745	3	70.0	34.8	36.2	28.9	0.0	0.0	0.0
1745	1800	3	70.0	34.8	36.2	28.9	0.0	0.0	0.0

SIGNAL OPERATION FOR: ASHLEY DR. E KENNEDY BLVD

3 DIAL CONTROLLER:

ANALYSIS PERIOD: 700. TO 1800. PHASING: 1 PHASE NS, 2 PHASE EW.

LEFT TURNS - NORTH: NONE, SOUTH: NONE, EAST: REST, WEST: REST.

	NORTH	SOUTH	EAST	WEST
DELAY TO THRU (VEH-HRS)	6.	21.	0.	36.
DELAY TO LEFT (VEH-HRS)	3.	0.	19.	1.
% SATURATION THRU	31.	51.	0.	73.
% SATURATION LEFT	43.	0.	46.	9.
MAX QUEUE TO THRU (VEH)	9.	20.	0.	14.
MAX QUEUE TO LEFT (VEH)	1.	0.	9.	1.
% STOPS TO THRU	35.	54.	0.	77.
% STOPS TO LEFT	47.	0.	81.	45.
EXCESS FUEL THRU (GAL)	13.	51.	0.	63.
EXCESS FUEL LEFT (GAL)	3.	0.	39.	2.
LEFT TURN CONFLICTS	1.	0.	0.	0.

SUMMARY			NORTH	SOUTH	EAST	WEST
		PH 1	GREEN	GREEN		
		PH 2			LEFT THRU	
SECONDS PER VEH	16.	PH 3				LEFT THRU
TOTAL VEH-HRS	85.	PH 4				
CRITICAL V/C	77.	PH 5				
EXCESS FUEL(GAL)	170.	PH 6				
TURN CONFLICTS	1.					

Figure 31. Example SOAP Output for Alternate 3 Dial Operation (Case 1).

SIGNAL OPERATION FOR: ASHLEY DR. E KENNEDY BLVD

ACTUATED CONTROLLER:

PHASING: 1 PHASE NS, 2 PHASE EW. PATTERN: A NS, EW EW.

LOST TIME PER PHASE: 3.5, TOTAL LOST TIME: 10.5

LEFT TURNS - NORTH: NONE, SOUTH: NONE, EAST: REST, WEST: REST.

MOVEMENTS		PATTERN PHASES PH 1	PH 2	PH 3	PH 4	PH 5	PH 6
NORTHBOUND	THRU	XXXX					
	LEFT	XXXX					
SOUTHBOUND	THRU	XXXX					
	LEFT	XXXX					
EASTBOUND	THRU		XXXX				
	LEFT		XXXX				
WESTBOUND	THRU			XXXX			
	LEFT			XXXX			

TIME FROM	TO	DIAL	CYCLE	PERCENT OF CYCLE TO EACH PHASE PH 1	PH 2	PH 3	PH 4	PH 5	PH 6
700	715	XXXX	67.0	31.7	38.7	29.6	0.0	0.0	0.0
715	730	XXXX	74.0	32.6	35.5	31.9	0.0	0.0	0.0
730	745	XXXX	75.2	32.6	35.1	32.3	0.0	0.0	0.0
745	800	XXXX	88.7	38.6	32.2	29.2	0.0	0.0	0.0
800	815	XXXX	72.3	33.2	34.7	32.1	0.0	0.0	0.0
815	830	XXXX	84.1	40.8	28.9	30.3	0.0	0.0	0.0
830	845	XXXX	80.2	34.8	36.1	29.1	0.0	0.0	0.0
845	900	XXXX	69.0	33.4	36.8	29.8	0.0	0.0	0.0
900	915	XXXX	76.2	37.1	31.4	31.5	0.0	0.0	0.0
915	930	XXXX	75.1	32.1	37.5	30.3	0.0	0.0	0.0
930	945	XXXX	74.6	28.1	38.4	33.5	0.0	0.0	0.0
945	1000	XXXX	74.6	34.2	35.3	30.5	0.0	0.0	0.0
1000	1015	XXXX	73.3	31.5	37.4	31.1	0.0	0.0	0.0
1015	1030	XXXX	75.8	30.7	36.5	32.8	0.0	0.0	0.0
1030	1045	XXXX	72.9	30.4	36.1	33.6	0.0	0.0	0.0
1045	1100	XXXX	68.6	31.6	37.1	31.3	0.0	0.0	0.0
1400	1415	XXXX	76.3	36.3	34.0	29.7	0.0	0.0	0.0
1415	1430	XXXX	74.4	32.6	37.1	30.3	0.0	0.0	0.0
1430	1445	XXXX	71.4	34.8	33.9	31.2	0.0	0.0	0.0
1445	1500	XXXX	69.3	30.0	38.1	31.9	0.0	0.0	0.0
1500	1515	XXXX	75.4	34.7	36.7	28.7	0.0	0.0	0.0
1515	1530	XXXX	68.5	33.1	36.2	30.7	0.0	0.0	0.0
1530	1545	XXXX	68.9	29.7	36.5	33.8	0.0	0.0	0.0
1545	1600	XXXX	79.1	33.2	35.4	31.5	0.0	0.0	0.0
1600	1615	XXXX	71.5	34.8	35.3	30.0	0.0	0.0	0.0
1615	1630	XXXX	69.3	30.4	38.2	31.4	0.0	0.0	0.0
1630	1645	XXXX	69.9	33.9	36.1	30.0	0.0	0.0	0.0
1645	1700	XXXX	73.9	33.9	35.9	30.3	0.0	0.0	0.0
1700	1715	XXXX	71.8	34.4	35.1	30.5	0.0	0.0	0.0
1715	1730	XXXX	74.8	35.5	33.5	31.0	0.0	0.0	0.0
1730	1745	XXXX	71.4	33.1	36.2	30.7	0.0	0.0	0.0
1745	1800	XXXX	71.1	36.8	34.0	29.2	0.0	0.0	0.0

SIGNAL OPERATION FOR: ASHLEY DR. E KENNEDY BLVD

ACTUATED CONTROLLER:

PHASING: 1 PHASE NS, 3 PHASE EW. PATTERN: A NS, ETW EW.

LOST TIME PER PHASE: 3.5, TOTAL LOST TIME: 10.5

LEFT TURNS - NORTH: NONE, SOUTH: NONE, EAST: REST, WEST: REST.

MOVEMENTS		PATTERN PHASES PH 1	PH 2	PH 3	PH 4	PH 5	PH 6
NORTHBOUND	THRU	XXXX					
	LEFT	XXXX					
SOUTHBOUND	THRU	XXXX					
	LEFT	XXXX					
EASTBOUND	THRU		XXXX	XXXX			
	LEFT		XXXX				
WESTBOUND	THRU			XXXX	XXXX		
	LEFT				XXXX		

TIME FROM	TO	DIAL	CYCLE	PERCENT OF CYCLE TO EACH PHASE PH 1	PH 2	PH 3	PH 4	PH 5	PH 6
700	715	XXXX	67.0	31.7	38.7	2.4	27.2	0.0	0.0
715	730	XXXX	74.0	32.6	35.5	7.8	24.0	0.0	0.0
730	745	XXXX	75.2	32.6	35.1	12.0	20.3	0.0	0.0
745	800	XXXX	88.7	38.6	32.2	12.9	16.3	0.0	0.0
800	815	XXXX	72.3	33.2	34.7	12.0	20.2	0.0	0.0
815	830	XXXX	84.1	40.8	28.9	12.6	17.7	0.0	0.0
830	845	XXXX	80.2	34.8	36.1	9.6	19.5	0.0	0.0
845	900	XXXX	69.0	33.4	36.8	9.1	20.7	0.0	0.0
900	915	XXXX	76.2	37.1	31.4	13.5	18.0	0.0	0.0
915	930	XXXX	75.1	32.1	37.5	8.7	21.7	0.0	0.0
930	945	XXXX	74.6	28.1	38.4	10.5	23.0	0.0	0.0
945	1000	XXXX	74.6	34.2	35.3	9.4	21.0	0.0	0.0
1000	1015	XXXX	73.3	31.5	37.4	8.3	22.8	0.0	0.0
1015	1030	XXXX	75.8	30.7	36.5	12.5	20.3	0.0	0.0
1030	1045	XXXX	72.9	30.4	36.1	13.4	20.1	0.0	0.0
1045	1100	XXXX	68.6	31.6	37.1	8.3	23.0	0.0	0.0
1400	1415	XXXX	76.3	36.3	34.0	7.1	22.6	0.0	0.0
1415	1430	XXXX	74.4	32.6	37.1	12.2	18.1	0.0	0.0
1430	1445	XXXX	71.4	34.8	33.9	10.7	20.5	0.0	0.0
1445	1500	XXXX	69.3	30.0	38.1	11.6	20.3	0.0	0.0
1500	1515	XXXX	75.4	34.7	36.7	6.1	22.6	0.0	0.0
1515	1530	XXXX	68.5	33.1	36.2	10.4	20.4	0.0	0.0
1530	1545	XXXX	68.9	29.7	36.5	12.8	21.0	0.0	0.0
1545	1600	XXXX	79.1	33.2	35.4	11.6	19.8	0.0	0.0
1600	1615	XXXX	71.5	34.8	35.3	9.1	20.9	0.0	0.0
1615	1630	XXXX	69.3	30.4	38.2	11.4	20.0	0.0	0.0
1630	1645	XXXX	69.9	33.9	36.1	8.1	22.0	0.0	0.0
1645	1700	XXXX	73.9	33.9	35.9	10.8	19.4	0.0	0.0
1700	1715	XXXX	71.8	34.4	35.1	11.3	19.2	0.0	0.0
1715	1730	XXXX	74.8	35.5	33.5	10.6	20.4	0.0	0.0
1730	1745	XXXX	71.4	33.1	36.2	7.2	23.5	0.0	0.0
1745	1800	XXXX	71.1	36.8	34.0	7.3	21.9	0.0	0.0

SIGNAL OPERATION FOR: ASHLEY DR. E KENNEDY BLVD

ACTUATED CONTROLLER:

ANALYSIS PERIOD: 700. TO 1800. PHASING: 1 PHASE NS, 2 PHASE EW.

LEFT TURNS - NORTH: NONE, SOUTH: NONE, EAST: REST, WEST: REST.

	NORTH	SOUTH	EAST	WEST
DELAY TO THRU (VEH-HRS)	6.	22.	0.	25.
DELAY TO LEFT (VEH-HRS)	2.	0.	20.	1.
% SATURATION THRU	30.	50.	0.	66.
% SATURATION LEFT	40.	0.	48.	8.
MAX QUEUE TO THRU (VEH)	9.	23.	0.	14.
MAX QUEUE TO LEFT (VEH)	1.	0.	9.	1.
% STOPS TO THRU	35.	53.	0.	71.
% STOPS TO LEFT	43.	0.	82.	44.
EXCESS FUEL THRU (GAL)	13.	51.	0.	53.
EXCESS FUEL LEFT (GAL)	2.	0.	41.	2.
LEFT TURN CONFLICTS	0.	0.	0.	0.

SUMMARY			NORTH	SOUTH	EAST	WEST
		PH 1	GREEN	GREEN		
		PH 2			LEFT THRU	
SECONDS PER VEH	14.	PH 3				LEFT THRU
TOTAL VEH-HRS	76.	PH 4				
CRITICAL V/C	87.	PH 5				
EXCESS FUEL(GAL)	162.	PH 6				
TURN CONFLICTS	0.					

SIGNAL OPERATION FOR: ASHLEY DR. E KENNEDY BLVD

ACTUATED CONTROLLER:

ANALYSIS PERIOD: 700. TO 1800. PHASING: 1 PHASE NS, 3 PHASE EW.

LEFT TURNS - NORTH: NONE, SOUTH: NONE, EAST: REST, WEST: REST.

	NORTH	SOUTH	EAST	WEST
DELAY TO THRU (VEH-HRS)	6.	22.	0.	25.
DELAY TO LEFT (VEH-HRS)	2.	0.	20.	1.
% SATURATION THRU	30.	50.	0.	66.
% SATURATION LEFT	40.	0.	48.	12.
MAX QUEUE TO THRU (VEH)	9.	23.	0.	14.
MAX QUEUE TO LEFT (VEH)	1.	0.	9.	1.
% STOPS TO THRU	35.	53.	0.	71.
% STOPS TO LEFT	43.	0.	82.	46.
EXCESS FUEL THRU (GAL)	13.	51.	0.	53.
EXCESS FUEL LEFT (GAL)	2.	0.	41.	2.
LEFT TURN CONFLICTS	0.	0.	0.	0.

SUMMARY			NORTH	SOUTH	EAST	WEST
		PH 1	GREEN	GREEN		
		PH 2			LEFT THRU	
SECONDS PER VEH	14.	PH 3			THRU	THRU
TOTAL VEH-HRS	77.	PH 4				LEFT THRU
CRITICAL V/C	87.	PH 5				
EXCESS FUEL(GAL)	162.	PH 6				
TURN CONFLICTS	0.					

Figure 32. Example SOAP Output for Alternate Actuated Operation.

S Y S T E M   S U M M A R Y   S H E E T

S Y S T E M   A L T E R N A T I V E S   S U M M A R Y

PROB	RUN	INTERSECTION	TOTAL DELAY # 1	TOTAL DELAY # 2	TOTAL DELAY # 3	TOTAL DELAY # 4	EXCESS FUEL # 1	EXCESS FUEL # 2	EXCESS FUEL # 3	EXCESS FUEL # 4
1	1	ASHLEY DR. E KENNEDY BLVD	84.9	87.2			170.0	170.4		
1	2	ASHLEY DR. E KENNEDY BLVD	76.4	76.6			161.7	161.8		
1	3	ASHLEY DR. E KENNEDY BLVD	84.0				167.0			

C O M P A R I S O N   O F   C A S E   S Y S T E M S

CASE #	CASE NAME	TOTAL DELAY	EXCESS FUEL
1	OPTIMAL DIAL & TIMING	84.94	169.99
2	FULL ACTUATION	76.45	161.71
3	EXIST. OPERS.(ACT.HDWY)	84.00	167.00

Figure 33. Example SOAP Output for Comparative Analysis.

However, if three dial operation would improve traffic flow at adjacent intersections then the results obtained for this SOAP output could be used to retime the signal with little change in level of service.

Summary of Work Effort Required

The following provide a brief summary of the work effort required for the above example problem.

Data Collection - Since the city maintained a file with plans showing intersection geometrics and signal operation, as well as records of existing signal timing and recent traffic counts, the data collection time for these elements was minimal. In order to obtain field data to calibrate the model for existing operations, approximately eight hours of technician time was utilized to obtain headway data for left turn and thru movements for each approach during two periods of the day. However, typical area-wide headway data obtained over a period of time could eliminate the need for this information except in unusual circumstances. Approximately six manhours of technician time was also utilized to obtain an estimate of the PCF for three approaches. This type of data would not normally be coded except where fixed time operation occurs and traffic flow is affected by adjacent signals within an interconnected system. The PCF may also be estimated by making a run with the TRANSYT-7F or SIGOP III models.

Data Coding - Using the coding form the data for existing conditions were coded within a two hour period. Since the existing conditions had been run, the coding required for defining and evaluating alternatives took less than one hour.

Computational - Most SOAP problems require considerably less than one minute of execution time. The calibration run took 1:59 seconds of CPU time while the optimization run took 6.52 seconds of CPU time. Core storage of 180K was required for each run.

REFERENCES

4.1 "Signal Operations Analysis Package - Executive Summary," University or Florida Transportation Research Center, FHWA Implementation Package 78-4, January, 1978.

4.2 "Signal Operations Analysis Package - Volume I - Computational Methodology," University of Florida Transportation Research Center, FHWA Implementation Package 78-4, January, 1978.

4.3 "Signal Operations Analysis Package - Volume II - User's Manual," University of Florida Transportation Research Center, FHWA Implementation Package 78-4, January, 1978.

4.4 "Signal Operations Analysis Package - Volume III - Programmer's Manual," University or Florida Transportation Research Center, FHWA Implementation Package 78-4, January, 1978.

4.5 "Signal Operations Analysis Package - Volume IV - Portable Calculator Routines," University of Florida Transportation Research Center, FHWA Implementation Package 78-4, January, 1978.

4.6 Webster, F.V., and B.M. Cobbe, "Traffic Signals," Road Research Technical Paper No. 56, London, 1966.

4.7 Claffey, P.J., "Running Costs of Motor Vehicles as Affected by Road Design and Traffic," NCHRP Report 111, 1971.

4.8 Tanner, J.C., "A Problem of Interface Between Two Queues," Biometrika Vol. 40, 1953.

4.9 Wagner, F.A., et al., "Improved Criteria for Traffic Signal Systems in Urban Networks," NCHRP Report 124, 1971.

4.10 "Definition and Measurement of Delay at Intersections, Volume 3 User's Manual," JHK and Association, FHWA Research Report 76-137,..............

Reports on the "Signal Operations Analysis Package", Implementation Package IP-79-9 are available from the Superintendent of Documents Government Printing Office, Washington, D.C. 20402 as follows:

Volume			
1	Computational Methodology	050-001-00151-9	2.50
2	User's Manual	050-001-00152-7	5.50
3	Portable Calculator Routines HP 67/97	050-001-00153-5	4.25
4	Portable Calculator Routines SR52/T159	050-001-00154-3	5.00
5	Programmer's Manual	050-001-00155-1	5.00

CHAPTER 5 - TEXAS (INTERSECTION SIMULATION)

Single intersection models such as SOAP (described in the previous chapter) are usually deterministic models which deal with traffic macroscopically and are primarily concerned with signal timing. However, several other aspects of highway intersections are of equal importance to the designer. Clearly the geometrics of the intersection are of great interest to designers. This aspect is generally treated by most models only as to its effect on capacity. Thus consideration of geometrics is largely based on analytical studies.

Another aspect even less open to mathematical treatment is driver behavior and its (reciprocal) effects on signal timing and geometrics. Driver behavior has been the target of numerous empirical studies, but results of these studies are difficult to transfer into a measurable effect that can be considered in intersection design by analytical or optimization methods. Only in the field of safety analysis has driver behavior been successfully accounted for in earlier applications.

Moreover, all intersections are not controlled by traffic signals. Many, indeed a far greater number than are signalized, either have stop or yield sign control or no control at all. There has been no effective tool for practitioners to analyze such intersections, other than by field studies.

With the growing complexity of intersection design and concern for improved planning and design of the highway and street system, the need for a relatively inexpensive method for detailed study of the variety of intersections and control techniques has become evident. To meet this need, the University of Texas' Center for Highway Research has developed the TEXAS simulation model for the Texas State Department of Highways and Public Transportation (SDHPT) to perform microscopic simulations of isolated intersections. The SDHPT maintains this model.

Figure 34. Intersection Geometric Problems

The TEXAS (Traffic EXperimental and Analytical Simulation) model is strictly an analysis tool. It does not recommend design decisions; it rigorously analyzes the particular set of conditions input. The user can evaluate alternative designs by performing several simulations with varied input parameters or data.

The model will simulate any intersection from two uncontrolled one-way streets to complex intersections with multiphase control, and/or multiple lane movements. Traffic control may be none, priority movement (e.g., stop or yield) or signalized. Signalization can be two-phase or up to six-phase pretimed; to eight-phase, dual ring, semiactuated or full actuated; and have protected, permissive or unprotected turns. There are virtually no restrictions on the configurations of the intersection that may be analyzed, thus, any intersection that is feasible from an engineering perspective can be simulated.

An extensive array of statistics are maintained and output by the TEXAS model, including delays, stops, queues, vehicle-miles, travel time, movement counts, and conflicts to name but a few of the most important.

Thus, the TEXAS simulation model is a valuable tool, which enables traffic engineers to evaluate proposed designs in the office without expensive and potentially dangerous field implementation.

MODEL DESCRIPTION

The TEXAS model was written at the Center for Highway Research at the University of Texas at Austin. The original FORTRAN IV program consists of over 14,700 lines of executable statements and an additional 4940 lines of internal documentation and comments. While TEXAS was written for a CDC 6600 computer, modifications are available for conversion to IBM OS/360. Two installation-specific subroutines are included, but FORTRAN versions of these are available. The model, which runs in three separate steps, requires a maximum of 110K octal words on the CDC computer and 210k bytes on the IBM computer.

Execution time is highly variable, dependent upon the nature of the case being simulated. But, in general, execution time eight to forty-eight times faster than real time on the CDC computer. On the IBM, execution times are somewhat longer.

The model contains three major subprograms which, as stated earlier, run independently. The Geometry Processor reads geometric data and "constructs" the physical intersection. Plots of the intersection and printed details are output, as well as outputs to a tape to be used later. The Driver-Vehicle Processor reads input data and "creates" the driver-vehicle traffic stream to be used in the traffic simulation. A number of classes of vehicles allow for the natural stochastic variation in traffic flow. Printed details and tape outputs for further use are also produced at this stage.

The main subprogram is the Simulation Processor, which reads the previous data tapes as well as additional card inputs (e.g., traffic control and other parameters), and performs the simulation. The Simulation Processor is a microscopic, stochastic simulation model with time scan updating. Outputs are punch card, printed results and graphic displays.

INPUT REQUIREMENTS

The necessary inputs for the TEXAS model were designed to be user oriented and minimal. There are two basic formats for the three processors in the model. Since the pre-simulation processors, the Geometry Processor (GEOPRO) and the Driver-Vehicle Processor (DVPRO), utilize the same input data, only one input format is required for the two processors. The simulation processor (SIMPRO) has its own separate input format. Both formats include alphanumeric coding.

Four basic types of information must be provided for the pre-simulation processors:

1. geometric information about the intersection including number of approaches, number of lanes, etc.,
2. traffic data such as volumes, speeds, etc.,
3. types of vehicles to be included in the simulation, and
4. types of drivers.

These values are primarily user-specified within certain limits. In addition, the GEOPRO plot output may be specified. Table 8 provides a summary description of the input

Table 8 - Input Requirements for Pre-Simulation Processors - TEXAS

CARD NAME	PURPOSE	DATA REQUIREMENTS
TITLE (1 per run)	Provide title of simulation	User information
NIBA (1 per run)	Define no. of inbound approaches	Total inbound approaches (max. 6)
LIBA (1 per run)	Identify nos. assigned for each inbound approach	Assign numbers 1-6
NOBA (1 per run)	Define no. of outbound approaches	Total outbound approaches
LOBA (1 per run)	Identify no. assigned for each outbound approach	Assign numbers 1-12
PARAMETER (1 per run)	Define simu. time, min. headways, no. vehicle & driver classes and % vehicles entering correct lane	Use default values or data from field studies
APPROACH LOCATION AND TRAFFIC FLOW (1 per run)	Define approach location and Traffic Operation Characteristics of each approach	Direction (azmuith), length (coordinates), no. lanes, speed limit, vol., types headway dist. and parameters, speed, etc.
TRAFFIC MIX (Optional)	Define percent of vehicle classes in traffic stream by class	Percent of vehicles in each class
LANE GEOMETRY (1 for each two lanes)	Define lane geometrics, legal movements and % traffic in each lane at begin of approach	Lane widths, length, legal movements (left, thru, right and/or U-turn) and percent traffic
ARC #1 (1 per run)	Identify number of arcs to complete geometry	Total number of arcs to be defined (max. 20)
ARC #2 (1 per line)	Define arc location and radius (curb returns, islands, etc.)	Begin azimuth, X & Y coordinates, degree of arc (sweep and radius)
Line #1 (1 per run)	Identify number of straight lines required to complete geometry	Total number of lines to be defined (max. 100)
Line #2 (1 per line))	Define each line required for islands, parking lanes, etc.	Begin and end X & Y coordinates.
SDR #1 (1 per run)	Identify number of sight distance restrictions	Total number of sight distance restrictions (max. 20)
SCR #2 (1 card per location)	Define each sight distance restriction	X & Y Coordinate of each corner (of building or tree line)
PLOT	Define plot info. for drawings (none, approaches, intersection)	Type of ink pen, scale desired, max. radius for paths, paper width, etc.)
OPTIONS	Identifies whether user is sup. vehicle and/or driver class. and to request summaries by class	Yes or no decision by user
DRIVER MIX (Optional)	Define driver mix	Percent of drivers in each class (max. 5)
VEHICLE LENGTH (Optional)	Define vehicle length	Length of vehicle in each class
VEHICLE CHARACTERISTICS (Optional)	Define vehicle operating characteristics	Type of vehicle operations (sluggish, average, responsive) for each class
DECEL (Optional)	Define max. uniform deceleration	deceleration rate (ft/sec/sec) for each class

Table 8 - Input Requirements for Pre-Simulation Processors - TEXAS (Continued)

CARD NAME	PURPOSE	DATA REQUIREMENTS
ACCEL (Optional)	Define max. uniform acceleration rate	Acceleration rate (ft/sec/sec) for each class
VELOCITY (Optional)	Define maximum velocity	Maximum velocity (ft/sec) for each class
VEHICLE RADIUS (Optional)	Define minimum turning radius	Minimum turning radius (ft) for each class
DRIVER O.F. (Optional)	Define operating characteristics	Type of driver (slow, average, aggressive) for each class
PIJR (Optional)	Define perception reaction time time	Driver perception reaction time for each class
SPECIAL VEHICLE (Optional)	To obtain data on a specific vehicle and driver class	Time period, location and type of vehicle, driver and speed

Table 9 - Input Requirements for Simulation Processor - TEXAS

CARD NAME	PURPOSE	DATA REQUIREMENTS
TITLE	Provide title of simulation	Arbitrary name
PARAMETER (1 per run)	Define simulation parameters	Time & length of simulation period, delay definition, car following equations, type traffic control, type of statistics requested, etc.
LANE CONTROL	Define type of control for each lane	Type of control (none, yield, stop, signal, etc.)
CAM STACK #1 (one per run, if signal)	Define number of intervals (cam stacks) for signal control	Number of intervals (cam stacks) in signal cycle
CAM STACK #2 (one for each interval)	Define lane control for each interval or cam stack	Phase number, interval length in secs (if fixed time) & signal indication for each lane
PHASE #1 (one per run, if signal)	Define number of phases	Total number of phases (max. 8)
PHASE #2 (semi-actuated signal only)	Define timing for street (non-actuated) phase for semi-actuated signal	Min. Green, amber, all-red intervals and the phase nos. which can be cleared to directly from this phase
PHASE #3 (one per actuated signal phase)	Define timing for each minor phase	Initial interval, vehicle interval, amber & all red clearance, max. extension, skip, & recall switches, clear to phase nos., type of detector connection, etc.
PHASE #4 (one per actuated phase)	Define detectors attached to each actuated phase	Detectors attached to this phase and type of operation

format for the pre-simulation processors. A typical deck stack is shown in Figure 35.

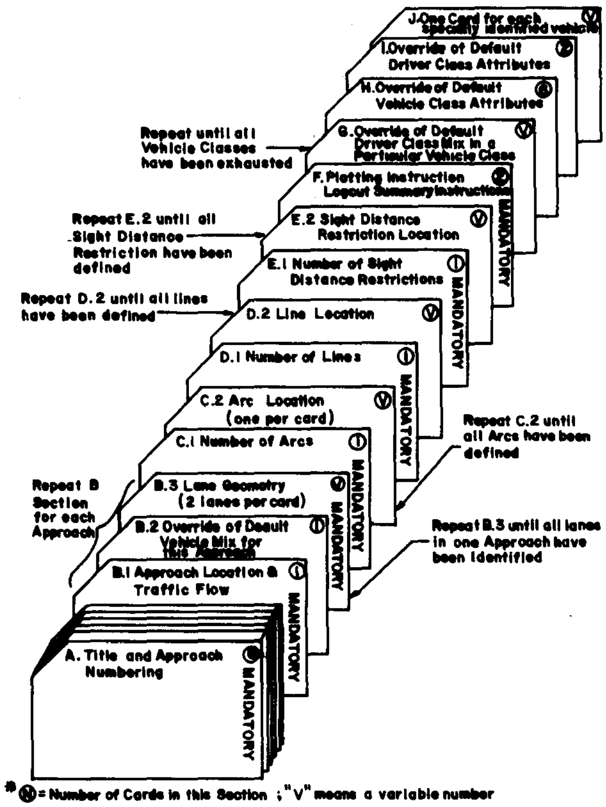

Figure 35. Pre-simulation Input Deck Stack

Input for the simulation processor consists of control parameters for the simulation itself and specifications regarding the traffic control devices at the study intersection. Table 9 outlines the input requirements for the simulation processor.

A complete description of the input requirements for the TEXAS model is given in Reference 5.3.

OPERATIONAL SUMMARY

TEXAS is a microscopic, deterministic and stochastic time-scan simulation model. Random effects are built into the data stream by specifying various classifications of driver-vehicle units. As noted previously, there are three major subprograms in the overall model, which are discussed individually below.

Geometry Processor

The purpose of the Geometry Processor (GEOPRO) is to describe the physical system to be simulated. The attributes of the system remain constant for any simulation of the physical configuration input. The geometric configuration of the intersection is usually based on the engineering data available from a scaled engineering drawing of the intersection. The only significant restrictions on the geometric layout is that all approaches must be linear, but may approach at

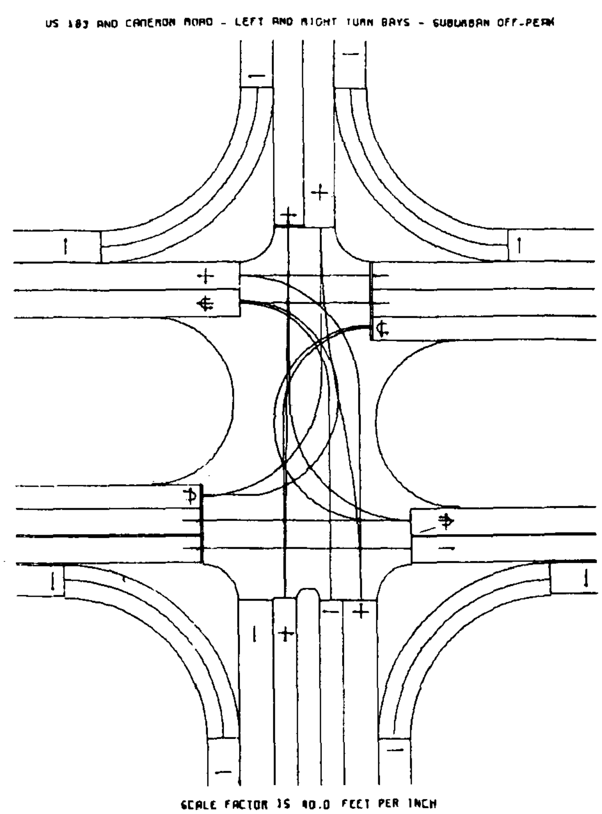

Figure 36. Typical Output of GEOPRO

any reasonable angle and may have no vertical curves. Curb radii, vehicle paths and lanes are all realistically flexible and bays (or parking in portions of lanes) can be described as lanes which are available only for specified sections.

After "constructing" the geometric layout, GEOPRO determines all allowable vehicle paths through the intersection and identifies all points of conflict. Lane changing within the intersection may be permitted as an option. Maximum speeds, sight distance restrictions and conflicts (including non-crossing conflicts, such as merges or close passing of opposing left-turns) are generated by GEOPRO. Plots of the intersection and vehicle paths are output by GEOPRO as are printed details and coded data output to tape to be used by the Simulation Processor.

Driver-Vehicle Processor

As noted earlier, the Driver-Vehicle Processor (DVPRO) reads the same data as GEOPRO, this subprogram is concerned with the preprocessing of driver-vehicle units. The data are generally available from routine traffic studies, and were described earlier. It is primarily in DVPRO where the random, or stochastic variation in the traffic stream is applied. The user may specify the number of driver and vehicle classes (defaults are three and ten, respectively). Driver classes are, for example, nonaggressive, normal or aggressive. Vehicle characteristics are length, vehicle operational factor (e.g., sluggish, normal or responsive), maximum acceleration and deceleration rates, maximum speed, and turning radius. Based on the percentage of drivers and vehicles assigned to each of the several classes a driver-vehicle class matrix is generated. The traffic streams (per approach) are generated by randomly assigning the above classes to each individual vehicle to be simulated. Thus, an input "queue" is built into arrays and each driver-vehicle unit is fully described in terms of the (mostly) randomly assigned attributes which are:

Table 10 - TEXAS Default Driver and Vehicle Characteristics

	1	2	3	4	5	6	7	8	9	10
	Small Car	Medium Car	Large Car	Vans, Mini-bus	Single unit	Semi-trailer	Full trailer	Recreational	Bus	Sports Car
Length	15	17	19	25	30	50	55	25	35	14
Operating Characteristics Factor	100	110	110	100	85	80	75	90	85	115
Maximum Deceleration	8	11	11	8	11	11	11	8	11	12
Maximum Acceleration	8	9	11	8	8	7	6	6	5	14
Maximum Velocity	150	192	200	150	160	160	150	150	125	205
Minimum Turning Radius	20	22	24	28	42	40	45	28	28	20
Percentage Aggressive Drivers	30	35	20	25	40	50	50	20	25	50
Percentage Average Drivers	40	35	40	50	30	40	40	30	50	40
Percentage Slow Drivers	30	30	40	25	30	10	10	50	25	10
Percentage in Traffic Stream	20	32	30	15	.5	.2	.1	.2	.5	1.5

	1	2	3
Driver Class and Type	Aggresive	Average	Slow
Driver Characteristics Factor	110	100	85
Perception-Reaction Time	0.5	1.0	1.5

- o queue-in time (sum of previous headways, or arrival time)
- o driver class number
- o vehicle class number
- o desired speed
- o desired outbound approach number
- o inbound lane number (inbound approach numbers are not randomly assigned)

Table 10 shows the default values used for the various characteristics. A variety of probability distributions are used to assign the above attributes, as discussed in a later section. At present, the only major limitations in this section are that pedestrian interference is not considered and there are no provisions for horizontal or vertical curves on the approaches.

Outputs are printed summaries of the input streams and coded data written to tape for use in the simulation model.

Traffic Simulation Processor

This subprogram (SIMPRO) is the actual simulation model. Using previously generated data stored on magnetic tape and further card inputs to establish parameters to be used, SIMPRO performs the dynamic activity computations required for the simulation.

SIMPRO handles the physical case of any single, multi-leg, multi-lane, mixed traffic intersection (including split intersections) either without control or with any conventional type of traffic sign or signal control. The model attempts to minimize preparatory calculations and is thus highly user oriented.

The model operates on a time scan basis, where at every time increment (1/2 to one second) the simulated position and operational status of every driver-vehicle unit and (any existing) control status are updated, as needed. The degree of updating depends on the likelihood of change. For example, the relative actions of driver-vehicle units are interdependent, thus must be updated at every time increment.

Some events (e.g., interval changes of traffic signal displays) are predictable and times are flagged for updating at the appropriate time increment. With regard to the simulation time increment, the shorter the time, the more accurate the results.

There are two control times of importance to the simulation process. The first is startup time, where the system is started empty and the simulation model proceeds to load the system. No statistics are recorded during this step. The user must input this time since no algorithm has yet been offered to reliably determine when equilibrium has been achieved. The developers have suggested using at least two minutes (simulated real time) for this step.

The second step is the actual simulation time, which is also user specified. Due to the high cost of simulation (despite significant compression from real time), simulation times will normally be short, compared to say field or macroscopic studies. The developers recommend at least ten minutes to obtain sufficient results for analysis.

The simulation process operates within the above time constraints in a manner very closely approximating the real world. Arrivals are random (due to the stochastically derived headways), decisions are dynamic (e.g., gap acceptance and lane changes are responsive to the immediate traffic environment) and the car following submodel is among the most complex, and realistic, of any existing model. At each instant, the model makes available to the simulated driver his desired speed, destination, present position, speed, acceleration, deceleration (as well as the rate of change of these, referred to as jerk) and the relative positions and velocities of adjacent vehicles. The "driver" may decide to maintain speed, accelerate, decelerate or maneuver to turn or change lanes. The decision is dependent on the driver-vehicle characteristics, roadway geometry, traffic control status and the actions of other driver-vehicle units on the system, within certain realistic constraints (e.g., minimum headways, prohibitions on changing to certain lanes, etc.).

Of several possible decisions available, that receiving the highest priority is based on the premise that drivers wish to sustain their desired speeds, but will obey traffic laws and will maintain safety and comfort. Once the decision is "made", future values of the position/velocity status variables are processed for use by driver-vehicle units which are dependent upon the present unit.

The order of processing vehicles is based on their position in the system. Outbound vehicles are processed first, then inbound, in the order of least time remaining in the system. A simplified flow chart of the simulation is given in Figure 37.

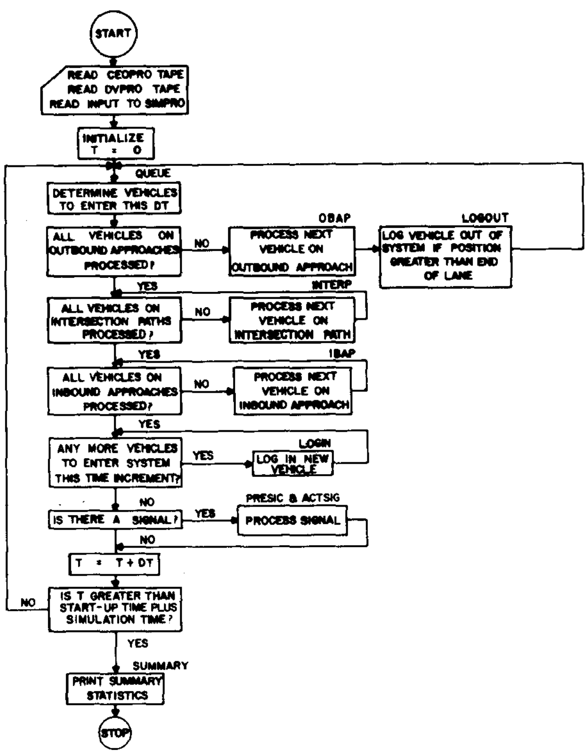

Figure 37. Generalized Flow Process for SIMPRO

COMPUTATIONAL ALGORITHMS

The computational capabilities of TEXAS are extremely complex and highly sophisticated, particularly in the SIMPRO subprogram. In the interest of brevity, only the more significant algorithms are included in the subsections below.

Geometry Processor (GEOPRO)

Construction of the physical layout of the intersection is based simply on the appropriate connection of required arcs and lines. Of more interest is the technique by which vehicles are tracked through the system. Coordinates are not used. GEOPRO establishes all possible paths through the system (e.g., see Figure 36) and the vehicle positions are stored (in the simulation) on the basis of position in the path. When the end of a path is reached, the vehicle is "transferred" to another path (or processed out of the system). These are all based on simple geometric or trigonometric computations (albeit complexly interrelated).

The most significant computational technique of interest in this subprogram is that for maximum speed on curves (i.e., turns). The relationship for maximum speed (V) is as follows:

$$V = \frac{-B + \sqrt{B^2 - 4AC}}{2A} \quad (5.1)$$

For radii greater than 300m (1000 ft.) the values of A, B and C are as follows:

A = one (1)
B = -15 x radius x (-0.001)
C = -15 x radius x 0.190

For radii less than 300m (1000 ft.) the values of A, B and C are as follows:

A = 1 - (15 x radius x 0.00013951)
B = -15 x radius x (-0.01404)
C = -15 x radius x 0.49671

These are based on AASHTO standards.

Driver-Vehicle Processor (DVPRO)

The major computational function of DVPRO is to randomly assign the various driver and vehicle characteristics discussed earlier. Probability density functions available for assigning headways (or arrival times) are the Erlang, gamma, log normal, negative exponential (shifted or unshifted) and uniform. The driver and vehicle classes, inbound lane and outbound approach are assigned based on an empirical discrete distribution (e.g., percentages of occurrence for each class). Desired speeds are derived from a normal distribution.

In the interest of brevity, only one example of each of the stochastic processes are given for headway and class assignments.

For Poisson distributed arrivals, the Erlang probability distribution can be used to represent the waiting time T until the Kth arrival. This distribution is thus the sum of K negative exponential variates with an identical expected value (mean of 1/). The probability density function is expressed as follows:

$$f(t) = \frac{\alpha^{K} \times T^{(K-1)}}{(K-1)!\, e^{-T}}, \text{ for } T>0, >0 \text{ and } K>0 \text{ and } K>0 \qquad (5.2)$$

$$0 \text{ elsewhere}$$

Without developing the entire process, α is equal to the mean divided by the variance of the headways and the Erlang variate, T, is found by

$$T = -\frac{1}{\alpha} \log (\pi_{1}^{K} RN) \qquad (5.3)$$

where π = the product of K random numbers (RN).

The empirical discrete probability function is, as the name implies, based on field studies. For example, inbound lane assignments would be based on actual measures of lane distributions. For a simple example, assume a two-lane approach on which P% of the traffic is in lane 1 and (1-P)% in lane 2. The lane assignment, L, is determined for each vehicle on this approach simply by

$$L = \begin{cases} 1, \text{ if } RN \leq P/100 \\ 2, \text{ if } RN > P/100 \end{cases} \qquad (5.4)$$

and P is within the range 0-100.

All characteristic assignments are made similarly, albeit by a somewhat more sophisticated algorithm to account for greater numbers of characteristics.

Traffic Simulation Processor (SIMPRO)

This is the most important subprogram in TEXAS, as noted earlier. The multitude of algorithms is simply too vast to include all of them in this Handbook, thus, only qualitative comments are offered about most of the computations. Only the more salient submodels are defined mathematically.

Acceleration and deceleration are based on empirically validated linear models.

Car following is based on a noninteger, microscopic, generalized car following equation as follows:

$$A_i = \frac{V_i^{\mu}}{(X_{i-1} - X_i)^{\lambda}} (V_{i-T}\ V)_i$$

where A_i = acceleration or deceleration of the i^{th} vehicle

V = velocity (of the i^{th} and $(i-1)$th, or lead, vehicles

X = location of the i^{th} and $(i-1)$th vehicles

α, μ, λ = empirically derived constants

The values of the parameters α, μ and λ may be set by the user, but suggested values are available. A review of Reference (5.1) is suggested before establishing these values.

Initial speed is based either on desired speed or a speed dictated by the traffic already in the lane ahead, subject to a complicated logical algorithm to determine whether a vehicle should accelerate, decelerate or remain at the initial speed.

Lane control strategies are based on a logical decision process which is dependent on the type of control. Driver responses are determined by traffic control, right-of-way and gap acceptance (depending on control type), right turn-on-red and other possible maneuvers. A complex set of algorithms is used for this function.

Lane changes may be optional (e.g., to achieve higher speed) or forced (e.g., a path does not exist from the present lane to the desired outbound leg). All optional lane changes are based on expected savings in delay, but penalties are based on empirical data. Lane changing geometry is also based on empirically validated trajectories.

Operational factors such as driver classification (e.g., degree of aggressiveness) and vehicle classification (e.g., responsiveness) affect the slopes of the speed change submodel and other similar parameters. Perception-reaction times affect the times at which decisions are implemented.

OUTPUTS REPORTS

As in the previous sections, the outputs are described separately for the three processors, plus error messages.

Geometry Processor (GEOPRO)

GEOPRO produces printed summaries and plots for inspection and a tape with data for use in SIMPRO. Printed outputs contain an echo of the input data with convenient column headings and listings of sight distance restrictions, intersection paths and intersection conflicts (Figure 40).

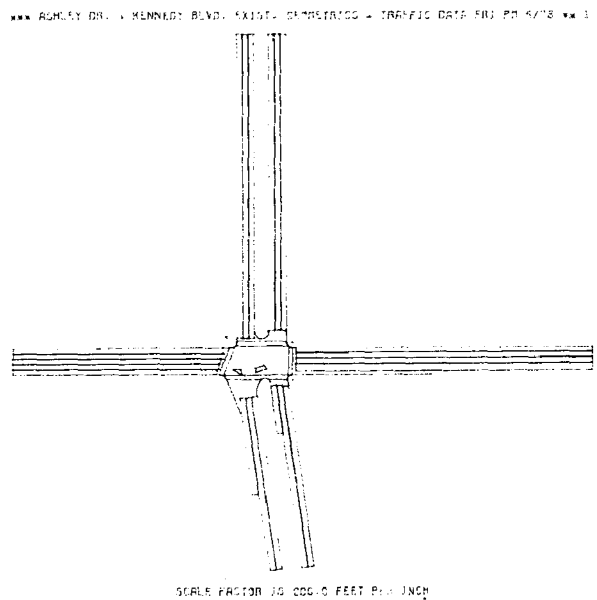

Figure 38. Overall Intersection Plot

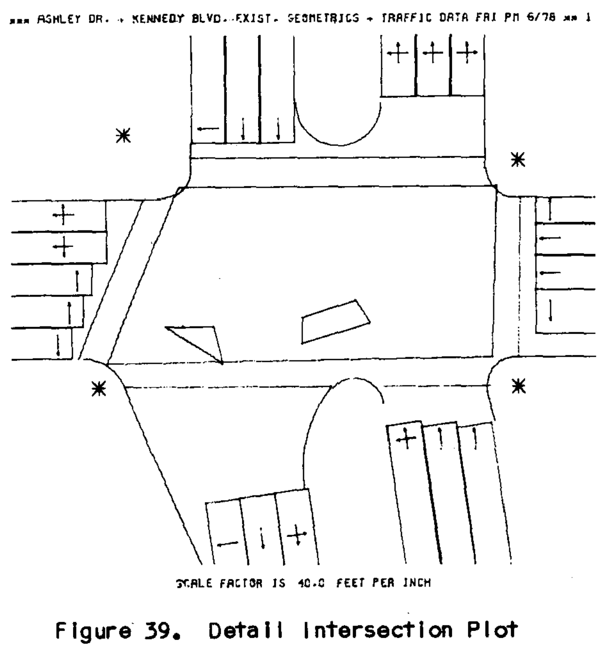

Figure 39. Detail Intersection Plot

```
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      TABLE  1  -  LISTING OF INBOUND APPROACH NUMBERS

                   1
                   2
                   3
                   4

         TOTAL NUMBER OF INBOUND APPROACHES =  4

      TABLE  2  -  LISTING OF OUTBOUND APPROACH NUMBERS

                   5
                   6
                   7

          TOTAL NUMBER OF OUTBOUND APPROACHES =  3

          TOTAL NUMBER OF INBOUND AND OUTBOUND APPROACHES =  7

      TABLE  3  -  LISTING OF APPROACHES

         APPROACH NUMBER -------------------     1
         APPROACH AZIMUTH ------------------   180
         BEGINNING CENTERLINE X COORDINATE -   500
         BEGINNING CENTERLINE Y COORDINATE -  1200
         SPEED LIMIT (MPH) -----------------    30
         NUMBER OF DEGREES FOR STRAIGHT ----    20
         NUMBER OF DEGREES FOR U-TURN ------    10
         NUMBER OF LANES -------------------     3

         LANE IL IBLN WIDTH ---LANE GEOMETRY--- LEGAL TURNS
           1   1   1   12      0  630   0  630   ( S )
                                                              (MEDIAN LANE)
           2   2   2   12      0  630   0  630   ( S )
           3   3   3   12      0  630   0  630   (  R)
                                                              (CURB LANE)

      TABLE  4  -  LISTING OF ARCS (FOR PLOTTING ONLY)

         ARC NUMBER ------------------------     1
         CENTER X COORDINATE ---------------   454
         CENTER Y COORDINATE ---------------   565
         BEGINNING AZIMUTH -----------------    90
         SWEEP ANGLE -----------------------    90
         RADIUS OF ARC ---------------------    10
         ROTATION FROM BEGINNING AZIMUTH ---
                                            CLOCKWISE
```

Figure 40. Example GEOPRO Output Report

TABLE 5 - LISTING OF LINES (FOR PLOTTING ONLY)

LINE NUMBER ---------------------- 1
START X COORDINATE ---------------- 435
START Y COORDINATE ---------------- 555
END X COORDINATE ------------------ 454
END Y COORDINATE ------------------ 555

TABLE 6 - LISTING OF SIGHT DISTANCE RESTRICTION COORDINATES

SIGHT DISTANCE RESTPICTION NUMBER - 1
X COORDINATE ---------------------- 441
Y COORDINATE ---------------------- 577

TABLE 7 - LISTING OF OPTIONS AND ADDITIONAL DATA

PRIMARY PATHS SELECTED

NO PLOT SELECTED

A STRAIGHT LINE WILL BE USED FOR A PATH WITH A RADIUS CI 500.00 FT

PROGRAM CHECKS TO SEE IF THE CENTER TO CENTER DISTANCE
BETWEEN VEHICLES BECOMES LESS THAN OR EQUAL TO 10 FEET

TABLE 8 - LISTING OF SIGHT DISTANCE RESTRICTION ENTRIES

SIGHT DISTANCE RESTPICTION ENTRY 1 IS NUMBER 1 FOR APPROACH 1
AND INVOLVES APPROACH 2

APPROACH	1	FROM	0	TO	25	CAN	SEE	APPROACH	2	FROM	617	TO	622
APPROACH	1	FROM	25	TO	50	CAN	SEE	APPROACH	2	FROM	617	TO	622
APPROACH	1	FROM	50	TO	75	CAN	SEE	APPROACH	2	FROM	617	TO	622
APPROACH	1	FROM	75	TO	100	CAN	SEE	APPROACH	2	FROM	617	TO	622
APPROACH	1	FROM	100	TO	125	CAN	SEE	APPROACH	2	FROM	616	TO	622
APPROACH	1	FROM	125	TO	150	CAN	SEE	APPROACH	2	FROM	616	TO	622
APPROACH	1	FROM	150	TO	175	CAN	SEE	APPROACH	2	FROM	616	TO	622
APPROACH	1	FROM	175	TO	200	CAN	SEE	APPROACH	2	FROM	615	TO	622
APPROACH	1	FROM	200	TO	225	CAN	SEE	APPROACH	2	FROM	615	TO	622
APPROACH	1	FROM	225	TO	250	CAN	SEE	APPROACH	2	FROM	614	TO	622
APPROACH	1	FROM	250	TO	275	CAN	SEE	APPROACH	2	FROM	614	TO	622
APPROACH	1	FROM	275	TO	300	CAN	SEE	APPROACH	2	FROM	613	TO	622
APPROACH	1	FROM	300	TO	325	CAN	SEE	APPROACH	2	FROM	612	TO	622
APPROACH	1	FROM	325	TO	350	CAN	SEE	APPROACH	2	FROM	611	TO	622
APPROACH	1	FROM	350	TO	375	CAN	SEE	APPROACH	2	FROM	610	TO	622
APPROACH	1	FROM	375	TO	400	CAN	SEE	APPROACH	2	FROM	609	TO	622
APPROACH	1	FROM	400	TO	425	CAN	SEE	APPROACH	2	FROM	607	TO	622
APPROACH	1	FROM	425	TO	450	CAN	SEE	APPROACH	2	FROM	605	TO	622
APPROACH	1	FROM	450	TO	475	CAN	SEE	APPROACH	2	FROM	603	TO	622
APPROACH	1	FROM	475	TO	500	CAN	SEE	APPROACH	2	FROM	599	TO	622
APPROACH	1	FROM	500	TO	525	CAN	SEE	APPROACH	2	FROM	594	TO	622
APPROACH	1	FROM	525	TO	550	CAN	SEE	APPROACH	2	FROM	586	TO	622
APPROACH	1	FROM	550	TO	575	CAN	SEE	APPROACH	2	FROM	573	TO	622
APPROACH	1	FROM	575	TO	600	CAN	SEE	APPROACH	2	FROM	545	TO	622

Figure 40. Example GEOPRO Output Report (Continued)

```
TABLE  9  -  LISTING OF PATHS

     PATH   1 GOES FROM LANE 1 OF APPROACH  1  TO LANE 1 OF APPROACH  6
        LENGTH OF PATH = 116 FEET-AND SPEED OF PATH = 44 FEET PER SECOND
        NUMBER OF CONFLICTS =  6  AND TURN CODE FOR PATH IS
                                                                STRAIGHT
        CONFLICT ENTRY NUMBERS ORDERED BY DISTANCE DOWN THIS PATH ARE
               3    2    4    5    6    1

TABLE 10  -  LISTING OF CONFLICTS
```

CONFLICT	PATH1	PATH2	APPR1	APPR2	DIST1	DIST2	ANGLE	INDEX1	INDEX2
1	1	4	1	2	109	111	6	6	5
2	1	5	1	2	33	83	98	2	6
3	1	6	1	2	23	84	94	1	6
4	1	9	1	3	34	66	108	3	4
5	1	12	1	4	43	64	270	4	2
6	1	13	1	4	54	67	271	5	2
7	2	5	1	2	32	95	96	3	8
8	2	6	1	2	23	96	94	1	7
9	2	9	1	3	31	78	96	2	6
10	2	12	1	4	43	52	271	4	1
11	2	13	1	4	54	55	271	5	1
12	3	6	1	2	38	135	4	1	8
13	4	8	2	3	45	23	109	3	1
14	4	9	2	3	52	22	88	4	1
15	4	10	2	3	32	26	95	2	1
16	4	11	2	3	20	28	89	1	1
17	5	8	2	3	45	42	88	3	2
18	5	9	2	3	85	68	9	7	5
19	5	9	2	3	107	91	356	9	7
20	5	10	2	3	32	41	88	2	2
21	5	11	2	3	20	41	89	1	2
22	5	12	2	4	63	86	143	5	4
23	5	13	2	4	47	109	132	4	4
24	6	8	2	3	44	56	94	4	4
25	6	10	2	3	32	56	93	2	3
26	6	11	2	3	19	54	91	1	3
27	6	12	2	4	51	103	124	5	5
28	6	13	2	4	37	124	117	3	6
29	7	11	2	3	29	84	0	1	4
30	8	12	3	4	82	131	0	5	6

```
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```

CONFLICT	PATH1	PATH2	APPR1	APPR2	DIST1	DIST2	ANGLE	INDEX1	INDEX2
31	8	13	3	4	44	111	40	3	5
32	9	12	3	4	50	79	126	3	3
33	9	13	3	4	37	92	108	2	3
34	10	13	3	4	62	152	0	4	7

```
TOTAL NUMBER OF CONFLICTS =    34
```

Figure 40. Example GEOPRO Output Report (Continued)

Plots include an overall layout of the system (Figure 38), the intersection detail and vehicle paths for each approach (a single example of which is shown in Figure 39). The composite vehicle paths, showing all potential conflicts can also be plotted, an example of which (for a different case) was shown in Figure 36. The plots may be interactively displayed on a CRT screen as well, if appropriate hardware exists.

The tape for SIMPRO contains extensive details needed for the simulation. These data may also be written to disk storage if desired.

Driver-Vehicle Processor (DVPRO)

Printed and tape outputs are issued by DVPRO. Some of the same input data discussed above are printed since both GEOPRO and DVPRO use the same input card deck. However, error checks are peculiar to the separate processors.

The printed output that are the driver-vehicle tables are illustrated in Figure 41.

Traffic Simulation Processor (SIMPRO)

A similar input data echo is issued by SIMPRO, but for the cards input exclusively for this subprogram. Other input data reports also provide more readable formats of the data for the system (Figure 42) and the traffic control.

The summary statistics for each approach, as well as the whole intersection, are reported. Traffic control statistics are also output, as appropriate. Finally, the printed output contains summary statistics of the simulation run itself.

Punched card outputs include the data listed in Figure 42. Specialized evaluation programs or existing statistical packages (SPSS, SAS, etc.) could be used to evaluate the results of alternative simulations.

Diagnostic Messages

Each processor has its own set of error messages, which are too numerous to list here.

The three processors have 59, 62 and 81 input data error messages, respectively. Unfortunately, once an error is detected, it is reported and execution stops. This could result in several runs to "debug" the input data.

Some errors are only detectable during execution in SIMPRO. These are likewise reported and the simulation is terminated.

ADDITIONAL FEATURES

The TEXAS simulation model produces a realistic simulation of intersection operations. The variety of inputs and outputs have been discussed previously and those discussions covered most of the available options. A summary review of these would appear to be warranted, however.

1. Geometry - any feasible design of a single intersection including divided highways which operate under a single signal controller, parking lanes, turn bays and channels.

2. Driver-vehicle units - extremely flexible classifications, all randomly assigned.

3. Turning - lane changes; right and left-on-red; U-turns, protected, permissive and unprotected.

4. Traffic Control - no control; stop or yield sign control; and/or fixed time, semi-actuated or full-actuated signal control. The latter may be based on detector calls set in the pulse or presence modes.

5. Outputs - printed input data, intermediate results and summary statistics of traffic MOE; line plots of geometrics, turning movements and sight- distance restrictions; and interactive graphics displays. Additionally, punched card outputs can be obtained for use in evaluating alternative designs or control strategies using other computer programs.

```
TABLE  3  -  DRIVER-VEHICLE PROCESSOR OPTIONS
    TIME FOR GENERATING VEHICLES (MIN) ----    15
    MINIMUM HEADWAY FOR VEHICLES (SEC) ----     1.0
    NUMBER OF VEHICLE CLASSES -------------    10
    NUMBER OF DRIVER CLASSES --------------     3
    PERCENT OF LEFT TURNS IN MEDIAN LANE --    80.
    PERCENT OF RIGHT TURNS IN CURB LANE ---    80.

TABLE  4  -  LISTING OF APPROACHES
    APPROACH NUMBER ----------------------     1
    APPROACH AZIMUTH ---------------------   180
    NUMBER OF LANES ----------------------     3
    NUMBER OF DEGREES FOR STRAIGHT --------   20
    HEADWAY DISTRIBUTION NAME ------------- SNEGEXP
                                                       PARAMETER =     0.90
    EQUIVALENT HOURLY VOLUME (VPH) -------- 1067
    APPROACH MEAN SPEED (MPH) -------------  22.0
    APPROACH 85 PERCENTILE SPEED (MPH) ----  25.0
       OUTBOUND APPROACH NUMBER ----------   5     6     7
    PERCENT GOING TO OUTBOUND APPROACHES --  0.   56.   44.
    USER SUPPLIED PERCENT OF VEHICLES -----  NO
       VEHICLE CLASS NUMBER --------------   1     2     3     4     5     6     7     8     9    10
    PROGRAM SUPPLIED PERCENT OF VEHICLES --  20.0  32.0  30.0  15.0  0.5   0.2   0.1   0.2   0.5   1.5
    PERCENT OF TRAFFIC ENTERING ON LANE 1 -  33.
                                                (MEDIAN LANE)
    PERCENT OF TRAFFIC ENTERING ON LANE 2 -  34.
    PERCENT OF TRAFFIC ENTERING ON LANE 3 -  33.
                                                (CURB LANE)

TABLE  5  -  DRIVER AND VEHICLE CLASS CHARACTERISTICS
    USER SUPPLIED DRIVER CLASS SPLIT ------   NO
    USER SUPPLIED VEHICLE CHARACTERISTICS -   NO
    USER SUPPLIED DRIVER CHARACTERISTICS --   NO
       VEHICLE CLASS NUMBER --------------    1     2     3     4     5     6     7     8     9    10
    VEHICLE LOGOUT SUMMARY REQUESTED ------   NO    NO   YES   YES   YES    NO    NO    NO   YES    NO
       DRIVER CLASS NUMBER ---------------    1     2     3
    DRIVER LOGOUT SUMMARY REQUESTED -------   NO   YES    NO

    DRIVER CLASS SPLIT
                                       (PROGRAM SUPPLIED VALUES)
       DRIVER CLASS NUMBER ---------------    1     2     3

       VEHICLE CLASS NUMBER  1 -----------  30.0  40.0  30.0
       VEHICLE CLASS NUMBER  2 -----------  35.0  35.0  30.0
       VEHICLE CLASS NUMBER  3 -----------  20.0  40.0  40.0
       VEHICLE CLASS NUMBER  4 -----------  25.0  50.0  25.0
       VEHICLE CLASS NUMBER  5 -----------  40.0  30.0  30.0
       VEHICLE CLASS NUMBER  6 -----------  50.0  40.0  10.0
       VEHICLE CLASS NUMBER  7 -----------  50.0  40.0  10.0
       VEHICLE CLASS NUMBER  8 -----------  20.0  30.0  50.0
       VEHICLE CLASS NUMBER  9 -----------  25.0  50.0  25.0
       VEHICLE CLASS NUMBER 10 -----------  50.0  40.0  10.0
    VEHICLE CHARACTERISTICS
                                       (PROGRAM SUPPLIED VALUES)
       VEHICLE CLASS NUMBER --------------    1     2     3     4     5     6     7     8     9    10

       LENGTH OF VEHICLES (FT) -----------   15    17    19    25    30    50    55    25    35    14
       VEHICLE OPERATIONAL FACTOR --------  100   110   110   100    85    80    75    90    85   115
       MAXIMUM DECELERATION (FT/SEC/SEC) -    8    11    11     8    11    11    11     8    11    12
       MAXIMUM ACCELERATION (FT/SEC/SEC) -    8     9    11     8     8     7     6     6     5    14
       MAXIMUM VELOCITY (FT/SEC) ---------  150   192   200   150   160   160   150   150   125   205
       MINIMUM TURNING RADIUS (FT) -------   20    22    24    28    42    40    45    28    28    20
    DRIVER CHARACTERISTICS
                                       (PROGRAM SUPPLIED VALUES)
       DRIVER CLASS NUMBER ---------------    1     2     3

       DRIVER OPERATIONAL FACTOR ---------  110   100    85
       DRIVER REACTION TIME (SEC) --------  0.5   1.0   1.5
```

Figure 41. Example DVPRO Output Report

TABLE 6 - GENERATION OF APPROACH HEADWAYS

APPROACH NUMBER	DISTRIBUTION NAME	NUMBER GENERATED	VOLUME GENERATED	INPUT VOLUME	PERCENT DIFFERENCE
1	SNEGEXP	278	1112	1067	4.22
2	SNEGEXP	234	936	905	3.43
3	SNEGEXP	121	484	530	-8.68
4	SNEGEXP	180	720	747	-3.61
TOTAL		813	3252	3249	0.09

TABLE 7 - EXPLANATION OF SPECIAL CASES

QTIME	VEHICLE CLASS	DRIVER CLASS	VELOCITY (FPS)	OUTBOUND APPROACH	INBOUND APPROACH	LANE NO.	LOGOUT PRINT	NOTE
480.00	9	1	15	7	1	3	1	2
480.46	9	1	15	7	1	3	1	14
480.46	9	1	15	7	1	3	1	13
720.00	9	1	15	5	2	4	1	2
720.00	9	1	15	5	2	4	1	13

NOTE EXPLANATION OF THE NOTE(S)

2 SPECIAL VEHICLE WAS READ IN
13 SPECIAL VEHICLE WAS INSERTED
14 HEADWAY LESS THAN 1.0 SECONDS FROM PREVIOUS VEHICLE ON SAME APPROACH AND LANE
SPECIAL VEHICLE HEADWAY INCREASED TO 1.0 SECONDS

TABLE 8 - FINAL APPROACH VOLUMES

APPROACH NUMBER	SPECIAL VEHICLES		GENERATED VEHICLES		TOTAL VEHICLES		INPUT VOLUME
	NUMBER FOR SIMULATION	VOLUME FOR SIMULATION	NUMBER FOR SIMULATION	VOLUME FOR SIMULATION	NUMBER FOR SIMULATION	VOLUME FOR SIMULATION	
1	0	0	278	1112	278	1112	1067
2	1	4	234	936	235	940	905
3	0	0	121	484	121	484	530
4	1	4	180	720	181	724	747
TOTAL	2	8	813	3252	815	3260	3249

2 SPECIAL VEHICLES WERE READ IN
0 SPECIAL VEHICLES WERE ELIMINATED

THE INTERSECTION HAS A JAM DENSITY OF 235 VEHICLES PER MILE
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TABLE 9 - STATISTICS OF GENERATION

```
APPROACH STATISTICS
-------------------

APPROACH NUMBER ------------------------   1
   OUTBOUND APPROACH NUMBER ----------   5    6    7
PERCENT GOING TO OUTBOUND APPROACHES --  0.0 53.6 46.4
   VEHICLE CLASS NUMBER --------------   1    2    3    4    5    6    7    8    9    10
GENERATION PERCENT OF VEHICLES --------  18.0 35.6 32.7 11.5 0.4 0.0  0.0  0.0  0.0  1.8
PERCENT OF TRAFFIC ENTERING ON LANE 1 -  29.9
                                              (MEDIAN LANE)
PERCENT OF TRAFFIC ENTERING ON LANE 2 -  36.3
PERCENT OF TRAFFIC ENTERING ON LANE 3 -  33.8
                                              (CURB LANE)
```

Figure 41. Example DVPRO Output Report (Continued)

```
START-UP TIME (MINUTES) -------------------------- =      3.00
SIMULATION TIME (MINUTES) ------------------------ =     12.00
STEP INCREMENT FOR SIMULATION TIME (SECONDS) ------ =      1.00

SPEED FOR DELAY BELOW XX MPH (MPH) ---------------- =     10.00

MAXIMUM CLEAR DISTANCE FOR BEING IN A QUEUE (FT) -- =     30.00

CAR FOLLOWING EQUATION LAMBDA --------------------- =      2.80000
CAR FOLLOWING EQUATION MU ------------------------- =      0.80000
CAR FOLLOWING EQUATION ALPHA ---------------------- =   4000.00000

SUMMARY STATISTICS PRINTED BY TURNING MOVEMENTS --- =    YES
SUMMARY STATISTICS PRINTED BY INBOUND APPROACH ---- =    YES

PUNCHED OUTPUT OF STATISTICS ---------------------- =    NO

WRITE TAPE FOR POLLUTION DISPERSION MODEL --------- =    NO

LEAD TIME GAP FOR CONFLICT CHECKING (SECONDS) ----- =      1.30
LAG TIME GAP FOR CONFLICT CHECKING (SECONDS) ------ =      0.50

INTERSECTION TRAFFIC CONTROL ---------------------- =      6
                                                          (SEMI-ACTUATED SIGNAL)
LANE CONTROL FOR THE 21 LANES = 5 5 5 5 5 5 5 5 5 5 5 5 5 1 1 1 1 1 1 1 1
C     WHERE  1 = OUTBOUND (OR BLOCKED INBOUND) LANE
             2 = UNCONTROLLED
             3 = YIELD SIGN
             4 = STOP SIGN
             5 = SIGNAL
             6 = SIGNAL WITH LEFT TURN ON RED
             7 = SIGNAL WITH RIGHT TURN ON RED


A TOTAL OF  8 CAM STACK ENTRIES

ENTRY  1 PHASE  1  *R  *R  *R  *F  *G  *G  *G  *F  *R  *R  *R  *R  *G
ENTRY  2 PHASE  1              **  **  **  **
ENTRY  3 PHASE  1                                                  **
ENTRY  4 PHASE  2          *G  *R  *R  *R  *P              *P  *P  *G
ENTRY  5 PHASE  2                                          **  **  **
ENTRY  6 PHASE  2          **                                      *G
ENTRY  7 PHASE  3  *G  *G  *G                  *G  *G  *G  *R  *R  *R
ENTRY  8 PHASE  3  **  **  **                  **  **  **

SUMMARY STATISTICS FOR ALL APPROACHES

TOTAL DELAY (VEHICLE-SECONDS) --------------------- =  30450.6
NUMBER OF VEHICLES INCURRING TOTAL DELAY ---------- =    644
PERCENT OF VEHICLES INCURRING TOTAL DELAY --------- =    100.0
AVERAGE TOTAL DELAY (SECONDS) --------------------- =     47.3
AVERAGE TOTAL DELAY/AVERAGE TRAVEL TIME ----------- =     58.1 PERCENT

QUEUE DELAY (VEHICLE-SECONDS) --------------------- =  25397.0
NUMBER OF VEHICLES INCURRING QUEUE DELAY ---------- =    519
PERCENT OF VEHICLES INCURRING QUEUE DELAY --------- =     80.6
AVERAGE QUEUE DELAY (SECONDS) --------------------- =     48.9
AVERAGE QUEUE DELAY/AVERAGE TRAVEL TIME ----------- =     60.2 PERCENT

STOPPED DELAY (VEHICLE-SECONDS) ------------------- =  18716.0
NUMBER OF VEHICLES INCURRING STOPPED DELAY -------- =    519
PERCENT OF VEHICLES INCURRING STOPPED DELAY ------- =     80.6
AVERAGE STOPPED DELAY (SECONDS) ------------------- =     36.1
AVERAGE STOPPED DELAY/AVERAGE TRAVEL TIME --------- =     44.3 PERCENT

DELAY BELOW 10.0 MPH (VEHICLE-SECONDS) ------------ =  30149.0
NUMBER OF VEHICLES INCURRING DELAY BELOW 10.0 MPH - =    577
PERCENT OF VEHICLES INCURRING DELAY BELOW 10.0 MPH  =     89.6
AVERAGE DELAY BELOW 10.0 MPH (SECONDS) ------------ =     52.3
AVERAGE DELAY BELOW 10.0 MPH/AVERAGE TRAVEL TIME -- =     64.3 PERCENT

VEHICLE-MILES OF TRAVEL --------------------------- =    137.234
AVERAGE VEHICLE-MILES OF TRAVEL ------------------- =      0.213
TRAVEL TIME (VEHICLE-SECONDS) --------------------- =  52373.2
AVERAGE TRAVEL TIME (SECONDS) --------------------- =     81.3
NUMBER OF VEHICLES PROCESSED ---------------------- =    644
VOLUME PROCESSED (VEHICLES/HOUR) ------------------ =   3220.0
TIME MEAN SPEED (MPH) = MEAN OF ALL VEHICLE SPEEDS  =     10.9
SPACE MEAN SPEED (MPH) = TOT DIST / TOT TRAVEL TIME =      9.4
AVERAGE DESIRED SPEED (MPH) ----------------------- =     22.8
AVERAGE MAXIMUM ACCELERATION (FT/SEC/SEC) --------- =      3.4
AVERAGE MAXIMUM DECELERATION (FT/SEC/SEC) --------- =      3.2

OVERALL AVERAGE TOTAL DELAY (SECONDS) ------------- =     47.3
OVERALL AVERAGE QUEUE DELAY (SECONDS) ------------- =     39.4
OVERALL AVERAGE STOPPED DELAY (SECONDS) ----------- =     29.1
OVERALL AVERAGE DELAY BELOW 10.0 MPH (SECONDS) ---- =     46.8

NUMBER OF COLLISIONS ------------------------------ =      5
NUMBER OF VEHICLES ELIMINATED (LANE FULL) --------- =      5
AVERAGE OF LOGIN SPEED/DESIRED SPEED (PERCENT) ---- =     96.1
```

Figure 42. Example SIMPRO Output Report

```
SUMMARY STATISTICS FOR SEMI-ACTUATED SIGNAL

MAIN STREET PHASE NUMBER ------------------------------- =    1
MAIN STREET MINIMUM ASSURED GREEN (SECONDS) ------- =  26.5
MAIN STREET AMBER CLEARANCE INTERVAL (SECONDS) ---- =   4.5
MAIN STREET ALL-RED CLEARANCE INTERVAL (SECONDS) -- =   0.0
MAIN STREET NUMBER OF PHASES CLEARED TO ----------- =   2
MAIN STREET LIST OF PHASES CLEARED TO ------------- =   2    3
NUMBER OF MAIN STREET GREEN PHASES----------------- =   7
AVERAGE LENGTH OF MAIN STREET GREEN (SECONDS) ----- =  28.0

SIGNAL PHASE NUMBER ------------------------------- =   2
INITIAL INTERVAL (SECONDS) ------------------------ =   9.0
VEHICLE INTERVAL (SECONDS) ------------------------ =   2.7
AMBER CLEARANCE INTERVAL (SECONDS) ---------------- =   4.5
ALL-RED CLEARANCE INTERVAL (SECONDS) -------------- =   0.0
MAXIMUM EXTENSION AFTER DEMAND ON RED (SECONDS) --- =  31.5
SKIP-PHASE SWITCH (ON/OFF) ------------------------ =   ON
AUTO-RECALL SWITCH (ON/OFF) ----------------------- =   OFF
PARENT/MINOR MOVEMENT PHASE OPTION (YES/NO) ------- =   NO
DUAL LEFT OPTION (YES/NO) ------------------------- =   NO
DETECTOR CONNECTION TYPE (AND/OR) ----------------- =   OR
NUMBER OF DETECTORS CONNECTED TO PHASE ------------ =   1
NUMBER OF PHASES CLEARED TO ----------------------- =   2
LIST OF PHASES CLEARED TO ------------------------- =   3    1
LIST OF DETECTORS CONNECTED TO PHASE -------------- =   3
NUMBER OF MAX-OUTS -------------------------------- =   3
AVERAGE TIME INTO PHASE FOR MAX-OUT (SECONDS) ----- =  33.0
NUMBER OF GAP-OUTS -------------------------------- =   4
AVERAGE TIME INTO PHASE FOR GAP-OUT (SECONDS) ----- =  26.3
1

SIGNAL PHASE NUMBER ------------------------------- =   3
INITIAL INTERVAL (SECONDS) ------------------------ =   9.0
VEHICLE INTERVAL (SECONDS) ------------------------ =   2.7
AMBER CLEARANCE INTERVAL (SECONDS) ---------------- =   4.5
ALL-RED CLEARANCE INTERVAL (SECONDS) -------------- =   0.0
MAXIMUM EXTENSION AFTER DEMAND ON RED (SECONDS) --- =  31.5
SKIP-PHASE SWITCH (ON/OFF) ------------------------ =   ON
AUTO-RECALL SWITCH (ON/OFF) ----------------------- =   OFF
PARENT/MINOR MOVEMENT PHASE OPTION (YES/NO) ------- =   NO
DUAL LEFT OPTION (YES/NO) ------------------------- =   NO
DETECTOR CONNECTION TYPE (AND/OR) ----------------- =   OR
NUMBER OF DETECTORS CONNECTED TO PHASE ------------ =   3
NUMBER OF PHASES CLEARED TO ----------------------- =   1
LIST OF PHASES CLEARED TO ------------------------- =   1
LIST OF DETECTORS CONNECTED TO PHASE -------------- =   1    4    5
NUMBER OF MAX-OUTS -------------------------------- =   7
AVERAGE TIME INTO PHASE FOR MAX-OUT (SECONDS) ----- =  33.0
NUMBER OF GAP-OUTS -------------------------------- =   0
AVERAGE TIME INTO PHASE FOR GAP-OUT (SECONDS) ----- =   0.0
1         SIMULATION PROCESSOR FOR THE TEXAS TRAFFIC SIMULATION PACKAGE

*** ASHLEY DR. & KENNEDY BLVD.-SOAP OPTIMUM SIGNAL TIMING  PM HOUR JUNE 1978 ***

     START-UP TIME    =  180.000 SECONDS       NUMBER OF VEHICLES PROCESSED =   93

     SIMULATION TIME =  720.000 SECONDS       NUMBER OF VEHICLES PROCESSED =  644

     NUMBER OF VEHICLES IN THE SYSTEM AT SUMMARY =    73
     AVERAGE NUMBER OF VEHICLES IN THE SYSTEM -- =   73.4  MAX =  97


     INITIAL      IM TIME =     0.203 SECONDS    COST = $  0.03

     START-UP     IM TIME =     6.573 SECONDS    COST = $  1.10
                  REAL/IM =    27.383

     SIMULATION   IM TIME =    40.923 SECONDS    COST = $  6.82
                  REAL/IM =    17.594

     SUMMARY      IM TIME =     0.147 SECONDS    COST = $  0.02

     TOTAL        IM TIME =    47.847 SECONDS    COST = $  7.97

     VEHICLE-SECONDS OF SIMULATION PER IM TIME = 1279.793

     VEHICLE UPDATES PER IM TIME = 1279.793
```

Figure 42. Example SIMPRO Output Report (Continued)

GEOPRO and SIMPRO use a special storage-management and logic-processing program called COLEASE (COordinated Logic Entity Attribute Simulation Environment). This program accomplishes two objectives: (1) it provides a mechanism which maximizes computer bit usage (storage) by disregarding normal word boundaries and (2) it establishes an efficient means for processing logical binary networks. By maximizing computer bit usage, the amount of storage is reduced with an associated increase in computer time required for the packing and unpacking of variables. The Fortran code that is part of the TEXAS Model and generated by COLEASE will run on any computer that has a Fortran compiler. To reduce computer time, these COLEASE generated Fortran routines have also been coded in machine language for CDC and IBM computers. These routines are completely transparent to the users of the TEXAS Model.

APPLICATIONS AND LIMITATIONS

The TEXAS Model analyzes a variety of conditions. Alternative geometric strategies, vehicle mixes and traffic control strategies can all be investigated. While separate runs are required for the three main processors, many runs could be made, say, with the Traffic Simulation Processor, using the same outputs of the two preprocessors.

While the TEXAS Model is extremely versatile and powerful, several limitations warrant notice. First is the absence of any effect by pedestrians. All-red signal phases can be modeled for pedestrian intervals at signalized intersections, but the interference to traffic by pedestrians moving simultaneously cannot be simulated.

Approaches must be straight and (essentially) at zero grade. In reality, many intersections have approaches on grades, which affect acceleration and deceleration. This can be compensated for somewhat by using different headway distributions or parameters for the effected approaches, but automatic adjustments would be more convenient.

External preemption of traffic signals cannot be modeled (e.g., bridge, RR or fire preemption).

No estimates of fuel consumption or vehicle exhaust emissions are presently included in the model; however, the Center for Highway Research is presently programming a fuel consumption and emissions submodel to add to the traffic simulator.

Finally, there is no provision for coordination, or even the effect of adjacent signals. Nearby signals will clearly affect the arrival patterns, tending to establish platoons. Despite the impressive variety of available arrival distributions, this type of effect cannot be simulated except by direct user input (special vehicles) of driver-vehicle units to OVPRO.

Despite these several limitations, the TEXAS intersection simulation model is an extremely powerful tool for the practicing traffic engineer.

EXAMPLE APPLICATION

The previous intersection example problem of Ashley Drive and Kennedy Boulevard, used for the SOAP model, was also selected to illustrate the use and capabilities of the TEXAS model. The following describes the problem and the use of TEXAS to evaluate existing and alternative intersection operation.

Problem Description

The intersection location, geometric and traffic control characteristics are the same as that described in Chapter 4, page 50. It is desired to determine if new signal timing would improve traffic flow and to determine what benefits would occur if the curb return radius on the northwest corner were increased.

Analysis of Existing Conditions

As with all models, it is desirable to code the input data required to simulate existing conditions. This not only provides a basis for determining the acceptability of the model but also as the basis for evaluating the alternatives.

The first step in coding data for existing conditions is to obtain a scaled drawing of the intersection geometrics. To code data, it is necessary to define approaches, lanes and detectors by numbers. To assist the user in coding data it is useful to indicate these directly on the plans or a sketch. Figure 43 illustrates the coding system used for this problem. (In actual practice a 1" = 20' scale plan was utilized.)

The geometrics of the intersection are coded based upon a coordinate system. For this problem, a system of coordinates was assigned to insure that all coordinates would be positive numbers.

In addition to the geometric configuration, it was also necessary to define approach volumes, percent in each lane, turning volumes, speeds, etc. Figure 44 illustrates the standard coding forms and coded data required to represent the example intersection problem.

To code the data required by the geometry and driver-vehicle processor was a fairly straightforward procedure with few areas of difficulty. Since no special studies had been conducted of the mix of vehicle classes and driver characteristics within the urban area, it was necessary to use the default values. However, communities who use the TEXAS Model extensively would want to conduct some reseach to determine if any changes are needed to reflect local conditions. Some judgement was also necessary to code headway distributions. There is a supplemental program (DISFIT) which is available to determine the best fit to an existing distribution. However, since actual data were not available, the user manual recommendations for medium to high volumes were utilized. A similar problem occurred in coding the data for the simulation processor where it was also necessary to use the user manual recommendations on car-following equation parameters.

Some problems did occur during execution of the model because of coding errors and several runs were required. Most errors were related to coordinates for some of the geometric features as well as improper coding of some clearance intervals for changes in signal indications.

Figure 45 illustrates the graphical output obtained from TEXAS Model showing intersection geometry and vehicle movements. Other plots obtained were shown previously in Figures 38 and 39.

Over 16 pages of printout are provided by the geometry processor and 8 pages by the driver vehicle processor. These data are basically a description of the input data and are useful for determining if data was properly coded and for identifying possible errors as well as a source listing of input data variables. Portions of this output are shown in Figures 40 and 41 as example output and have not been repeated here.

Figure 46 presents summary statistics of the simulation processor for existing conditons. There were actually twenty-three pages of output, however only the portions concerning overall intersection operation and operating characteristics on the north approach (which would be affected by geometric improvements) were included.

These statistics should be compared with observed field data to determine if the model does represent actual traffic operation. Data which could be useful for this comparison would include data obtained from a typical intersection delay study (Reference 4.10). Field data should be obtained on a per lane, as well as on per approach, basis. Since this study was not done for this location, a comparison is not possible.

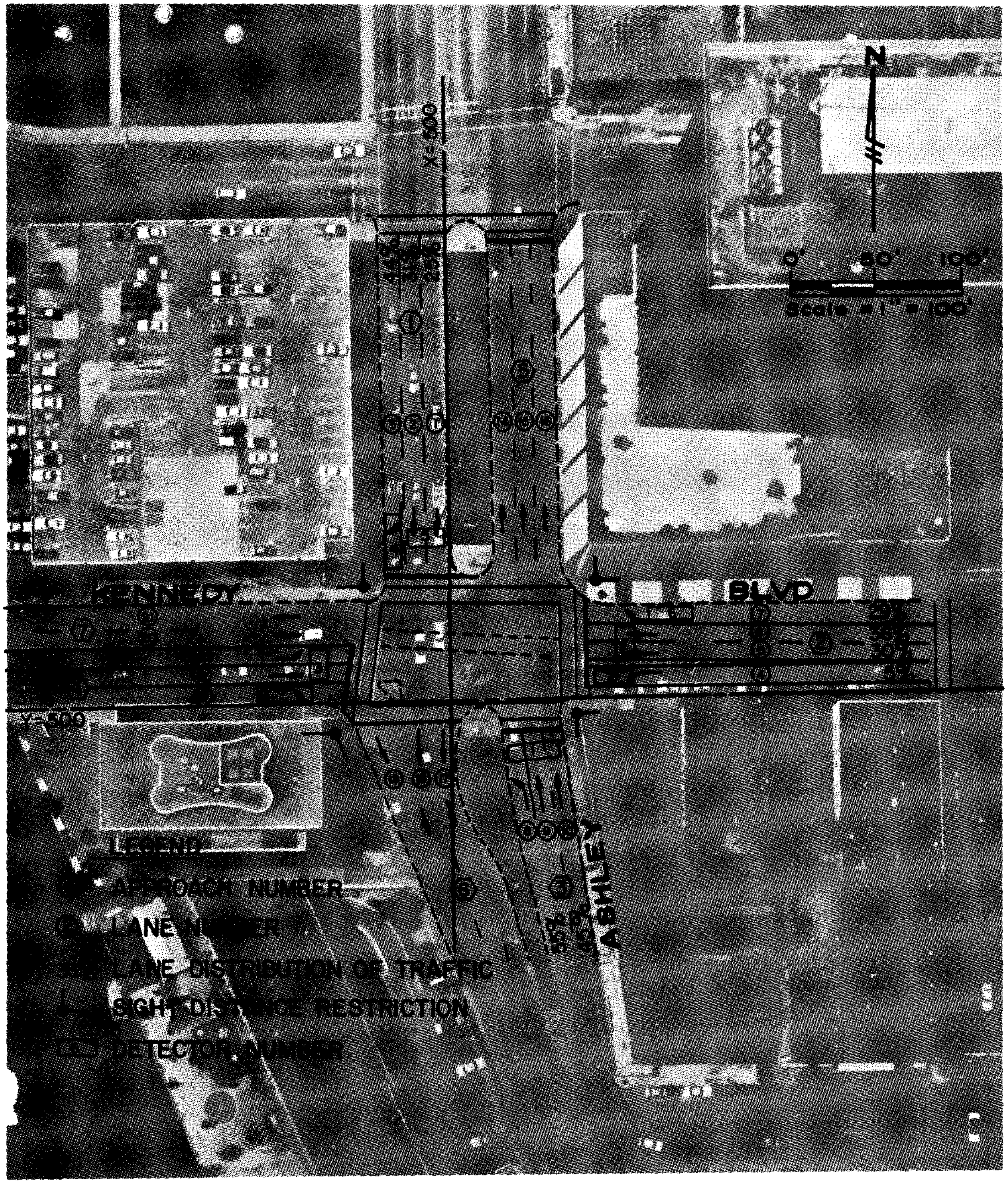

Figure 43. TEXAS Intersection Data-Ashley Dr & Kennedy Blvd.

TEXAS STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

THE TEXAS MODEL FOR INTERSECTION TRAFFIC

GEOMETRY AND DRIVER-VEHICLE PROCESSOR INPUT - FORM 1

SHEET 1 OF 16
DATE 4/18/81
PREPARED BY ASB

TITLE CARD (MANDATORY)

UP TO 80 ALPHANUMERIC CHARACTERS - CENTERED IF DESIRED
*** ASHLEY DR. & KENNEDY BLVD. - EXIST. GEOMETRICS & TRAFFIC DATA FRI. PM 6/78 **

NUMBER OF INBOUND APPROACHES (MANDATORY)

NUMBER OF INBOUND APPROACHES
4

1 <= NUMBER OF INBOUND APPROACHES <= 6

LIST OF INBOUND APPROACHES (MANDATORY)

INBOUND APPROACH NUMBER					
A	B	C	D	E	F
1	2	3	4		

1 <= INBOUND APPROACH NUMBER <= 12

NUMBER OF OUTBOUND APPROACHES (MANDATORY)

NUMBER OF OUTBOUND APPROACHES
3

1 <= NUMBER OF OUTBOUND APPROACHES <= 6

LIST OF OUTBOUND APPROACHES (MANDATORY)

OUTBOUND APPROACH NUMBER					
A	B	C	D	E	F
5	6	7			

1 <= OUTBOUND APPROACH NUMBER <= 12

PARAMETERS OPTION CARD (MANDATORY)

TOTAL NUMBER OF APPROACHES	SIMULATION TIME IN MIN (DEF=12)	MINIMUM HEADWAY IN SEC DEF=1.0	NUMBER OF VEHICLE CLASSES DEF=10	NUMBER OF DRIVER CLASSES DEF=3	% LEFT TURNS IN MEDIAN LANE DEF=80	% RIGHT TURNS IN CURB LANE DEF=80
7	15					

2 <= TOTAL NUMBER OF APPROACHES <= 12
12 <= SIMULATION TIME <= 65
SIMULATION TIME INCLUDES START-UP TIME
1.0 <= MINIMUM HEADWAY <= 3.0
1 <= NUMBER OF VEHICLE CLASSES <= 15
1 <= NUMBER OF DRIVER CLASSES <= 5
50 <= % LEFT TURNS IN MEDIAN LANE <= 100
50 <= % RIGHT TURNS IN CURB LANE <= 100

ORDER OF INPUT CARDS

NUM	M/O	CARD TITLE
1	M	TITLE CARD
1	M	NUMBER OF INBOUND APPROACHES
1	M	LIST OF INBOUND APPROACHES
1	M	NUMBER OF OUTBOUND APPROACHES
1	M	LIST OF OUTBOUND APPROACHES
1	M	PARAMETERS OPTION CARD
V	M	APPROACH CARD ---- GROUPED
1	O	TRAFFIC MIX CARD - GROUPED
V	M	LANE CARD -------- GROUPED
1	M	ARC CARD 1
V	O	ARC CARD 2
1	M	LINE CARD 1
V	O	LINE CARD 2
1	M	SDR CARD 1
V	O	SDR CARD 2
1	M	PLOT CARD
1	M	OPTIONS CARD
V	O	DRIVER MIX CARD
1	O	VEHICLE LENGTH CARD
1	O	VEHICLE OPERATIONAL CHARACTERISTIC CARD
1	O	VEHICLE MAXIMUM UNIFORM DECELERATION CARD
1	O	VEHICLE MAXIMUM UNIFORM ACCELERATION CARD
1	O	VEHICLE MAXIMUM VELOCITY CARD
1	O	VEHICLE MINIMUM TURNING RADIUS CARD
1	O	DRIVER OPERATIONAL FACTOR CARD
1	O	DRIVER PERCEPTION/REACTION TIME CARD
V	O	SPECIAL VEHCILE CARD

NUM IS NUMBER OF CARDS (V IS VARIABLE)
M/O IS MANDATORY OR OPTIONAL

PROGRAM 152217A AND 152217B

SHEET 2 OF 16
DATE 4/18/81
PREPARED BY ASB

GEOMETRY AND DRIVER-VEHICLE PROCESSOR INPUT - FORM 2

APPROACH CARD (MANDATORY)

APPROACH NUMBER	AZIMUTH IN DEG	X COORDINATE IN FT	Y COORDINATE IN FT	SPEED LIMIT IN MI/HR	NUMBER OF LANES	NUMBER OF DEGREES FOR STRAIGHT DEF=20	NUMBER OF DEGREES FOR U-TURN DEF=10	DISTRIBUTION NAME	EQUIVALENT HOURLY VOLUME IN VEH/HR	DISTRIBUTION PARAMETER	MEAN SPEED IN MI/HR	85% SPEED IN MI/HR	% OF VEHICLES TO OUTBOUND APPROACH A	B	C	D	E	F	TRAFFIC MIX CARD (YES/NO) DEF=NO
1	130	500	1200	30	3			SNEGEXP	1067	0.90	22.0	25.0	0	56	44				

(Columns from DEGREES FOR STRAIGHT through TRAFFIC MIX CARD: COMPLETE FOR INBOUND APPROACHS ONLY)

1 <= APPROACH NUMBER <= 12
0 <= AZIMUTH <= 353
0 <= X COORDINATE <= 2250
0 <= Y COORDINATE <= 2250
10 <= SPEED LIMIT <= 80
1 <= NUMBER OF LANES <= 6
0 <= NUMBER OF DEGREES FOR STRAIGHT <= 45
0 <= NUMBER OF DEGREES FOR U-TURN <= 45
DISTRIBUTION NAMES ARE CONSTAN/ERLANG/GAMMA/LOGNRML/NEGEXP/SNEGEXP/UNIFORM
0 <= EQUIVALENT HOURLY VOLUME <= 4000
DISTRIBUTION PARAMETER FOR CONSTANT IS NONE
DISTRIBUTION PARAMETER FOR ERLANG IS INTEGER VALUE (ROUNDED UP OR DOWN) FOR MEAN**2/VARIANCE (PARAMETER => 1)
DISTRIBUTION PARAMETER FOR GAMMA IS MEAN**2/VARIANCE (PARAMETER => 1.0)
DISTRIBUTION PARAMETER FOR LOGNRML IS STANDARD DEVIATION
DISTRIBUTION PARAMETER FOR NEGEXP IS NONE
DISTRIBUTION PARAMETER FOR SNEGEXP IS MINIMUM HEADWAY IN SEC (PARAMETER => MEAN HEADWAY = 3600/VOLUME)
DISTRIBUTION PARAMETER FOR UNIFORM IS STANDARD DEVIATION
10.0 <= MEAN SPEED <= 80.0
MEAN SPEED <= 85% SPEED <= 2.0364334*MEAN SPEED <= 90.0
0 <= % OF VEHICLES TO OUTBOUND APPROACH <= 100 AND SUM EQUALS 100

TRAFFIC MIX CARD (ONLY IF APPROACH CARD COL 78-80 = YES)

% OF VEHICLE CLASS IN APPROACH TRAFFIC BY VEHICLE CLASS														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15

0.0 <= % VEHICLE CLASS IN APPROACH TRAFFIC <= 100.0 AND SUM EQUALS 100.0

LANE CARD (MANDATORY)

LANE WIDTH IN FT (LANE 1, THEN LANE 3, AND THEN LANE 5)	BEG 1	END 1	BEG 2	END 2	U	L	S	R	% APPR VOLUME (INBOUND ONLY)	LANE WIDTH IN FT (LANE 2, THEN LANE 4, AND THEN LANE 6)	BEG 1	END 1	BEG 2	END 2	U	L	S	R	% APPR VOLUME (INBOUND ONLY)
12	0	630	0	630			S		33	12	0	630	0	630			S		34
12	0	630	0	630				R	33										

8 <= LANE WIDTH <= 15
0 <= BEG1 <= END1 <= BEG2 <= END2 <= 1000 (BEG1 = 0 FOR INBOUND LANES)
FOR ALL LANE USABLE SPECIFY BEG1=VAL END1=VAL BEG2=BEG1 END2=END1
FOR LANE BLOCKED AT START SPECIFY BEG1=0 END1=0 BEG2=VAL END2=VAL
FOR LANE BLOCKED AT END SPECIFY BEG1=VAL END1=VAL BEG2=1000 END2=1000
FOR LANE BLOCKED IN MIDDLE SPECIFY BEG1=VAL END1=VAL BEG2=VAL END2=VAL
0 <= % APPR VOLUME <= 100 AND SUM EQUAL 100 FOR INBOUND APPROACHS ONLY

PROGRAM 152217A AND 152217B

FORM 1435-1

Figure 44. Coded Input Data for TEXAS Model of Ashley Dr. & Kennedy Blvd.

TEXAS STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

THE TEXAS MODEL FOR INTERSECTION TRAFFIC

GEOMETRY AND DRIVER-VEHICLE PROCESSOR INPUT - FORM 2 CONTINUED

SHEET 3 OF 16
DATE 9/18/81
PREPARED BY ASB

APPROACH CARD (MANDATORY)

APPROACH NUMBER	AZIMUTH IN DEG	X COORDINATE IN FT	Y COORDINATE IN FT	SPEED LIMIT IN MI/HR	NUMBER OF LANES	NUMBER OF DEGREES FOR STRAIGHT DEF=20	NUMBER OF DEGREES FOR U-TURN DEF=10	DISTRIBUTION NAME	EQUIVALENT HOURLY VOLUME IN VEH/HR	DISTRIBUTION PARAMETER	MEAN SPEED IN MI/HR	85% SPEED IN MI/HR	% OF VEHICLES TO OUTBOUND APPROACH A	B	C	D	E	F	TRAFFIC MIX CARD (YES/NO) DEF=NO
2	270	1200	508	30	4			SNEGEXF	905	0.90	22.0	25.0	29	5	66				

LANE CARD (MANDATORY)

LANE WIDTH IN FT (Lane 1, 3, 5)	BEG 1	END 1	BEG 2	END 2	U	L	S	R	% APPR VOLUME (INBOUND ONLY)	LANE WIDTH IN FT (Lane 2, 4, 6)	BEG 1	END 1	BEG 2	END 2	U	L	S	R	% APPR VOLUME (INBOUND ONLY)
15	0	622	0	622		L			10	12	0	622	0	622			S		35
11	0	622	0	622			S		35	9	0	622	0	622				R	20

GEOMETRY AND DRIVER-VEHICLE PROCESSOR INPUT - FORM 2 CONTINUED

SHEET 4 OF 16
DATE 9/18/81
PREPARED BY ASB

APPROACH CARD (MANDATORY)

APPROACH NUMBER	AZIMUTH IN DEG	X COORDINATE IN FT	Y COORDINATE IN FT	SPEED LIMIT IN MI/HR	NUMBER OF LANES	NUMBER OF DEGREES FOR STRAIGHT DEF=20	NUMBER OF DEGREES FOR U-TURN DEF=10	DISTRIBUTION NAME	EQUIVALENT HOURLY VOLUME IN VEH/HR	DISTRIBUTION PARAMETER	MEAN SPEED IN MI/HR	85% SPEED IN MI/HR	% OF VEHICLES TO OUTBOUND APPROACH A	B	C	D	E	F	TRAFFIC MIX CARD (YES/NO) DEF=NO
3	352	584	100	30	3			SNEGEXP	530	0.90	22.0	25.0	92	0	8				

LANE CARD (MANDATORY)

LANE WIDTH IN FT (Lane 1, 3, 5)	BEG 1	END 1	BEG 2	END 2	U	L	S	R	% APPR VOLUME (INBOUND ONLY)	LANE WIDTH IN FT (Lane 2, 4, 6)	BEG 1	END 1	BEG 2	END 2	U	L	S	R	% APPR VOLUME (INBOUND ONLY)
12	0	0	280	392		L	S		0	12	0	390	0	390			S		50
12	0	388	0	388			S		50										

GEOMETRY AND DRIVER-VEHICLE PROCESSOR INPUT - FORM 2 CONTINUED

SHEET 5 OF 16
DATE 9/18/81
PREPARED BY ASB

APPROACH CARD (MANDATORY)

APPROACH NUMBER	AZIMUTH IN DEG	X COORDINATE IN FT	Y COORDINATE IN FT	SPEED LIMIT IN MI/HR	NUMBER OF LANES	NUMBER OF DEGREES FOR STRAIGHT DEF=20	NUMBER OF DEGREES FOR U-TURN DEF=10	DISTRIBUTION NAME	EQUIVALENT HOURLY VOLUME IN VEH/HR	DISTRIBUTION PARAMETER	MEAN SPEED IN MI/HR	85% SPEED IN MI/HR	% OF VEHICLES TO OUTBOUND APPROACH A	B	C	D	E	F	TRAFFIC MIX CARD (YES/NO) DEF=NO
4	9	0	533	30	3			SNEGEXP	747	0.90	26.0	30.0	69	31	0				

LANE CARD (MANDATORY)

LANE WIDTH IN FT (Lane 1, 3, 5)	BEG 1	END 1	BEG 2	END 2	U	L	S	R	% APPR VOLUME (INBOUND ONLY)	LANE WIDTH IN FT (Lane 2, 4, 6)	BEG 1	END 1	BEG 2	END 2	U	L	S	R	% APPR VOLUME (INBOUND ONLY)
11	0	430	0	430		L			25	11	0	427	0	427		L			40
11	0	423	0	423				R	35										

GEOMETRY AND DRIVER-VEHICLE PROCESSOR INPUT - FORM 2 CONTINUED

SHEET 6 OF 16
DATE 9/18/81
PREPARED BY ASB

APPROACH CARD (MANDATORY)

APPROACH NUMBER	AZIMUTH IN DEG	X COORDINATE IN FT	Y COORDINATE IN FT	SPEED LIMIT IN MI/HR	NUMBER OF LANES	NUMBER OF DEGREES FOR STRAIGHT DEF=20	NUMBER OF DEGREES FOR U-TURN DEF=10	DISTRIBUTION NAME	EQUIVALENT HOURLY VOLUME IN VEH/HR	DISTRIBUTION PARAMETER	MEAN SPEED IN MI/HR	85% SPEED IN MI/HR	% OF VEHICLES TO OUTBOUND APPROACH A	B	C	D	E	F	TRAFFIC MIX CARD (YES/NO) DEF=NO
5	0	530	570	30	3														

LANE CARD (MANDATORY)

LANE WIDTH IN FT (Lane 1, 3, 5)	BEG 1	END 1	BEG 2	END 2	U	L	S	R	% APPR VOLUME (INBOUND ONLY)	LANE WIDTH IN FT (Lane 2, 4, 6)	BEG 1	END 1	BEG 2	END 2	U	L	S	R	% APPR VOLUME (INBOUND ONLY)
12	0	610	0	610		L	S			12	0	610	0	610		L	S		
12	0	610	0	610			S	R											

8 <= LANE WIDTH <= 15
0 <= BEG1 <= END1 <= BEG2 <= END2 <= 1000 (BEG1 = 0 FOR INBOUND LANES)
FOR ALL LANE USABLE SPECIFY BEG1=VAL END1=VAL BEG2=BEG1 END2=END1
FOR LANE BLOCKED AT START SPECIFY BEG1=0 END1=0 BEG2=VAL END2=VAL
FOR LANE BLOCKED AT END SPECIFY BEG1=VAL END1=VAL BEG2=1000 END2=1000
FOR LANE BLOCKED IN MIDDLE SPECIFY BEG1=VAL END1=VAL BEG2=VAL END2=VAL
0 <= % APPR VOLUME <= 100 AND SUM EQUAL 100 FOR INBOUND APPROACHS ONLY

PROGRAM 152217A AND 152217B

FORM 1435-2

Figure 44. Coded Input Data for TEXAS Model of Ashley Dr. & Kennedy Blvd. (Continued)

TEXAS STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

THE TEXAS MODEL FOR INTERSECTION TRAFFIC

GEOMETRY AND DRIVER-VEHICLE PROCESSOR INPUT - FORM 2 CONTINUED

SHEET 7 OF 16
DATE 4/12/81
PREPARED BY ASB

APPROACH CARD (MANDATORY)

APPROACH NUMBER	AZIMUTH IN DEG	X COORDINATE IN FT	Y COORDINATE IN FT	SPEED LIMIT IN MI/HR	NUMBER OF LANES	NUMBER OF DEGREES FOR STRAIGHT DEF=20	NUMBER OF DEGREES FOR U-TURN DEF=10	DISTRIBUTION NAME	EQUIVALENT HOURLY VOLUME IN VEH/HR	DISTRIBUTION PARAMETER	MEAN SPEED IN MI/HR	85% SPEED IN MI/HR	A	B	C	D	E	F	TRAFFIC MIX CARD (YES/NO) DEF=NO
6	172	504	455	30	3														

(Columns from "Number of degrees for straight" onward: COMPLETE FOR INBOUND APPROACHS ONLY; A–F: % OF VEHICLES TO OUTBOUND APPROACH)

LANE CARD (MANDATORY)

INFORMATION FOR LANE 1, THEN LANE 3, AND THEN LANE 5

LANE WIDTH IN FT	BEG 1	END 1	BEG 2	END 2	U	L	S	R	% APPR VOLUME (INBOUND ONLY)
12	0	360	0	360		L	S		
12	0	200	360	360				R	

INFORMATION FOR LANE 2, THEN LANE 4, AND THEN LANE 6

LANE WIDTH IN FT	BEG 1	END 1	BEG 2	END 2	U	L	S	R	% APPR VOLUME (INBOUND ONLY)
12	0	360	0	360			S		

GEOMETRY AND DRIVER-VEHICLE PROCESSOR INPUT - FORM 2 CONTINUED

SHEET 8 OF 16
DATE 4/12/81
PREPARED BY ASB

APPROACH CARD (MANDATORY)

APPROACH NUMBER	AZIMUTH IN DEG	X COORDINATE IN FT	Y COORDINATE IN FT	SPEED LIMIT IN MI/HR	NUMBER OF LANES	NUMBER OF DEGREES FOR STRAIGHT DEF=20	NUMBER OF DEGREES FOR U-TURN DEF=10	DISTRIBUTION NAME	EQUIVALENT HOURLY VOLUME IN VEH/HR	DISTRIBUTION PARAMETER	MEAN SPEED IN MI/HR	85% SPEED IN MI/HR	A	B	C	D	E	F	TRAFFIC MIX CARD (YES/NO) DEF=NO
7	270	443	533	30	2														

(Columns from "Number of degrees for straight" onward: COMPLETE FOR INBOUND APPROACHS ONLY; A–F: % OF VEHICLES TO OUTBOUND APPROACH)

LANE CARD (MANDATORY)

INFORMATION FOR LANE 1, THEN LANE 3, AND THEN LANE 5

LANE WIDTH IN FT	BEG 1	END 1	BEG 2	END 2	U	L	S	R	% APPR VOLUME (INBOUND ONLY)
11	5	435	5	435		L	S		

INFORMATION FOR LANE 2, THEN LANE 4, AND THEN LANE 6

LANE WIDTH IN FT	BEG 1	END 1	BEG 2	END 2	U	L	S	R	% APPR VOLUME (INBOUND ONLY)
11	0	435	0	435			S	R	

GEOMETRY AND DRIVER-VEHICLE PROCESSOR INPUT - FORM 3

SHEET 9 OF 16
DATE 4/12/81
PREPARED BY ASB

ARC CARD 1 (MANDATORY)

NUMBER OF ARCS: 7

0 <= NUMBER OF ARCS <= 20

ARC CARD 2
(ONLY IF ARC CARD COL 1-4 GT 0)

ARC NUMBER	X CENTER IN FT	Y CENTER IN FT	BEGIN AZIMUTH IN DEG	SWEEP ANGLE IN DEG	RADIUS IN FT
1	454	565	90	90	10
2	515	588	90	180	15
3	576	565	180	90	10
4	576	490	0	-98	10
5	520	483	83	-133	10
6	546	462	309	-48	44
7	427	485	0	69	15

1 <= ARC NUMBER <= 20
0 <= X CENTER <= 2250
0 <= Y CENTER <= 2250
0 <= BEGIN AZIMUTH <= 359
-360 <= SWEEP ANGLE <= 360
1 <= RADIUS <= 127

LINE CARD 1 (MANDATORY)

NUMBER OF LINES: 23

0 <= NUMBER OF LINES <= 100

LINE CARD 2 (MAX=100 CARDS)
(ONLY IF LINE CARD COL 1-4 GT 0)

LINE NUMBER	X BEG IN FT	Y BEG IN FT	X END IN FT	Y END IN FT
1	435	555	454	555
2	464	565	464	574
3	566	565	566	590
4	576	555	583	555
5	576	500	876	500
6	566	488	569	478
7	441	490	472	418
8	455	511	472	511
9	472	511	475	498
10	475	498	455	511
11	502	519	521	520
12	521	520	526	512
13	526	512	502	505
14	502	505	502	514
15	460	559	570	559
16	464	569	566	569
17	570	559	568	500
18	578	555	577	500
19	588	500	435	499
20	568	490	530	490
21	512	490	441	490
22	435	498	460	559
23	425	500	448	555

1 <= LINE NUMBER <= 100
0 <= X BEG <= 2250
0 <= Y BEG <= 2250
0 <= X END <= 2250
0 <= Y END <= 2250

□ - CHECK IF CONTINUED

SDR CARD 1 (MANDATORY)

NUMBER OF SDR'S: 4

0 <= NUMBER OF SDR'S <= 20

SDR CARD 2
(ONLY IF SDR CARD 1 COL 1-4 GT 0)

SDR NUMBER	X COORDINATE IN FT	Y COORDINATE IN FT
1	441	577
2	577	568
3	577	490
4	432	490

1 <= SDR NUMBER <= 20
0 <= X COORDINATE <= 2250
0 <= Y COORDINATE <= 2250

PROGRAM 1S2217A AND 1S2217B

FORM 1436-1

Figure 44. Coded Input Data for TEXAS Model of Ashley Dr. & Kennedy Blvd. (Continued)

TEXAS STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

THE TEXAS MODEL FOR INTERSECTION TRAFFIC

GEOMETRY AND DRIVER-VEHICLE PROCESSOR INPUT - FORM 4

SHEET 10 OF 16
DATE 4/14/87
PREPARED BY [illegible]

PLOT CARD (MANDATORY)

PATH TYPE (PRIMARY/OPTION1) DEF=PRIMARY	PLOT OPTION (NOPLOT/PLOT/PLOTI/PLOTR) DEF=PLOT	PLOT TYPE (SAME/SEPARATE) DEF=SEPARATE	PLOT SCALE FACTOR IN FT/IN FOR APPROACH DEF=SCALED	PLOT SCALE FACTOR IN FT/IN FOR INTERSECTION DEF=SCALED	MAXIMUM RADIUS FOR PATHS IN FT DEF=500.0	MINIMUM DISTANCE BETWEEN PATHS IN FT DEF=10	PLOT PAPER WIDTH IN IN (12/30) DEF=30
	NOPLOT						

100.0 <= MAXIMUM RADIUS FOR PATHS <= 900.0
6 <= MINIMUM DISTANCE BETWEEN PATHS <= 20

OPTIONS CARD (MANDATORY) (YES/NO WITH DEF=NO FOR ALL)

USER SUPPLIED DRIVER MIX	USER SUPPLIED VEHICLE DATA	USER SUPPLIED DRIVER DATA	LOGOUT SUMMARY FOR DRIVER/VEHICLE UNIT BY VEHICLE CLASS															LOGOUT SUMMARY FOR DRIVER/VEHICLE UNIT BY DRIVER CLASS				
			01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	1	2	3	4	5
NO	NO	NO	NO	NO	YES	YES	YES	NO	NO	NO	YES	NO						NO	YES	NO		

DRIVER MIX CARD (ONLY IF OPTIONS CARD COL 1-3 = YES)

	PERCENT CLASS I DRIVER IN CLASS J VEHCILE					
	DRIVER CLASS 1	DRIVER CLASS 2	DRIVER CLASS 3	DRIVER CLASS 4	DRIVER CLASS 5	
VEHICLE CLASS 01						ONLY IF THE NUMBER OF VEHICLE CLASSES => 01
VEHICLE CLASS 02						ONLY IF THE NUMBER OF VEHICLE CLASSES => 02
VEHICLE CLASS 03						ONLY IF THE NUMBER OF VEHICLE CLASSES => 03
VEHICLE CLASS 04						ONLY IF THE NUMBER OF VEHICLE CLASSES => 04
VEHICLE CLASS 05						ONLY IF THE NUMBER OF VEHICLE CLASSES => 05
VEHICLE CLASS 06						ONLY IF THE NUMBER OF VEHICLE CLASSES => 06
VEHICLE CLASS 07						ONLY IF THE NUMBER OF VEHICLE CLASSES => 07
VEHICLE CLASS 08						ONLY IF THE NUMBER OF VEHICLE CLASSES => 08
VEHICLE CLASS 09						ONLY IF THE NUMBER OF VEHICLE CLASSES => 09
VEHICLE CLASS 10						ONLY IF THE NUMBER OF VEHICLE CLASSES => 10
VEHICLE CLASS 11						ONLY IF THE NUMBER OF VEHICLE CLASSES => 11
VEHICLE CLASS 12						ONLY IF THE NUMBER OF VEHICLE CLASSES => 12
VEHICLE CLASS 13						ONLY IF THE NUMBER OF VEHICLE CLASSES => 13
VEHICLE CLASS 14						ONLY IF THE NUMBER OF VEHICLE CLASSES => 14
VEHICLE CLASS 15						ONLY IF THE NUMBER OF VEHICLE CLASSES = 15

0.0 <= PERCENT <= 100.0 AND EACH ROW SUM EQUAL 100.0

PROGRAM 152217A AND 152217B FORM 1436-2

GEOMETRY AND DRIVER-VEHICLE PROCESSOR INPUT - FORM 7

SPECIAL VEHCILE CARD (OPTIONAL) (MAX=UNLIMITED)

QUEUE-IN TIME IN SEC	VEHICLE CLASS	DRIVER CLASS	DESIRED SPEED IN FT/SEC	DESIRED OUTBOUND APPROACH	INBOUND APPROACH	INBOUND LANE	VEHICLE LOGOUT SUMMARY
480.00	9	1	15	7	1	3	1
720.00	9	1	15	5	2	4	1

0 <= QUEUE-IN TIME <= 60*SIMULATION TIME IN MINUTES <= 3900
QUEUE-IN TIME INCLUDES START-UP TIME
1 <= VEHICLE CLASS <= NUMBER OF VEHICLE CLASSES
1 <= DRIVER CLASS <= NUMBER OF DRIVER CLASSES
1 <= DESIRED SPEED <= [illegible]
1 <= DESIRED OUTBOUND APPROACH <= 12
1 <= INBOUND APPROACH <= 12
1 <= INBOUND LANE <= NUMBER OF LANES FOR INBOUND APPROACH
INBOUND LANE 1 IS MEDIAN LANE AND INBOUND LANE N IS CURB LANE
0=NO AND 1=YES FOR VEHICLE LOGOUT SUMMARY

PROGRAM 152217A AND 152217B FORM 1438-1

Figure 44. Coded Input Data for TEXAS Model of Ashley Dr. & Kennedy Blvd. (Continued)

TEXAS STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION
THE TEXAS MODEL FOR INTERSECTION TRAFFIC
SIMULATION PROCESSOR INPUT - FORM 1

SHEET 12 OF 16
DATE 9/18/81
PREPARED BY ASB

TITLE CARD (MANDATORY)

UP TO 80 ALPHANUMERIC CHARACTERS - CENTERED IF DESIRED

*** ASHLEY DR. & KENNEDY BLVD. - EXISTING TRAFFIC CONTROLS PM HOUR JUNE 1978 ***

PARAMETER CARD (MANDATORY)

START-UP TIME IN MIN	SIMULATION TIME IN MIN	STEP INCREMENT FOR SIMULATION TIME (DT) IN SEC	SPEED FOR DELAY BELOW XX MPH IN MPH	MAX CLEAR DISTANCE FOR BEING IN A QUEUE IN FT	TRADITIONAL CAR-FOLLOWING EQUATION PARAMETERS: LAMBDA	MU	ALPHA	TYPE OF INTERSECTION CONTROL	STATISTICAL SUMMARY BY TURNING MOVEMENT (YES/NO) DEF=YES	STATISTICAL SUMMARY BY INBOUND APPROACH (YES/NO) DEF=YES	PUNCHED OUTPUT STATISTICS (YES/NO) DEF=YES	POLLUTION TAPE (YES/NO) DEF=NO	VEHICLE CONFLICT ZONE TIMES IN SEC: LEAD ZONE	LAG ZONE	OPTIONAL - EXPERT USER ONLY: TIME INTERVAL FOR INTERMEDIATE STATISTICS IN SEC DEF=INF	TIME TO BEGIN DETAILED DRIVER-VEHICLE UNIT TRACE PRINT IN SEC DEF=INF	ERROR CHECKING
3.00	12.00	1.00	10	30	2.800	0.800	4000	6	YES	YES	NO	NO	1.30	.50			

2.00 <= START-UP TIME <= 5.00
DURING START-UP TIME NO STATISTICS ARE GATHERED
10.00 <= SIMULATION TIME <= 60.00
DURING SIMULATION TIME STATISTICS ARE GATHERED
0.50 <= STEP INCREMENT FOR SIMULATION TIME (DT) <= 1.60
RECOMMENDED DT FOR SIGNAL IS 1.00
RECOMMENDED DT FOR NON-SIGNAL IS 0.50
0 <= SPEED FOR DELAY BELOW XX MPH <= 40
4 <= MAX CLEAR DISTANCE FOR BEING IN A QUEUE <= 40 AND RECOMMENDED IS 30
2.300 <= CAR-FOLLOWING LAMBDA <= 4.000 AND RECOMMENDED IS 2.800
0.800 <= CAR-FOLLOWING MU <= 1.000 AND RECOMMENDED IS 0.800
0 <= CAR-FOLLOWING ALPHA <= 10000 AND RECOMMENDED IS 4000
1 <= TYPE OF INTERSECTION CONTROL <= 7
TYPE OF INTERSECTION CONTROL = 1 = UNCONTROLLED
TYPE OF INTERSECTION CONTROL = 2 = YIELD
TYPE OF INTERSECTION CONTROL = 3 = LESS THAN ALL-WAY STOP
TYPE OF INTERSECTION CONTROL = 4 = ALL-WAY STOP
TYPE OF INTERSECTION CONTROL = 5 = PRETIMED SIGNAL
TYPE OF INTERSECTION CONTROL = 6 = SEMI-ACTUATED SIGNAL
TYPE OF INTERSECTION CONTROL = 7 = FULL-ACTUATED SIGNAL
1.00 <= TIME OF LEAD CONFLICT ZONE <= 3.00 AND RECOMMENDED IS 1.50
1.00 <= TIME OF LAG CONFLICT ZONE <= 3.00 AND RECOMMENDED IS 2.50
COL 71-80 ARE RESTRICTED TO USE BY EXPERT USERS AND SYSTEM PROGRAMMERS ONLY FOR CORRECTING THE PROGRAM
BLANK=YES AND X=NO FOR ERROR CHECKING OPTION

LANE CONTROL CARD (MANDATORY)

LANE CONTROL FOR EACH LANE BY GEOMETRY PROCESSOR LANE NUMBER IL

01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
5	5	5	5	5	5	5	5	5	5	5	5	5	1	1	1	1	1	1	1	1																													

GEOMETRY PROCESSOR LANE NUMBER IL IS THE NUMBER FROM TABLE 3 UNDER THE COLUMN HEADING IL IN THE GEOMETRY PROCESSOR OUTPUT
1 <= LANE CONTROL <= 7
LANE CONTROL = 1 = OUTBOUND LANE OR AN INBOUND LANE WHICH ENDS BEFORE THE INTERSECTION
LANE CONTROL = 2 = UNCONTROLLED (ONLY IF TYPE OF INTERSECTION CONTROL <= 3)
LANE CONTROL = 3 = YIELD SIGN (ONLY IF TYPE OF INTERSECTION CONTROL => 2)
LANE CONTROL = 4 = STOP SIGN (ONLY IF TYPE OF INTERSECTION CONTROL = 3 OR 4)
LANE CONTROL = 5 = SIGNAL WITHOUT LEFT OR RIGHT TURN ON RED (ONLY IF TYPE OF INTERSECTION CONTROL => 5)
LANE CONTROL = 6 = SIGNAL WITH LEFT TURN ON RED (ONLY IF TYPE OF INTERSECTION CONTROL => 5)
LANE CONTROL = 7 = SIGNAL WITH RIGHT TURN ON RED (ONLY IF TYPE OF INTERSECTION CONTROL => 5)

ORDER OF INPUT CARDS

NUM	M/O	CARD TITLE
1	M	TITLE CARD
1	M	PARAMETER CARD
1	M	LANE CONTROL CARD
1	O	CAM STACK CARD 1
V	O	CAM STACK CARD 2
1	O	SEMI-ACTUATED SIGNAL CONTROLLER PHASE CARD 1
1	O	SEMI-ACTUATED SIGNAL CONTROLLER MAJOR STREET PHASE CARD 2
V	O	SEMI-ACTUATED SIGNAL CONTROLLER MINOR STREET PHASE CARD 3 ---------- GROUPED
V	O	SEMI-ACTUATED SIGNAL CONTROLLER MINOR STREET PHASE DETECTOR CARD 4 - GROUPED
1	O	FULL-ACTUATED SIGNAL CONTROLLER PHASE CARD 1
V	O	FULL-ACTUATED SIGNAL CONTROLLER PHASE CARD 2 ---------- GROUPED
V	O	FULL-ACTUATED SIGNAL CONTROLLER PHASE DETECTOR CARD 3 - GROUPED
1	O	DETECTOR CARD 1
V	O	DETECTOR CARD 2

NUM IS NUMBER OF CARDS (V IS VARIABLE)
M/O IS MANDATORY OR OPTIONAL

PROGRAM 152217C

FORM 1439

TEXAS STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION
THE TEXAS MODEL FOR INTERSECTION TRAFFIC
SIMULATION PROCESSOR INPUT - FORM 2

SHEET 13 OF 16
DATE 9/18/81
PREPARED BY ASB

CAM STACK CARD 1 (ONLY IF PARAMETER CARD COL 39-40 IS 5, 6, OR 7)

NUMBER OF SIGNAL CONTROLLER CAM STACK POSITIONS
[illegible]

4 <= NUMBER OF SIGNAL CONTROLLER CAM STACK POSITIONS <= 72

CAM STACK CARD 2 (MAX=72 CARDS) (ONLY IF PARAMETER CARD COL 39-40 IS 5, 6, OR 7)

SIGNAL INDICATION THREE-CHARACTER CODE FOR EACH LANE BY GEOMETRY PROCESSOR INBOUND LANE NUMBER IBLN

PHASE NUMBER	TIME SPAN OF CAM STACK POSITION IN SEC (PRETIMED ONLY)	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1		AR	AR	AR	AP	AG	AG	AG	AR	AR	AR	AR	AR	AG												
1					AA	AA	AA	AA																		
1														AA												
2				AG	AR	AR	AR	AR				AP	AP	AG												
2												AA	AA	AA												
2				AA										AG												
3		AG	AG	AG					AG	AG	AG	AR	AR	AR												
3		AA	AA	AA					AA	AA	AA															

1 <= PHASE NUMBER <= 8
1 <= TIME SPAN <= 999 (ONLY IF TYPE OF INTERSECTION CONTROL = 5 = PRETIMED SIGNAL)
SIGNAL INDICATION THREE-CHARACTER CODES ARE:
AG = ALL GREEN
AA = ALL AMBER
AR = ALL RED
AP = ALL PROTECTED
LGA = LEFT TURN GREEN AND ALL OTHERS AMBER
LGR = LEFT TURN GREEN AND ALL OTHERS RED
LAG = LEFT TURN AMBER AND ALL OTHERS GREEN
LAR = LEFT TURN AMBER AND ALL OTHERS RED
LRG = LEFT TURN RED AND ALL OTHERS GREEN
LRA = LEFT TURN RED AND ALL OTHERS AMBER
LPG = LEFT TURN PROTECTED GREEN AND ALL OTHERS GREEN
LPA = LEFT TURN PROTECTED GREEN AND ALL OTHERS AMBER
LPR = LEFT TURN PROTECTED GREEN AND ALL OTHERS RED
SGA = STRAIGHT GREEN AND ALL OTHERS AMBER
SGR = STRAIGHT GREEN AND ALL OTHERS RED
SAG = STRAIGHT AMBER AND ALL OTHERS GREEN
SAR = STRAIGHT AMBER AND ALL OTHERS RED
SRG = STRAIGHT RED AND ALL OTHERS GREEN
SRA = STRAIGHT RED AND ALL OTHERS AMBER
RGA = RIGHT TURN GREEN AND ALL OTHERS AMBER
RGR = RIGHT TURN GREEN AND ALL OTHERS RED
RAG = RIGHT TURN AMBER AND ALL OTHERS GREEN
RAR = RIGHT TURN AMBER AND ALL OTHERS RED
RRG = RIGHT TURN RED AND ALL OTHERS GREEN
RRA = RIGHT TURN RED AND ALL OTHERS AMBER
UNS = UNSIGNALIZED LANE (CHANNELIZED RIGHT TURN OR LANE BLOCKED AT INTERSECTION)
IT IS NOT NECESSARY TO DUPLICATE THE THREE-CHARACTER CODE FOR AN INBOUND LANE IF THE SIGNAL INDICATION REMAINS THE SAME
GEOMETRY PROCESSOR INBOUND LANE NUMBER IBLN IS THE NUMBER FROM TABLE 3 UNDER THE COLUMN HEADING IBLN IN THE GEOMETRY PROCESSOR OUTPUT

PROGRAM 152217C

FORM 1440-1

Figure 44. Coded Input Data for TEXAS Model of Ashley Dr. & Kennedy Blvd. (Continued)

TEXAS STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

THE TEXAS MODEL FOR INTERSECTION TRAFFIC

SIMULATION PROCESSOR INPUT - FORM 3

SHEET 14 OF 16
DATE [illegible]
PREPARED BY [illegible]

SEMI-ACTUATED SIGNAL CONTROLLER PHASE CARD 1 (ONLY IF PARAMETER CARD COL 39-40 IS 6)

NUMBER OF SEMI-ACTUATED SIGNAL CONTROLLER PHASES
3

2 <= NUMBER OF SEMI-ACTUATED SIGNAL CONTROLLER PHASES <= 8

SEMI-ACTUATED SIGNAL CONTROLLER MAJOR STREET PHASE CARD 2 (ONLY IF PARAMETER CARD COL 39-40 IS 6)

PHASE NUMBER	MINIMUM ASSURED GREEN IN SEC		AMBER CLEARANCE INTERVAL IN SEC	ALL-RED CLEARANCE INTERVAL IN SEC		NUMBER OF PHASES WHICH CAN BE CLEARED TO DIRECTLY FROM THIS PHASE	1ST	2ND	3RD	4TH	5TH	6TH	7TH
1	34.2		4.5	0.0		2	2	3					

MINIMUM ASSURED GREEN => STEP INCREMENT FOR SIMULATION TIME (DT)
AMBER CLEARANCE INTERVAL => 0.0
ALL-RED CLEARANCE INTERVAL => 0.0
IF ALL-RED CLEARANCE INTERVAL TIME IS GREATER THAN ZERO THEN THE LAST SIGNAL INDICATION DEFINED FOR THIS PHASE MUST BE THE ALL-RED CLEARANCE INTERVAL
1 <= NUMBER OF PHASES WHICH CAN BE CLEARED TO DIRECTLY FROM THIS PHASE <= 7
1 <= PHASE NUMBER WHICH CAN BE CLEARED TO DIRECTLY FROM THIS PHASE <= NUMBER OF SEMI-ACTUATED SIGNAL CONTROLLER PHASES <= 8
THE LIST OF PHASES WHICH CAN BE CLEARED TO DIRECTLY FROM THIS PHASE MUST BE IN PRIORITY ORDER
THERE MUST BE AN AMBER CLEARANCE SIGNAL INDICATION DEFINED FOR EACH PHASE WHICH CAN BE CLEARED TO DIRECTLY FROM THIS PHASE AND IN THE ORDER DEFINED BY THE LIST OF PHASES

SEMI-ACTUATED SIGNAL CONTROLLER MINOR STREET PHASE CARD 3 (ONLY IF PARAMETER CARD COL 39-40 IS 6)

PHASE NUMBER	INITIAL INTERVAL IN SEC	VEHICLE INTERVAL IN SEC	AMBER CLEARANCE INTERVAL IN SEC	ALL-RED CLEARANCE INTERVAL IN SEC	MAXIMUM EXTENSION IN SEC	SKIP PHASE SWITCH (ON/OFF) DEF=OFF	RECALL SWITCH (ON/OFF) DEF=OFF	MINOR MOVEMENT CONTROLLER (YES/NO) DEF=NO	DUAL LEFT FOLLOWED BY TWO SINGLE LEFTS (YES/NO) DEF=NO	DETECTOR CONNECTION (AND/OR) DEF=OR	NUMBER OF DETECTORS ATTACHED TO THIS PHASE	NUMBER OF PHASES WHICH CAN BE CLEARED TO DIRECTLY FROM THIS PHASE	1ST	2ND	3RD	4TH	5TH	6TH	7TH
2	9.0	2.7	4.5	0.0	19.8	ON	OFF	NO	NO	OR	1	2	3	1					

2 <= PHASE NUMBER <= NUMBER OF SEMI-ACTUATED SIGNAL CONTROLLER PHASES <= 8
INITIAL INTERVAL => STEP INCREMENT FOR SIMULATION TIME (DT)
VEHICLE INTERVAL => STEP INCREMENT FOR SIMULATION TIME (DT)
AMBER CLEARANCE INTERVAL => 0.0
ALL-RED CLEARANCE INTERVAL => 0.0
IF ALL-RED CLEARANCE INTERVAL TIME IS GREATER THAN ZERO THEN THE LAST SIGNAL INDICATION DEFINED FOR THIS PHASE MUST BE THE ALL-RED CLEARANCE INTERVAL
MAXIMUM EXTENSION => 0.0
0 <= NUMBER OF DETECTORS ATTACHED TO THIS PHASE <= 10
1 <= NUMBER OF PHASES WHICH CAN BE CLEARED TO DIRECTLY FROM THIS PHASE <= 7
1 <= PHASE NUMBER WHICH CAN BE CLEARED TO DIRECTLY FROM THIS PHASE <= NUMBER OF SEMI-ACTUATED SIGNAL CONTROLLER PHASES <= 8
THE LIST OF PHASES WHICH CAN BE CLEARED TO DIRECTLY FROM THIS PHASE MUST BE IN PRIORITY ORDER
THERE MUST BE AN AMBER CLEARANCE SIGNAL INDICATION DEFINED FOR EACH PHASE WHICH CAN BE CLEARED TO DIRECTLY FROM THIS PHASE AND IN THE ORDER DEFINED BY THE LIST OF PHASES

SEMI-ACTUATED SIGNAL CONTROLLER MINOR STREET PHASE DETECTOR CARD 4 (ONLY IF NUMBER OF DETECTORS FOR PHASE => 1)

LIST OF DETECTOR NUMBERS ATTACHED TO THIS PHASE									
01	02	03	04	05	06	07	08	09	10
3									

-20 <= - TOTAL NUMBER OF DETECTORS <= DETECTOR NUMBER <= TOTAL NUMBER OF DETECTORS <= 20
A "NOT" CONNECTION SHOULD BE CODED AS A NEGATIVE NUMBER
ALL POSITIVE CONNECTED DETECTORS SHOULD BE CODED FIRST THEN THE NEGATIVE CONNECTED DETECTORS
IF THE FIRST DETECTOR IS NEGATIVE THEN THE REMAINDER OF THE DETECTORS MUST BE NEGATIVE
AN ALL-RED REST PHASE HAS ALL NEGATIVE CONNECTIONS

PROGRAM 152217C

SHEET 15 OF 16
DATE [illegible]
PREPARED BY [illegible]

SIMULATION PROCESSOR INPUT - FORM 3 CONTINUED

SEMI-ACTUATED SIGNAL CONTROLLER MINOR STREET PHASE CARD 3 (ONLY IF PARAMETER CARD COL 39-40 IS 6)

PHASE NUMBER	INITIAL INTERVAL IN SEC	VEHICLE INTERVAL IN SEC	AMBER CLEARANCE INTERVAL IN SEC	ALL-RED CLEARANCE INTERVAL IN SEC	MAXIMUM EXTENSION IN SEC	SKIP PHASE SWITCH (ON/OFF) DEF=OFF	RECALL SWITCH (ON/OFF) DEF=OFF	MINOR MOVEMENT CONTROLLER (YES/NO) DEF=NO	DUAL LEFT FOLLOWED BY TWO SINGLE LEFTS (YES/NO) DEF=NO	DETECTOR CONNECTION (AND/OR) DEF=OR	NUMBER OF DETECTORS ATTACHED TO THIS PHASE	NUMBER OF PHASES WHICH CAN BE CLEARED TO DIRECTLY FROM THIS PHASE	1ST	2ND	3RD	4TH	5TH	6TH	7TH
3	9.0	2.7	4.5	0.0	22.5	ON	OFF	NO	NO	OR	3	1	1						

SEMI-ACTUATED SIGNAL CONTROLLER MINOR STREET PHASE DETECTOR CARD 4 (ONLY IF NUMBER OF DETECTORS FOR PHASE => 1)

LIST OF DETECTOR NUMBERS ATTACHED TO THIS PHASE									
01	02	03	04	05	06	07	08	09	10
1	4	5							

-20 <= - TOTAL NUMBER OF DETECTORS <= DETECTOR NUMBER <= TOTAL NUMBER OF DETECTORS <= 20
A "NOT" CONNECTION SHOULD BE CODED AS A NEGATIVE NUMBER
ALL POSITIVE CONNECTED DETECTORS SHOULD BE CODED FIRST THEN THE NEGATIVE CONNECTED DETECTORS
IF THE FIRST DETECTOR IS NEGATIVE THEN THE REMAINDER OF THE DETECTORS MUST BE NEGATIVE
AN ALL-RED REST PHASE HAS ALL NEGATIVE CONNECTIONS

SIMULATION PROCESSOR INPUT - FORM 5

DETECTOR CARD 1 (ONLY IF PARAMETER CARD COL 39-40 IS 6 OR 7 AND DETECTORS WERE USED)

TOTAL NUMBER OF DETECTORS
4

1 <= TOTAL NUMBER OF DETECTORS <= 20

DETECTOR CARD 2 (ONLY IF DETECTOR CARD 1 COL 1-4 GT 0)

DETECTOR NUMBER	DETECTOR TYPE (PULSE/PRESENCE) DEF=PRESENCE	DISTANCE DOWN APPROACH TO DETECTOR LOCATIONS: BEG	END	APPROACH NUMBER	NUMBER OF LANES COVERED BY THIS DETECTOR	LIST OF LANES COVERED BY THIS DETECTOR: 1	2	3	4	5	6
1	PULSE	360	366	3	3	1	2	3			
3	PULSE	400	406	4	2	1	2				
4	PRESENCE	600	626	1	1	3					
5	PULSE	605	611	1	2	1	2				

1 <= DETECTOR NUMBER <= 20
0 <= DISTANCE DOWN APPROACH TO DETECTOR LOCATION <= LENGTH OF APPROACH <= 1000
APPROACH NUMBER IS THE NUMBER FROM TABLE 3 IN THE GEOMETRY PROCESSOR OUTPUT (INBOUND APPROACHES ONLY)
1 <= APPROACH NUMBER <= 1?
1 <= NUMBER OF LANES COVERED BY THIS DETECTOR <= NUMBER OF LANES FOR THIS APPROACH <= 6
1 <= LANE NUMBER COVERED BY THIS DETECTOR <= NUMBER OF LANES FOR THIS APPROACH <= 6
MAXIMUM NUMBER OF DETECTORS PER INBOUND LANE IS 5

PROGRAM 152217C

FORM 1443

Figure 44. Coded Input Data for TEXAS Model of Ashley Dr. & Kennedy Blvd. (Continued)

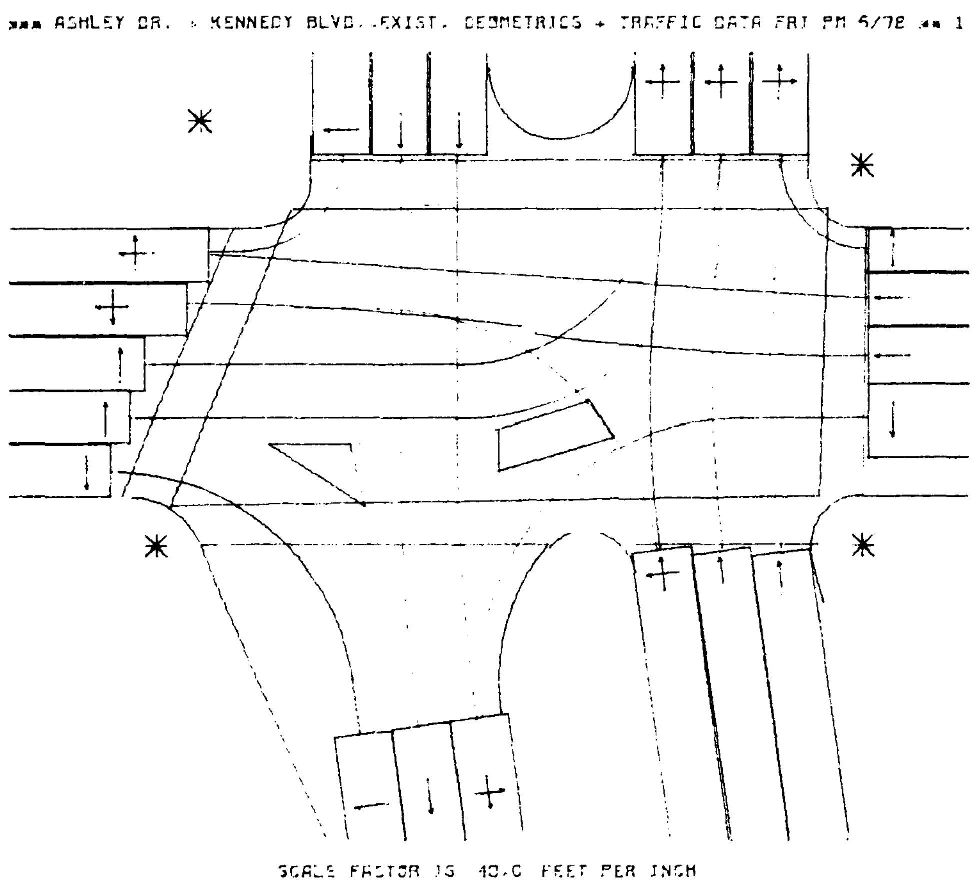

Figure 45. Pen Plot of Intersection Geometrics and Vehicles Movements of Example Intersections.

```
START-UP TIME (MINUTES) --------------------------- =      3.00
SIMULATION TIME (MINUTES) ------------------------- =     12.00
STEP INCREMENT FOR SIMULATION TIME (SECONDS) ------ =      1.00

SPEED FOR DELAY BELOW XX MPH (MPH) ---------------- =     10.00

MAXIMUM CLEAR DISTANCE FOR BEING IN A QUEUE (FT) -- =     30.00

CAR FOLLOWING EQUATION LAMBDA --------------------- =      2.80000
CAR FOLLOWING EQUATION MU ------------------------- =      0.80000
CAR FOLLOWING EQUATION ALPHA ---------------------- =   4000.00000

SUMMARY STATISTICS PRINTED BY TURNING MOVEMENTS --- =    YES
SUMMARY STATISTICS PRINTED BY INBOUND APPROACH ---- =    YES

PUNCHED OUTPUT OF STATISTICS ---------------------- =    NO

WRITE TAPE FOR POLLUTION DISPERSION MODEL --------- =    NO

LEAD TIME GAP FOR CONFLICT CHECKING (SECONDS) ----- =      1.30
LAG TIME GAP FOR CONFLICT CHECKING (SECONDS) ------ =      0.50

INTERSECTION TRAFFIC CONTROL ---------------------- =      6
                                                             (SEMI-ACTUATED SIGNAL)


LANE CONTROL FOR THE 21 LANES = 5 5 5 5 5 5 5 5 5 5 5 5 5 1 1 1 1 1 1 1 1
0      WHERE  1 = OUTBOUND (OR BLOCKED INBOUND) LANE
              2 = UNCONTROLLED
              3 = YIELD SIGN
              4 = STOP SIGN
              5 = SIGNAL
              6 = SIGNAL WITH LEFT TURN ON RED
              7 = SIGNAL WITH RIGHT TURN ON RED

A TOTAL OF  8 CAM STACK ENTRIES

ENTRY  1 PHASE  1  *R  *R  *R  *P  *G  *G  *G  *R  *R  *R  *R  *R  *G
ENTRY  2 PHASE  1              **  **  **  **
ENTRY  3 PHASE  1                                                  **
ENTRY  4 PHASE  2          *G  *R  *P  *R  *P                  *P  *P  *G
ENTRY  5 PHASE  2                                              **  **  **
ENTRY  6 PHASE  2          **                                          *G
ENTRY  7 PHASE  3  *G  *G  *G                      *G  *G  *G  *R  *R  *R
ENTRY  8 PHASE  3  **  **  **                      **  **  **
1         SIMULATION PROCESSOR FOR THE TEXAS TRAFFIC SIMULATION PACKAGE

*** ASHLEY DR. & KENNEDY BLVD.-EXISTING TRAFFIC CONTROLS PM HOUR JUNE  1978 ***

A TOTAL OF 3 SIGNAL PHASES

SEMI-ACTUATED SIGNAL MAIN STREET INFORMATION
MAIN STREET PHASE NUMBER -------------------------- =   1
MAIN STREET MINIMUM ASSURED GREEN (SECONDS) ------- =  34.2
MAIN STREET AMBER CLEARANCE INTERVAL (SECONDS) ---- =   4.5
MAIN STREET ALL-RED CLEARANCE INTERVAL (SECONDS) -- =   0.0
MAIN STREET NUMBER OF PHASES CLEARED TO ----------- =   2
MAIN STREET LIST OF PHASES CLEARED TO ------------- =   2   3


SIGNAL PHASE NUMBER ------------------------------- =   2
INITIAL INTERVAL (SECONDS) ------------------------ =   9.0
VEHICLE INTERVAL (SECONDS) ------------------------ =   2.7
AMBER CLEARANCE INTERVAL (SECONDS) ---------------- =   4.5
ALL-RED CLEARANCE INTERVAL (SECONDS) -------------- =   0.0
MAXIMUM EXTENSION AFTER DEMAND ON RED (SECONDS) --- =  19.8
SKIP-PHASE SWITCH (ON/OFF) ------------------------ =   ON
AUTO-RECALL SWITCH (ON/OFF) ----------------------- =   OFF
PARENT/MINOR MOVEMENT PHASE OPTION (YES/NO) ------- =   NO
DUAL LEFT OPTION (YES/NO) ------------------------- =   NO
DETECTOR CONNECTION TYPE (AND/OR) ----------------- =   OR
NUMBER OF DETECTORS CONNECTED TO PHASE ------------ =   1
NUMBER OF PHASES CLEARED TO ----------------------- =   2
LIST OF PHASES CLEARED TO ------------------------- =   3   1
LIST OF DETECTORS CONNECTED TO PHASE -------------- =   3
SIGNAL PHASE NUMBER ------------------------------- =   3
INITIAL INTERVAL (SECONDS) ------------------------ =   9.0
VEHICLE INTERVAL (SECONDS) ------------------------ =   2.7
AMBER CLEARANCE INTERVAL (SECONDS) ---------------- =   4.5
ALL-RED CLEARANCE INTERVAL (SECONDS) -------------- =   0.0
MAXIMUM EXTENSION AFTER DEMAND ON RED (SECONDS) --- =  22.5
SKIP-PHASE SWITCH (ON/OFF) ------------------------ =   ON
AUTO-RECALL SWITCH (ON/OFF) ----------------------- =   OFF
PARENT/MINOR MOVEMENT PHASE OPTION (YES/NO) ------- =   NO
DUAL LEFT OPTION (YES/NO) ------------------------- =   NO
DETECTOR CONNECTION TYPE (AND/OR) ----------------- =   OR
NUMBER OF DETECTORS CONNECTED TO PHASE ------------ =   3
NUMBER OF PHASES CLEARED TO ----------------------- =   1
LIST OF PHASES CLEARED TO ------------------------- =   1
LIST OF DETECTORS CONNECTED TO PHASE -------------- =   1   4   5
1          SIMULATION PROCESSOR FOR THE TEXAS TRAFFIC SIMULATION PACKAGE
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Figure 46. SIMPRO Summary Statistics for Existing Conditions at Ashley Dr. and Kennedy Blvd.

```
A TOTAL OF   4 DETECTORS

 DETECTOR NUMBER ------------ =     1
DETECTOR TYPE -------------- = PULSE
 STARTING POSITION (FEET) --- =  360
STOPPING POSITION (FEET) --- =  366
 APPROACH NUMBER ------------ =    3
NUMBER OF LANES ------------ =    3
 LIST OF LANE NUMBERS ------- =    1     2     3

DETECTOR NUMBER ------------ =    3
 DETECTOR TYPE -------------- = PULSE
STARTING POSITION (FEET) --- =  400
 STOPPING POSITION (FEET) --- =  406
APPROACH NUMBER ------------ =    4
 NUMBER OF LANES ------------ =    2
LIST OF LANE NUMBERS ------- =    1     2

 DETECTOR NUMBER ------------ =    4
DETECTOR TYPE -------------- = PRESENCE
 STARTING POSITION (FEET) --- =  600
STOPPING POSITION (FEET) --- =  626
 APPROACH NUMBER ------------ =    1
NUMBER OF LANES ------------ =    1
 LIST OF LANE NUMBERS ------- =    3

DETECTOR NUMBER ------------ =    5
 DETECTOR TYPE -------------- = PULSE
STARTING POSITION (FEET) --- =  605
 STOPPING POSITION (FEET) --- =  611
APPROACH NUMBER ------------ =    1
 NUMBER OF LANES ------------ =    2
LIST OF LANE NUMBERS ------- =    1     2

***** VEH =  72 IBAP =  1 TURN = 2   60.8373  58.0000  54.0000  60.0000   0.2098  97.7707   7.7268  20.4545   3.1765   1.8000 ****
 ***** VEH =  76 IBAP =  3 TURN = 2   58.7218  56.0000  56.0000  58.0000   0.2045  94.8773   7.7612  20.3665   5.0000   4.8750 ****
***** VEH =  95 IBAP =  1 TURN = 2   40.7537  40.0000  35.0000  38.0000   0.2096  73.3419  10.3004  23.1818   3.1765   4.9500 ****
 ***** VEH =  90 IBAP =  3 TURN = 2   49.4941  42.0000  42.0000  47.0000   0.2053  83.7300   8.8271  21.5882   4.3529   2.1750 ****
***** VEH =  69 IBAP =  3 TURN = 2   70.6232  66.0000  66.0000  69.0000   0.2047 103.5176   7.1200  22.4064   3.8235   4.7625 ****
 ***** VEH =  85 IBAP =  3 TURN = 2   59.1894  53.0000  50.0000  55.0000   0.2045  90.1260   8.1704  23.8023   3.4118   2.2125 ****
***** VEH = 101 IBAP =  3 TURN = 2   36.1213  29.0000  25.0000  34.0000   0.2053  70.2412  10.5226  21.6623   4.7059   5.8875 ****
 ***** VEH = 111 IBAP =  3 TURN = 2   27.6528  26.0000  21.0000  25.0000   0.2045  60.4812  12.1751  22.4306   2.3824   4.7250 ****
***** VEH = 118 IBAP =  1 TURN = 2   24.2368  19.0000  11.0000  16.0000   0.2098  53.3947  14.1485  25.9091   3.3529   2.4750 ****
 ***** VEH = 112 IBAP =  1 TURN = 3   24.3055   0.0      0.0     33.0000   0.2089  59.7875  12.5786  21.1951   4.5882   2.1375 ****
 ***** VEH = 123 IBAP =               18.1333  16.0000   6.0000  13.0000   0.2098  51.7091  14.[illegible]  [illegible].5000   3.0588   3.1125 ****
***** VE[illegible]                      [illegible]711  15.0000   9.0000  15.0000   0.2045                                  [illegible]88   1.8750 ****
                                               11.0000   2.0000                                                                 4.8000 ***

SUMMARY STATISTICS FOR INBOUND APPROACH  1 FOR TURN CODE = RIGHT

TOTAL DELAY (VEHICLE-SECONDS) --------------------- =   8651.0
 NUMBER OF VEHICLES INCURRING TOTAL DELAY ---------- =     79
PERCENT OF VEHICLES INCURRING TOTAL DELAY --------- =    100.0
 AVERAGE TOTAL DELAY (SECONDS) --------------------- =    109.5
AVERAGE TOTAL DELAY/AVERAGE TRAVEL TIME ----------- =     75.9 PERCENT

QUEUE DELAY (VEHICLE-SECONDS) --------------------- =   8200.0
 NUMBER OF VEHICLES INCURRING QUEUE DELAY ---------- =     76
PERCENT OF VEHICLES INCURRING QUEUE DELAY --------- =     96.2
 AVERAGE QUEUE DELAY (SECONDS) --------------------- =    107.9
AVERAGE QUEUE DELAY/AVERAGE TRAVEL TIME ----------- =     74.7 PERCENT

STOPPED DELAY (VEHICLE-SECONDS) ------------------- =   3899.0
 NUMBER OF VEHICLES INCURRING STOPPED DELAY -------- =     76
PERCENT OF VEHICLES INCURRING STOPPED DELAY ------- =     96.2
 AVERAGE STOPPED DELAY (SECONDS) ------------------- =     51.3
AVERAGE STOPPED DELAY/AVERAGE TRAVEL TIME --------- =     35.5 PERCENT

DELAY BELOW 10.0 MPH (VEHICLE-SECONDS) ------------ =   9921.0
 NUMBER OF VEHICLES INCURRING DELAY BELOW 10.0 MPH - =     79
PERCENT OF VEHICLES INCURRING DELAY BELOW 10.0 MPH  =    100.0
 AVERAGE DELAY BELOW 10.0 MPH (SECONDS) ------------ =    125.6
AVERAGE DELAY BELOW 10.0 MPH/AVERAGE TRAVEL TIME -- =     87.0 PERCENT

 VEHICLE-MILES OF TRAVEL --------------------------- =     16.504
AVERAGE VEHICLE-MILES OF TRAVEL ------------------- =      0.209
 TRAVEL TIME (VEHICLE-SECONDS) --------------------- =  11403.2
AVERAGE TRAVEL TIME (SECONDS) --------------------- =    144.3
 NUMBER OF VEHICLES PROCESSED ---------------------- =     79
VOLUME PROCESSED (VEHICLES/HOUR) ------------------ =    395.0
 TIME MEAN SPEED (MPH) = MEAN OF ALL VEHICLE SPEEDS  =      5.5
SPACE MEAN SPEED (MPH) = TOT DIST / TOT TRAVEL TIME =      5.2
 AVERAGE DESIRED SPEED (MPH) ----------------------- =     21.9
AVERAGE MAXIMUM ACCELERATION (FT/SEC/SEC) --------- =      3.8
 AVERAGE MAXIMUM DECELERATION (FT/SEC/SEC) --------- =      3.2

 OVERALL AVERAGE TOTAL DELAY (SECONDS) ------------- =    109.5
OVERALL AVERAGE QUEUE DELAY (SECONDS) ------------- =    103.8
 OVERALL AVERAGE STOPPED DELAY (SECONDS) ----------- =     49.4
OVERALL AVERAGE DELAY BELOW 10.0 MPH (SECONDS) ---- =    125.6

PERCENT OF APPROACH VEHICLES MAKING MOVEMENT ------ =     37.4

1          SIMULATION PROCESSOR FOR THE TEXAS TRAFFIC SIMULATION PACKAGE
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Figure 46. SIMPRO Summary Statistics for Existing Conditions at Ashley Dr. and Kennedy Blvd. (Continued)

```
SUMMARY STATISTICS FOR ALL APPROACHES

TOTAL DELAY (VEHICLE-SECONDS) --------------------- =  37089.3
 NUMBER OF VEHICLES INCURRING TOTAL DELAY ---------- =    640
PERCENT OF VEHICLES INCURRING TOTAL DELAY --------- =     99.8
 AVERAGE TOTAL DELAY (SECONDS) -------------------- =     58.0
AVERAGE TOTAL DELAY/AVERAGE TRAVEL TIME ----------- =     63.0 PERCENT

QUEUE DELAY (VEHICLE-SECONDS) --------------------- =  31707.0
 NUMBER OF VEHICLES INCURRING QUEUE DELAY ---------- =    528
PERCENT OF VEHICLES INCURRING QUEUE DELAY --------- =     82.4
 AVERAGE QUEUE DELAY (SECONDS) -------------------- =     60.1
AVERAGE QUEUE DELAY/AVERAGE TRAVEL TIME ----------- =     65.3 PERCENT

STOPPED DELAY (VEHICLE-SECONDS) ------------------- =  23040.0
 NUMBER OF VEHICLES INCURRING STOPPED DELAY -------- =    528
PERCENT OF VEHICLES INCURRING STOPPED DELAY ------- =     82.4
 AVERAGE STOPPED DELAY (SECONDS) ------------------ =     43.6
AVERAGE STOPPED DELAY/AVERAGE TRAVEL TIME --------- =     47.5 PERCENT

DELAY BELOW 10.0 MPH (VEHICLE-SECONDS) ------------ =  37297.0
 NUMBER OF VEHICLES INCURRING DELAY BELOW 10.0 MPH - =    579
PERCENT OF VEHICLES INCURRING DELAY BELOW 10.0 MPH  =     90.3
 AVERAGE DELAY BELOW 10.0 MPH (SECONDS) ----------- =     64.4
AVERAGE DELAY BELOW 10.0 MPH/AVERAGE TRAVEL TIME -- =     70.1 PERCENT

VEHICLE-MILES OF TRAVEL --------------------------- =    136.554
 AVERAGE VEHICLE-MILES OF TRAVEL ------------------ =      0.213
TRAVEL TIME (VEHICLE-SECONDS) --------------------- =  58934.5
 AVERAGE TRAVEL TIME (SECONDS) -------------------- =     91.9
NUMBER OF VEHICLES PROCESSED ---------------------- =    641
 VOLUME PROCESSED (VEHICLES/HOUR) ----------------- =   3205.0
TIME MEAN SPEED (MPH) = MEAN OF ALL VEHICLE SPEEDS  =     10.3
 SPACE MEAN SPEED (MPH) = TOT DIST / TOT TRAVEL TIME =     8.3
AVERAGE DESIRED SPEED (MPH) ----------------------- =     22.8
 AVERAGE MAXIMUM ACCELERATION (FT/SEC/SEC) -------- =      3.5
AVERAGE MAXIMUM DECELERATION (FT/SEC/SEC) --------- =      3.2

OVERALL AVERAGE TOTAL DELAY (SECONDS) ------------- =     57.9
OVERALL AVERAGE QUEUE DELAY (SECONDS) ------------- =     49.5
 OVERALL AVERAGE STOPPED DELAY (SECONDS) ---------- =     35.9
OVERALL AVERAGE DELAY BELOW 10.0 MPH (SECONDS) ---- =     58.2

NUMBER OF COLLISIONS ------------------------------ =      2
 NUMBER OF VEHICLES ELIMINATED (LANE FULL) -------- =      8
AVERAGE OF LOCTN SPEED/DESIRED SPEED (PERCENT) ---- =     94.4


SUMMARY STATISTICS FOR SEMI-ACTUATED SIGNAL

MAIN STREET PHASE NUMBER -------------------------- =   1
 MAIN STREET MINIMUM ASSURED GREEN (SECONDS) ------ =  34.7
MAIN STREET AMBER CLEARANCE INTERVAL (SECONDS) ---- =   4.5
 MAIN STREET ALL-RED CLEARANCE INTERVAL (SECONDS) -- =  0.0
MAIN STREET NUMBER OF PHASES CLEARED TO ----------- =   2
 MAIN STREET LIST OF PHASES CLEARED TO ------------ =   2    3
NUMBER OF MAIN STREET GREEN PHASES----------------- =   8
 AVERAGE LENGTH OF MAIN STREET GREEN (SECONDS) ---- =  36.0


SIGNAL PHASE NUMBER ------------------------------- =   2
 INITIAL INTERVAL (SECONDS) ----------------------- =   9.0
VEHICLE INTERVAL (SECONDS) ------------------------ =   2.7
 AMBER CLEARANCE INTERVAL (SECONDS) --------------- =   4.5
ALL-RED CLEARANCE INTERVAL (SECONDS) -------------- =   0.0
 MAXIMUM EXTENSION AFTER DEMAND ON RED (SECONDS) --- = 19.8
SKIP-PHASE SWITCH (ON/OFF) ------------------------ =   ON
 AUTO-RECALL SWITCH (ON/OFF) ---------------------- =   OFF
PARENT/MINOR MOVEMENT PHASE OPTION (YES/NO) ------- =   NO
 DUAL LEFT OPTION (YES/NO) ------------------------ =   NO
DETECTOR CONNECTION TYPE (AND/OR) ----------------- =   OR
 NUMBER OF DETECTORS CONNECTED TO PHASE ----------- =   1
NUMBER OF PHASES CLEARED TO ----------------------- =   2
 LIST OF PHASES CLEARED TO ------------------------ =   3    1
LIST OF DETECTORS CONNECTED TO PHASE -------------- =   3
 NUMBER OF MAX-OUTS ------------------------------- =   7
AVERAGE TIME INTO PHASE FOR MAX-OUT (SECONDS) ----- =  21.0
NUMBER OF GAP-OUTS -------------------------------- =   0
 AVERAGE TIME INTO PHASE FOR GAP-OUT (SECONDS) ---- =   0.0
1

 SIGNAL PHASE NUMBER ------------------------------ =   3
INITIAL INTERVAL (SECONDS) ------------------------ =   9.0
 VEHICLE INTERVAL (SECONDS) ----------------------- =   2.7
AMBER CLEARANCE INTERVAL (SECONDS) ---------------- =   4.5
 ALL-RED CLEARANCE INTERVAL (SECONDS) ------------- =   0.0
MAXIMUM EXTENSION AFTER DEMAND ON RED (SECONDS) --- =  22.5
 SKIP-PHASE SWITCH (ON/OFF) ----------------------- =   ON
AUTO-RECALL SWITCH (ON/OFF) ----------------------- =   OFF
 PARENT/MINOR MOVEMENT PHASE OPTION (YES/NO) ------ =   NO
DUAL LEFT OPTION (YES/NO) ------------------------- =   NO
 DETECTOR CONNECTION TYPE (AND/OR) ---------------- =   OR
NUMBER OF DETECTORS CONNECTED TO PHASE ------------ =   3
 NUMBER OF PHASES CLEARED TO ---------------------- =   1
 LIST OF PHASES CLEARED TO ------------------------ =   1
LIST OF DETECTORS CONNECTED TO PHASE -------------- =   1    4    5
 NUMBER OF MAX-OUTS ------------------------------- =   7
AVERAGE TIME INTO PHASE FOR MAX-OUT (SECONDS) ----- =  24.0
 NUMBER OF GAP-OUTS ------------------------------- =   0
AVERAGE TIME INTO PHASE FOR GAP-OUT (SECONDS) ----- =   0.0


START-UP TIME   =  180.000 SECONDS      NUMBER OF VEHICLES PROCESSED =   95

SIMULATION TIME =  720.000 SECONDS      NUMBER OF VEHICLES PROCESSED =  641

NUMBER OF VEHICLES IN THE SYSTEM AT SUMMARY =    71
AVERAGE NUMBER OF VEHICLES IN THE SYSTEM -- =   83.3  MAX = 106
```

Figure 46. SIMPRO Summary Statistics for Existing Conditions at Ashley Dr. and Kennedy Blvd. (Continued)

Define & Analyze Alternative

In order to evaluate alternative intersection improvements, the user must modify previously coded data to reflect the proposed changes. For the purpose of this problem two alternatives were defined.

One alternative which can be evaluated is a change in signal timing. As previously indicated the present signal is operating as a semi-actuated controller with a ninety second background cycle. The TEXAS Model does not have any provision for controlling a signal under system control. However, it is possible to evaluate the intersection under present signal timing without the background cycle. The minimum green time on main street (westbound phase) was reduced from 34.2 sec to 26.5 sec., and the maximum green time for the other phases was increased to 33 sec. each from the present maximum of 19.8 sec. for eastbound movement and 22.5 seconds for north-south movement.

Only three (3) cards to SIMPRO required modification to reflect these changes.

A second alternative that can be evaluated is an increase in the curb return radius on the northwest corner. The present radius is ten (10) feet. Due to this tight radius most vehicles, particular trucks and buses, have to slow down in order to negotiate the turn. To evaluate the benefit of an improved turn radius a change was made in the coding to reflect a fifty (50) foot radius. Only two cards to GEOPRO required modifications to reflect these changes.

Evaluation of Results

The output reports obtained as a result of the simulation runs provide detailed information of the operating characteristics on the intersection under each of the conditions modeled. Tables 11, 12 and 13 provide a comparison of the results obtained for each condition relative to signal operation and lane and intersection operating characteristics. The following summarizes the results.

Revised Signal Time Alternate - Table 11 compares the statistics on the operation of the semi-actuated signal controller. As a result of lowering the minimum assured green time on main street from 34.2 seconds to 26.5 seconds, the average length of main street green was reduced from 36 seconds to 28 seconds. This reduction of main street green time and the resulting reduction in overall delay at the intersection indicates that the present minimum green setting on the main street phase is too high. Increasing phase 2 (eastbound dual left turn) maximum extension from 19.8 seconds to 31.5 seconds reduced the number of cycles that the phase maxed-out (3 of 7 cycles or 40%). On the other hand when phase 3 maximum green time was increased from 22.5 seconds to 31.5 seconds the cycle still maxed out each cycle.

The effect these signal timing changes had on intersection operation can be seen on Table 12. For the intersection as a whole, the total delay per vehicle was reduced by 7.2% (from 57.9 seconds to 47.3 seconds), while overall stopped delay decreased from 35.9 seconds to 29.1 seconds. This reduced stopped delay would be noticeable to the motoring public. Tentative data (reference 4.10) comparing perceived levels of service with mean stopped delay indicate an increase in the level of service of this intersection from "E" to "D".

Further benefits of the revised signal timing can be seen as an effect on traffic flow in the southbound right turn lane. This movement partially occurs during phase 2 which received an increase in green time. A significant improvement occurs for traffic in this lane as a result of the increased time for this movement (phase 2 & 3). Average queue length has decreased from 12.9 vehicles to 8.0 vehicles with an accompanying reduction in average stopped delay from 49.4 seconds to 21.8 seconds.

For this location an increase in cycle length may be advantageous. Further changes in minimum and maximum greens could be input into the model to determine optimum signal timing. However, since the signal is part of a system, additional studies are required to determine the impact of increased cycle length on other intersections within the system.

Table 11 - Comparison of Alternative Statistics for Semi-Actuated Signal

Statistics	ALTERNATIVES Existing Conditions	Revised Signal Timing	Increased Turn Radius
Main Street Phase Number	1	1	1
Main Street Minimum Assured Green (Sec)	34.2	26.5	34.2
Main Street Amber Clearance Interval (Sec)	4.5	4.5	4.5
Main Street All-Red Clearance Interval (Sec)	0.0	0.0	0.0
Main Street Number of Phases Cleared to	2	2	2
Main Street List of Phases Cleared to	2 3	2 3	2 3
Number of Main Street Green Phases	8	7	8
Average Length of Main Street Green (Sec)	36.0	28.0	36.0
Signal Phase Number	2	2	2
Initial Interval (Sec)	9.0	9.0	9.0
Vehicle Interval (Sec)	2.7	2.7	2.7
Amber Clearance Interval (Sec)	4.5	4.5	4.5
All-Red Clearance Interval (Sec)	0.0	0.0	0.0
Maximum Extension After Demand on Red (Sec)	19.8	31.5	19.8
Skip-Phase Switch (On/Off)	ON	ON	ON
Auto-Recall Switch (On/Off)	OFF	OFF	OFF
Parent/Minor Movement Phase Option (Yes/No)	NO	NO	NO
Dial Left Option (Yes/No)	NO	NO	NO
Detector Connection Type (And/Or)	OR	OR	OR
Number of Detectors Connected to Phase	1	1	1
Number of Phases Cleared to	2	2	2
List of Phases Cleared to	3 1	3 1	3 1
List of Detectors Connected to Phase	3	3	3
Number of Max-outs	7	3	7
Average Time Into Phase for Max-out (Sec)	21.0	33.0	21.0
Number of Gap-Outs	0	4	0
Average Time Into Phase For Gap-Out (Sec)	0.0	26.3	0.0
Signal Phase Number	3	3	3
Initial Interval (Sec)	9.0	9.0	9.0
Vehicle Interval (Sec)	2.7	2.7	2.7
Amber Clearance Interval (Sec)	4.5	4.5	4.5
All-Red Clearance Interval (Sec)	0.0	0.0	0.0
Maximum Extension After Demand on Red (Sec)	22.5	31.5	22.5
Skip-Phase Switch (On/Off)	ON	ON	ON
Auto-Recall Switch (On/Off)	OFF	OFF	OFF
Parent/Minor Movement Phase Option (Yes/No)	NO	NO	NO
Dual Left Option (Yes/No)	NO	NO	NO
Detector Connection Type (And/Or)	OR	OR	OR
Number of Detectors Connected to Phase	3	3	3
Number of Phases Cleared to	1	1	1
List of Phases Cleared to	1	1	1
List of Detectors Connected to Phases	1 4 5	1 4 5	1 4 5
Number of Max-Outs	7	7	7
Average Time Into Phase For Max-Out (Sec)	24.0	33.0	24.0
Number of Gap-Outs	0	0	0
Average Time Into Phase For Gap-Out (Sec)	0.0	0.0	0.0

Table 12 - Comparison of Alternative Statistics for Entire Intersection (All Approaches)

Measures of Effectiveness	ALTERNATIVES Existing Conditions	Revised Signal Timing	Increased Turn Radius
Total Delay (Vehicle-Seconds)	37089.3	30450.6	31309.6
Number of Vehicles Incurring Total Delay	640	644	645
Percent of Vehicles Incurring Total Delay	99.8	100.0	99.8
Average Total Delay (Seconds)	58.0	47.3	48.5
Average Total Delay/Average Travel Time	63.0 percent	58.1 percent	58.7 percent
Queue Delay (Vehicle-Seconds)	31707.0	25397.0	26374.0
Number of Vehicles Incurring Queue Delay	528	519	518
Percent of Vehicles Incurring Queue Delay	82.4	80.6	80.2
Average Queue Delay (Seconds)	60.1	48.9	50.9
Average Queue Delay/Average Travel Time	65.3 percent	60.2 percent	61.5 percent
Stopped Delay (Vehicle-Seconds)	23040.0	18716.0	202215.0
Number of Vehicles Incurring Stopped Delay	528	519	516
Percent of Vehicles Incurring Stopped Delay	82.4	80.6	80.2
Average Stopped Delay (Seconds)	43.6	36.1	35.0
Average Stopped Delay/Average Travel Time	47.5 percent	44.3 percent	47.2 percent
Delay Below 10.0 MPH (Vehicle-Seconds)	37297.0	30149.0	30270.0
Number of Vehicles Incurring Delay Below 10.0 MPH	579	577	583
Percent of Vehicles Incurring Delay Below 10.0 MPH	90.3	89.6	90.2
Average Delay Below 10.0 MPH (Seconds)	64.4	52.3	51.9
Average Delay Below 10.0 MPH/Average Travel Time	70.1 percent	64.3 percent	62.8 percent
Vehicle-Miles of Travel	136.554	137.234	137.920
Average Vehicle-Miles of Travel	0.213	0.213	0.213
Travel Time (Vehicle-Seconds)	58934.5	52373.2	53446.6
Average Travel Time (Seconds)	91.9	81.3	82.7
Number of Vehicles Processed	641	644	646
Volume Processed (Vehicles/Hour)	3205.0	3220.0	3230.0
Time Mean Speed (MPH) = Mean of All Vehicle Speeds	10.3	10.9	10.9
Space Mean Speed (MPH) = TOT Dist/TOT Travel Time	8.3	9.4	9.3
Average Desired Speed (MPH)	22.8	22.8	22.7
Average Maximum Acceleration (Ft/Sec/Sec)	3.5	3.4	3.4
Average Maximum Deceleration (Ft/Sec/Sec)	3.2	3.2	3.2
Overall Average Total Delay (Seconds)	57.9	47.3	48.5
Overall Average Queue Delay (Seconds)	49.5	39.4	40.8
Overall Average Stopped Delay (Seconds)	35.9	29.1	31.3
Overall Average Delay Below 10.0 MPH (Sec)	58.2	46.8	46.9
Number of Collisions	2	5	1
Number of Vehicles Eliminated (Lane Full)	8	5	3
Average of Login Speed/Desired Speed (Percent)	94.4	96.1	96.7

Table 13 - Comparison of Alternative Statistics for Southbound Right Turn Lane

Measures of Effectiveness (MOE)	ALTERNATIVES Existing Conditions	Revised Signal Timing	Increased Turn Radius
Total Delay (Vehicle-Seconds)	8651.0	6585.9	5639.2
Number of Vehicles Incurring Total Delay	79	95	98
Percent of Vehicles Incurring Total Delay	100.0	100.0	100.0
Average Total Delay (Seconds)	109.5	69.3	57.5
Average Total Delay/Average Travel Time	75.9 percent	66.7 percent	62.3 percent
Queue Delay (Vehicle-Seconds)	8200.0	5498.0	4520.0
Number of Vehicles Incurring Queue Delay	76	86	85
Percent of Vehicles Incurring Queue Delay	96.2	90.5	86.7
Average Queue Delay (Seconds)	107.9	63.9	53.2
Average Queue Delay/Average Travel Time	74.7 percent	61.5 percent	57.5 percent
Stopped Delay (Vehicle-Seconds)	3899.0	2071.0	2038.0
Number of Vehicles Incurring Stopped Delay	76	86	85
Percent of Vehicles Incurring Stopped Delay	96.2	90.5	86.7
Average Stopped Delay (Seconds)	51.3	24.1	24.0
Average Stopped Delay/Average Travel Time	35.5 percent	23.2 percent	25.9 percent
Delay Below 10.0 MPH (Vehicle-Seconds)	9921.0	7840.0	5984.0
Number of Vehicles Incurring Delay Below 10.0 MPH	79	95	98
Percent of Vehicles Incurring Delay Below 10.0 MPH	100.0	100.0	100.0
Average Delay Below 10.0 MPH (Seconds)	125.6	82.5	61.1
Average Delay Below 10.0 MPH/Average Travel Time	87.0 percent	79.4 percent	66.1 percent
Vehicle-Miles of Travel	16.504	19.847	20.361
Average Vehicle-Miles of Travel	0.209	0.209	0.208
Travel Time (Vehicle-Seconds)	11403.2	9872.4	9058.1
Average Travel Time (Seconds)	144.3	103.9	92.4
Number of Vehicles Processed	79	95	98
Volume Processed (Vehicles/Hour)	395.0	475.0	490.0
Time Mean Speed (MPH) = Mean of All Vehicle Speeds	5.5	7.6	8.7
Space Mean Speed (MPH) = TOT Dist/TOT Travel Time	5.2	7.2	6.1
Average Desired Speed (MPH)	21.9	21.9	21.6
Average Maximum Acceleration (Ft/Sec/Sec)	3.8	3.7	3.5
Average Maximum Deceleration (Ft/Sec/Sec)	3.2	3.0	3.0
Overall Average Total Delay (Seconds)	109.5	69.3	67.5
Overall Average Queue Delay (Seconds)	103.8	57.9	46.1
Overall Average Stopped Delay (Seconds)	49.4	21.8	20.8
Overall Average Delay Below 10.0 MPH (Sec)	125.6	82.5	61.1
Percent of Approach Vehicles Making Movement	37.4	43.2	44.3
Average Queue Length	12.9	8.0	6.5
Maximum Queue Length	20	16	16

Increased Turn Radius

The increase in the radius for the southbound right turn lane from ten (10) feet to fifty (50) feet resulted in significant improvements for traffic. Table 13 provides the most meaningful statistics. As would be expected, an advantageous change occurred in all measures of effectiveness.

The most noticeable change is the increase in the number of vehicles per hour the approach accommodates (from 395 vehicle per hour to 490 vehicles per hour), an increase of approximately 24%. As a result of the increased volume, and higher travel speed in the turn the average stopped delay has decreased from 49.4 seconds to 20.0 seconds (a 58% decrease). This is further demonstrated by the reduction in average queue length from 12.9 vehicle to 6.8 schedules.

Summary of Work Effort Required

The following statements provide a brief summary of the work effort required to solve the above example problem.

Data Collection - Since data on traffic volume, signal timing and geometric designs were available from city files, little time was required. However, no field study was conducted to validate the model. It would be desirable to conduct an intersection delay study to obtain information on the number of vehicles stopped and stopped delay per vehicle for each lane and movement. Also data on headway distribution would be advisable. This would require two people for 45-60 minutes per approach, or approximately eight (8) manhours of data collection. An additional four-six manhours would be required for data summary and evaluation.

Data Coding - Approximately eight hours were required to code the existing condition. Another six to eight trial runs were required to review output and determine corrections required. This time would have been considerably shorter had someone been available who was familiar with model output to assist in identifying coding errors. Once the existing conditions data was coded and the model execution completed, only a few trials were required to make changes. In actual practice, one should plan on three or four mandays of effort to properly code and calibrate the model to existing conditions.

Computer Time - Execution time for the 12 minute simulation period on the IBM 360/320 for the various runs required slightly over 110 seconds per run. Core storage of 258K was required. The same problem was run on the developers CYBER 170/75 and required an average of 59 seconds.

REFERENCES

5.1 Lee, C. E., T. W. Rioux and C.R. Copeland, "The Texas Model for Intersection Traffic - Development, "Report No. FHW-ATX78-184-1, University of Texas Center for Highway Research, December, 1977.

5.2 Lee, C. E., T. W. Rioux, V. S. Savur and C. R. Copeland, "The Texas Model for Intersection Traffic - Programmer's Guide, "Report No. FHWATX78184-2, University of Texas Center for Highway Research, December, 1977.

5.3 Lee, C. E., G. E. Grayson, C. R. Copeland, J. W. Miller, T. W. Rioux and V. S. Savur, "The Texas Model for Intersection Traffic - User's Guide," Report No. FHWATX78-184-3, University of Texas Center for Highway Research, July, 1977.

5.4 Lee, C. E., V. S. Savur and G. E. Grayson, "The Texas Model for Intersection Traffic - Analysis of Signal Warrants and Intersection Capacity, "Report No. FHWATX78-184-4, University of Texas Center for Highway Research, July, 1978.

5.5 Rioux, T. W. and C. E. Lee, "TEXAS - A Microscopic Traffic Simulation Package for Isolated Intersections, " presented at the 56th annual meeting of the Transportation Research Board, Washington, D.C., 1977.

CHAPTER 6 - PASSER II(80) (ARTERIAL OPTIMIZATION MODEL)

The use of systems for coordinating traffic signals along arterial highways to provide continuous movement of traffic has been a commonly used traffic control strategy for many years. The design of such systems has become increasingly more sophisticated, as here the hardware systems themselves.

In recent years, computer programs have been used to determine the "optimal" signal system design. Programs such as SIGART, SIGPROG, and SIGOP have all been used, often extensively. However, these earlier models suffer several serious limitations in today's technological environment. Modern traffic controllers are extremely sophisticated and can handle multi-phase, multi-split requirements. The earlier programs are generally unaole to deal with this level of sophistication.

Today's operating environment is frequently a linear arterial highway with multiphase control at any intersection with either a fixed or semi-actuated control system. The computer model described in this chapter was developed in response to the needs of practicing traffic engineers to design optimal signal timing in this environment. The original model, called PASSER I, was developed at Texas A&M University's Texas Transportation Institute for use in the Dallas Corridor Project sponsored by the Federal Highway Administration (FHWA) and the Texas State Department of Highways and Public Transportation (SDHPT) in cooperation with the City of Dallas. It was later adapted and expanded as PASSER II for off-line processing and analysis purposes in HPR Project 165, sponsored jointly by the Texas SDHPT and FHWA.

The Texas SDHDT maintains the model and it is used extensively by its staff as well as numerous local traffic engineers. The current version is called PASSER II(80) hereafter referred to as PASSER 80. The computer program is written in FORTRAN IV. The model has been set up on numerous computers with relatively little difficulty. It is estimated that machines with core storage of 92K bytes can handle most problems.

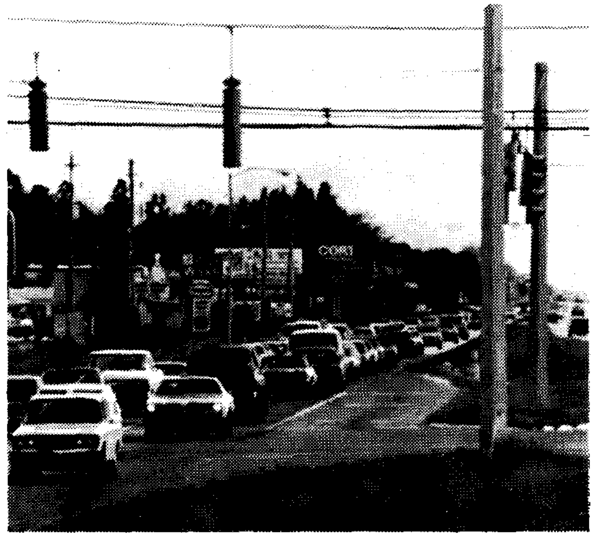


Figure 47. Typical Signalized Arterial System in Urbanized Area.

MODEL DESCRIPTION

PASSER 80 is an acronym for Progression Analysis and Signal System Evaluation Routine, version 1980. The basic purpose of the model is to assist the traffic engineer in determining optimal traffic signal timings for progression along an arterial considering various multiphase sequences.

The model was designed to calculate all of the signal timing information needed for plan development and field implementation. The program calculates degree of saturation, delay and probability of queue clearance for all movements.

The optimization algorithm of PASSER 80 identifies (from those permitted) the best cycle length, phasing sequence and offsets--best being defined as that combination which results in the greatest bandwidths in both directions of travel. Phase splits are calculated to minimize delay at each intersection.

INPUT REQUIREMENTS

The authors of the model designed the program to use data normally collected and used by practicing traffic engineers in developing signal timing plans. The current program can handle up to twenty (20) signalized intersections along a single arterial highway.

Three types of input cards are used for PASSER 80 - 1) arterial header data, 2) intersection header data, and 3) intersection detail data. These data are recorded on standard computer input cards and submitted for computer processing as shown in Figure 48.

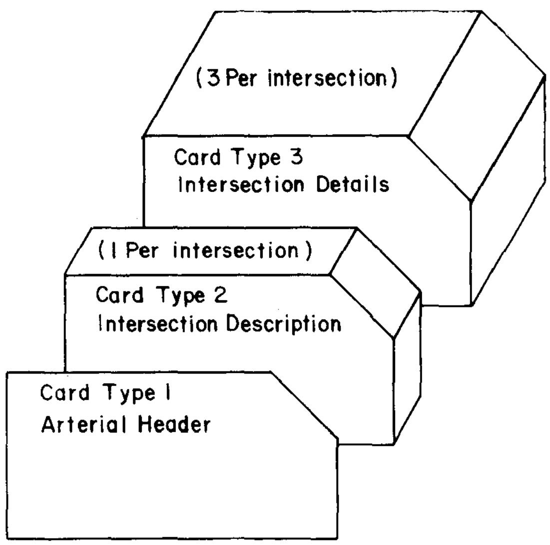


Figure 48. Passer II Data Deck

Arterial Header - This single card is used to describe the arterial signal system under study and defines the general analysis parameters and options.

Intersection Header - One card is required for each signalized intersection to describe the location, connecting link description and signal phasing information.

Intersection Details - Three cards are required for each signalized intersection. Card one is for traffic volumes for each of the movements, card two is for the saturation flow rates for the respective traffic movements and the third card is to establish the minimum phase length for each movement.

A summary description of the input data for each of the card types is included in Table 14. A more detailed description and hints on coding input data are included in the reference material. Standard coding forms are also available (Ref. 6.8).

OPERATIONAL SUMMARY

PASSER 80 is a macroscopic, deterministic optimization model. The user inputs minimum and maximum cycle lengths and the number of seconds the program will increment and use between the lower and upper cycle length limits. With these data, the program seeks the optimal design by iteratively varying the splits and offsets for each design cycle length and determining the "bandwidth efficiency". The variation of splits is naturally constrained by the minimum green times input. The variation of offsets is about the desired progression speeds input.

It is suggested that for best engineering, the range of cycle lengths be limited to ten (10) seconds between minimum and maximum. This limitation only means that it is necessary to make multiple runs with varied minimum and maximum cycle lengths and minimum movement green times to study a broader range of possibilities.

The model can analyze up to four (4) arterial phase sequences (with or without overlap) per intersection and will select, from those available for consideration, the phase sequence at each intersection that provides the best overall arterial progression. The permissible phase sequences which can be selected for evaluation are shown in Figure 49.

Table 14 - Input Requirements for PASSER 80

CARD TYPE	DATA DESCRIPTION	REQUIREMENTS
Arterial Header Card (1 per arterial)	Run Number	Arbitrary number to identify run
	Name of City & Arterial	User Choice
	District Number	User Choice
	Date of Run	Month, Day, Year
	No. of Signalized Intersections	Maximum 20
	Isolated or Progressive	Type of operation
	Smallest Cycle Length	Greater than sum of minimum green
	Largest Cycle Length	Normally 10 sec. over minimum cycle
	Cycle Length Increments	No. of seconds to increment between the lower and upper bounds on the cycle length in even seconds
	Bandwidth Specification Option (Optional)	Percent of total bandwidth to be provided in "B" direction
	Variable Speed Option(Optional)	Analysis to include variation of link speeds(±2 mph)
	Printer Plot (Optional)	Time-space diagram (TSD) printed
	Line Plot (Optional)	Use Line Plotter for TSD
	Standard or NEMA	Whether movement numbers are to be standard or NEMA number.
Intersection Header Card (1 per intersection)	Name of Cross-street	Required
	Intersection Number	Sequential in "A" direction.
	Distance "A" Direction	Distance in feet from previous signal to this one in "A" direction
	"A" Direction - Average Speed	Desired average progression speed in "A" direction
	Distance "B" Direction	Distance in feet from this signal to the next in the "B" direction
	"B" Direction - Average Speed	Desired average progression speed in "B" direction
	Queue Clearance "A" side (Optional)	Amount of time by which the progression band will lag the start of the "A" direction green
	Queue Clearance "B" side (Optional)	Amount of time by which the progression band will lag the start of the "B" direction green
	Phase sequence for arterial (code at least one)	a) Leading left-turns b) Leading thrus c) Leading green d) Lagging green
	Phase sequence for cross-street (only one)	
Intersection Detail Cards (3 per intersection)	Traffic Volumes *	Intersection number and traffic volumes for each movement
	Saturation Capacity Flow*	Intersection number and saturation flow for each movement
	Minimum Green Times*	Intersection number and minimum green time for each movement

*These data are placed on separate cards for each intersection.

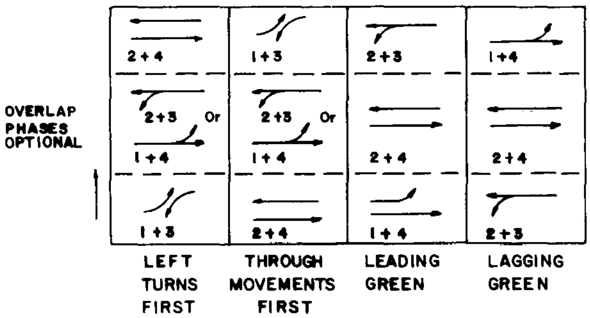


Figure 49. Permissible Phase Sequences

The user must select one or more of the four basic phase sequences for the arterial permitting the program to select the optimal solution for arterial progression and only one sequence for the cross-street approach. The user has the option to either delete a phase, to specify only one of the specific sequences and/or to permit overlap between phases.

COMPUTATIONAL ALGORITHMS

The developers of the model have combined Brooks Interference Algorithm with Little's Optimized Unequal Bandwidth Equation, and extended them to multi-phase signal operations.

The program first determines the optimal demand/capacity relationships and from these green splits are determined. Trial cycle lengths, phase, patterns and offsets are varied to determine the "best" set of timings, i.e. that which maximizes the bandwidths.

The salient computational expressions include the following:

(1) <u>Determine Maximum Bandwidth</u> (B_{max}) <u>by Direction.</u>

$$B_{max} = G_{O_{min}} + G_{I_{min}} - I_{I_{min}} \qquad (6.1)$$

where: $G_{O_{min}}$ = minimum outbound progressive green.

$G_{I_{min}}$ = minimum inbound progressive green.

$I_{I_{min}}$ = minimum possible inbound band interference optimized subject to upper and lower limits.

(2) <u>Determine Maximum Band Efficiency</u> (E_c)

$$E_c = \frac{B_a + B_b}{2C} \qquad (6.2)$$

where B_a = bandwidth in "A" direction

B_b = bandwidth in "B" direction

C = cycle length

(3) <u>Determine Green Time</u> (g)

Green times (including clearances) are determined by a gradient search technique which minimizes delay at the intersection (subject to specified minimum greens). The algorithm shifts the phase change times in small increments until the least calculated delay is obtained. The calculation of delay is discussed later.

The last relationship (the objective function) is the basis of the most significant algorithm used. Some earlier models required that the bandwidths be equal. This is not the case for PASSER 80, in fact neither direction is automatically favored.

If it is desired to favor one direction, this can be done by use of the minimum percent of progressive bandwidth (Option 1) on the Arterial Header Card or by appropriate adjustments to the desired progressive speeds on the Intersection Header Card or by adjustments to minimum green times on the Intersection Detail Card. This is subject to the availability of sufficient green time to be absorbed by the "B" direction.

(4) Degree of Saturation (X)

$$X = \frac{VC}{gS} \qquad (6.3)$$

where: V = traffic volume
C = cycle length
g = effective green time
S = saturation flow rate

(5) Estimate of Delay (D)

The delay estimate is based on a modification to Webster's method. The modification takes into account the differences in arrival rates between green and red.

$$D = \frac{VR\ C(1-g/c)^2}{2V[1+(VR/(S-VG))]} + \frac{X^2}{2(V/3600)(1-X)}$$

$$-0.65(C/(V/3600))^{1/3} \quad X^{(2+5gk)} \qquad (6.4)$$

where: VR = traffic arrivals on red
VG = traffic arrivals on green

and all other terms have been defined previously.

(6) Probability of Queue Clearance (P)

The probability of the queues clearing in the available time is calculated by Miller's method:

$$P = 1 - e^{-1.58\emptyset} \qquad (6.5)$$

when: e = the natural base of logarithms
$\emptyset = [(1-X)/X] - (Sg/3600)^{1/2}$

There are several limitations on these estimates, as described in Reference 6.8.

OUTPUT REPORTS

Outputs from PASSER 80 consist of printed reports and optional time space plots by either the printer or line plotter.

Printed Reports

The printed reports are of two types. The first is simply a listing of the input data as submitted to the computer. This report, illustrated on Figure 50, shows all input data in a clear, readable format.

At the top of the report information is shown that was provided on the arterial header card. Following this heading is a description of the information coded for each intersection. Notice that each of the permissible phase patterns that can be evaluated at this intersection is shown, as well as an indication if overlap is permitted. Also shown are the volumes, saturation flows and minimum green time for each movement. The movement numbers correspond to a standard coding format (or NEMA standard movement numbers if requested).

The second report (Figure 51) includes guidelines for minimum and maximum cycle length for each intersection of operating at an isolated intersection. These are based on an assumed level of service of "D" on all approaches. If the "optimal" cycle length given in the "Best Solution" (figure 52) is not within this range, excess delay may overcome the benefits of progression.

The third report presents the "Best Solution" for signal timing at the intersections in the system. As shown on Figure 52, the report presents cycle length, bandwidth efficiency, attainability and average progression speeds thru the system. Then, for each intersection, the detailed results are reported. The offset is given, along with the phasing strategy. Then for each phase the included movements and green time (including amber and all-red) are given. Finally the degree of saturation, delay, probability of queue clearance and levels of service based on each of these are given for all movements. Total delay is also given for each intersection and the entire artery.

Plots (Optional)

Figure 53 shows a typical printer plot of the time-space diagram. Both bands are plotted

```
                         MULTIPHASE ARTERIAL PROGRESSION PROGRAM - PASSER II-80
              TAMPA, FLA    ASHLEY DRIVE                  DISTRICT  1      10/23/81     RUN NO.   5
 OPTIONS IN EFFECT ARE # 2

              INPUT DATA

       NUMBER OF              LOWER CYCLE          UPPER CYCLE          CYCLE
       INTERSECTIONS          LENGTH               LENGTH               INCREMENT

          8                      80                   90                   2
*********************************************************************************************************

***** INTERSECTION 1      JACKSON

       DISTANCE  0 TO  1      SPEED                                   DISTANCE  1 TO  0      SPEED
           0. FT              25. MPH                                      0. FT             25. MPH

         MAJOR ST.            MINOR ST.
       A SIDE QUEUE CLEARANCE           B SIDE QUEUE CLEARANCE
                 0 SEC                              4 SEC
       THROUGH MOVEMENTS FIRST      WITH OVERLAP
       LAGGING GREEN                WITH OVERLAP
                                                   MOVEMENTS

                                  1        2        3        4        5        6        7        8

       VOLUMES                    0      484      436      577        0        0        0        0

       SAT. CAPACITY              0     3590     1640     3590        0        0        0        0

       MINIMUM GREEN              0       14       23       14        0        0        0        0
```

Figure 50. Typical Listing of PASSER 80 Input Data

```
                 CODING ERROR MESSAGES

            NO APPARENT CODING ERRORS

                                          MINIMUM ADVISABLE       MAXIMUM ADVISABLE
                                          CYCLE LENGTH            CYCLE LENGTH

            INTERSECTION  1 JACKSON           34.                     50.
            INTERSECTION  2 KENNEDY           47.                     69.
            INTERSECTION  3 MADISON           38.                     56.
            INTERSECTION  4 TWIGGS            42.                     63.
            INTERSECTION  5 ZACK              34.                     50.
            INTERSECTION  6 POLK              47.                     69.
            INTERSECTION  7 CASS              34.                     50.
            INTERSECTION  8 TYLER             81.                    100.

       IF THE CYCLE LENGTH SELECTED IN THE BEST SOLUTION IS NOT WITHIN THE RANGE SHOWN ABOVE
      THE MAXIMUM BAND WIDTH MAY BE PRESENT BUT UNDULY LARGE DELAY MAY BE PRESENT
```

Figure 51. PASSER 80 Optimal Cycle Length Ranges

MULTIPHASE ARTERIAL PROGRESSION PROGRAM - PASSER II-80

TAMPA, FLA ASHLEY DRIVE DISTRICT 1 10/23/81 RUN NO. 5

BEST SOLUTION

CYCLE LENGTH = 90 SEC. BAND A = 28 SEC. BAND B = 17 SEC. 0.26 EFFICIENCY 0.80 ATTAINABILITY
AVERAGE PROGRESSION SPEED - BAND A = 27 MPH. BAND B = 27 MPH.

****

**** INTERSECTION 1 0.0 SECONDS OFFSET ARTERIAL PHASE SEQUENCE IS THROUGH MOVEMENTS FIRST
JACKSON 0.0 % OFFSET CROSS STREET PHASE SEQUENCE IS THROUGH MOVEMENTS FIRST

	ARTERIAL				CROSS STREET			
MOVEMENTS	2+4	2+3	1+3	TOTAL MAJOR ST	6+8	6+7	5+7	TOTAL MINOR ST
GREEN TIME SECS	34.9	55.1	0.0	90.0	0.0	0.0	0.0	0.0
GREEN TIME (%)	38.8	61.2	0.0	****	0.0	0.0	0.0	0.0

---------------------- MEASURE OF EFFECTIVENESS ----------------------

MOVEMENTS	1	2	3	4	5	6	7	8
XRATIO	0.0	0.141	0.468	0.470	0.0	0.0	0.0	0.0
LEVEL OF SERVICE		A	A	A				
DELAY(SEC/VEH)	0.0	1.76	12.85	23.90	0.0	0.0	0.0	0.0
LEVEL OF SERVICE		A	A	B				
PROBABILITY OF CLEARING QUEUE	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
LEVEL OF SERVICE		A	A	A				

TOTAL INTERSECTION DELAY (SEC/VEH) 13.52

Figure 52. Typical PASSER 80 "Best Solution" Report

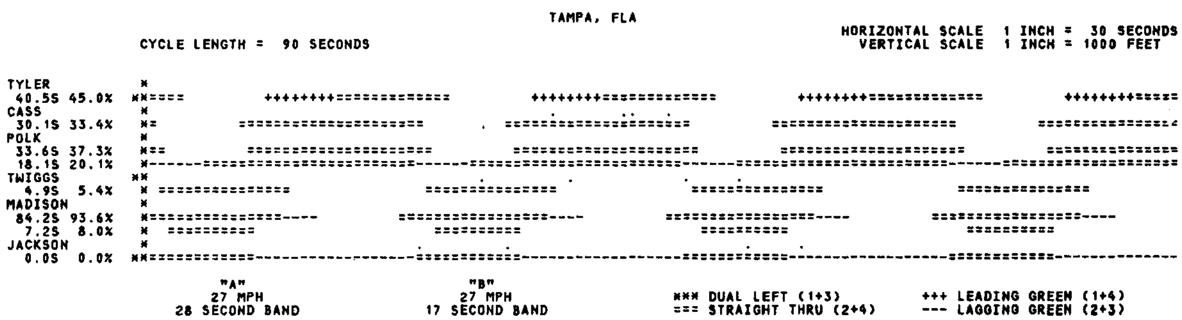


Figure 53. Typical PASSER 80 Time Space Diagram Plot

and their widths and speeds are written at the bottom of the plot. The horizontal (time) scale plots show the phasing for dual left, straight thru, and leading and lagging green. Blank sections are red on the artery. The plot can be used to quickly identify critical intersections or to "fine tune" the offsets by shifting them to provide more lag green time ahead of the band to clear queues.

ADDITIONAL FEATURES

PASSER 80 was written to design progression along an arterial. It can also be used to analyze single intersections. To analyze single intersections the user would input a dummy link with zero speeds and distances. The remainder of the input data should be the same as the input for the intersection to be analyzed.

To analyze existing signal timing the user should input the known cycle length, with no variation allowed and zero traffic volumes on the intersection detail cards. The program will then use the minimum green as the actual green. This feature permits the user to examine other traffic engineering improvements, such as installing median refuge zones to reduce pedestrian clearances or alterations in parking policies.

The model can also be run in the "isolated" mode, which will design phase splits based on minimum delays, but no offset optimization is performed and all arrivals are assumed to be uniform. This feature, however, requires a constant cycle length on all signals.

APPLICATIONS AND LIMITATIONS

PASSER 80 is a tool to assist the engineer in analyzing individual signalized intersection operations or to determine optimum time-space based progression along an arterial. The program determines optimal values of all traffic signal timing parameters: cycle length, splits, phase sequences and offsets. Several program runs may be needed before a final progression solution is calculated.

The major limitation is the narrow range of cycle lengths that can be tried in a given run, but, as stated earlier, this is easily overcome by multiple runs. The reason for this is that infeasible solutions may result for certain cycle lengths. The restricted range of cycle lengths affords the user the opportunity of carefully examining "optimal" solutions at several cycle lengths, thereby eliminating the infeasible solutions.

Finally, while phase sequencing is automatically "optimized", selection of the best sequences depends on so many factors requiring engineering judgment. On the other hand the program can assist the engineer by giving the optimal solution under a variety of sequence strategies input in several runs.

EXAMPLE APPLICATION

To illustrate the capabilities and use of PASSER 80 an existing signalized arterial which is in operation in the downtown area of Tampa, Florida, was selected as an example application. The following describes the arterial and the use of the PASSER 80 model to evaluate the existing signal system.

Problem Description

A link node sketch of the arterial used for the purpose of illustrating the PASSER 80 model capabilities and applications is shown in Figure 54. This arterial, Ashley Drive, is located along the western boundary of the Tampa CBD. Ashley Drive provides one of the major entrances to the CBD from the adjacent urbanized area via Interstate I-75 whose on and off ramps lead directly onto Ashley Drive. Access to the connecting one-way streets serving the downtown area to the east is provided as well as major parking facilities to the west.

Ashley Drive is a multi-lane divided roadway varying from two lanes in each direction at the south end to six and eight lanes at the

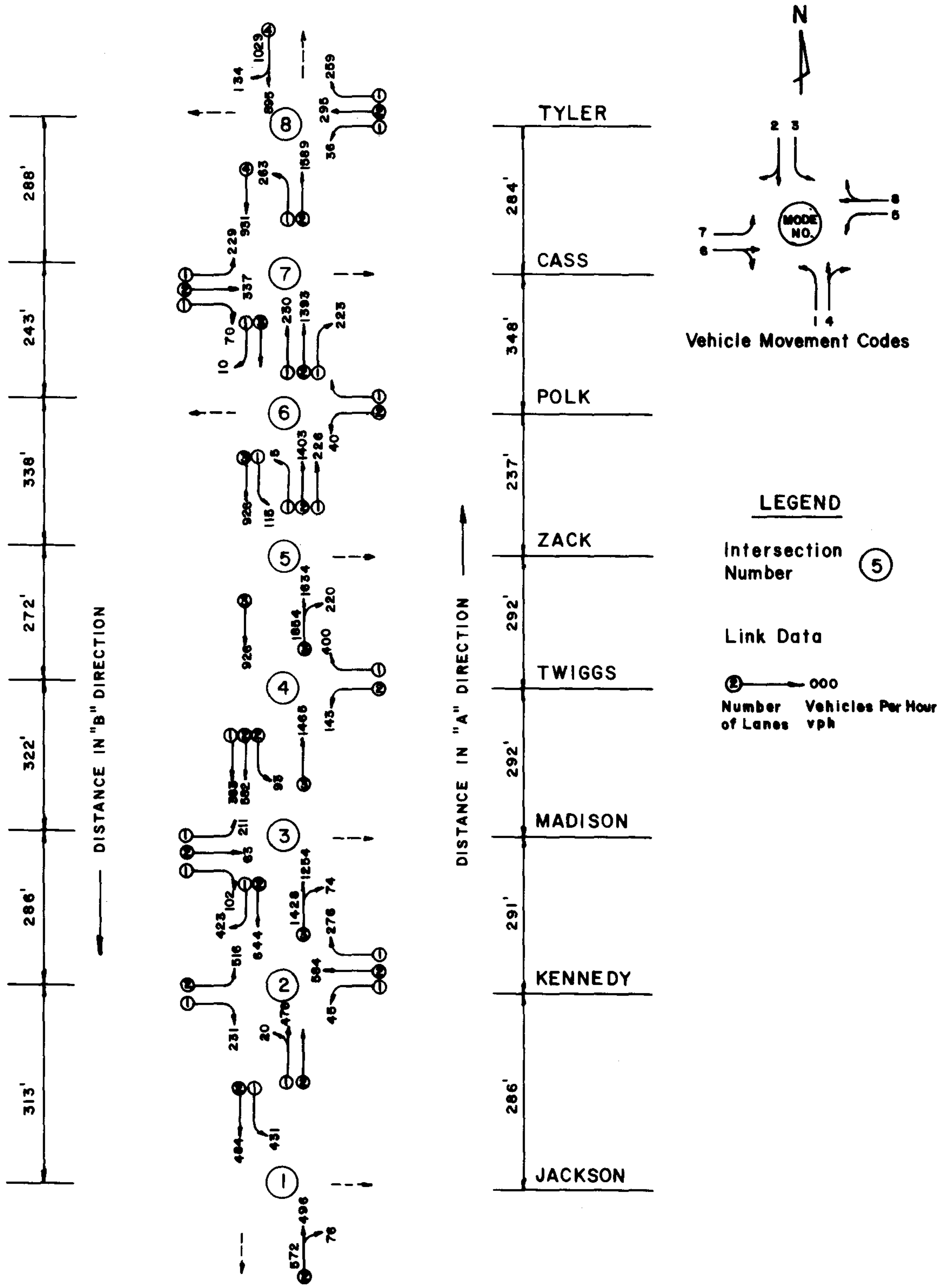


Figure 54. PASSER 80 Link-Node Network - Ashley Drive

north end. Exclusive left turn storage is provided for all permitted left turns. In several instances curb lanes have been restricted for right turn vehicles only. Curb parking is not permitted, although there are frequent driveways to major parking facilities. Although buses use the facility, there are no bus stops.

Traffic signals control the eight street intersections. One is a two phase fixed time signal at the south end, Jackson Street. The remaining intersections are controlled by actuated signals. However, the signals are all supervised by a Master Controller with three dial operation. In actuality the seven actuated signals act as semi-actuated signals with a background cycle during the P.M. peak hours of 90 seconds. Detectors are located on the side streets or in left turn bays, to call the minor phases except at Kennedy Boulevard.

Kennedy Boulevard was the example problem used in the chapter for the SOAP model. The major (non-actuated) phase is on the east approach of Kennedy Boulevard. Although it operates as a five phase signal, it can be considered to basically serve as a three phase controller. The other two phases are basically a lag phase for minor left or right turn minor movements to provide additional pedestrian clearance on two approaches.

At the intersection of Madison Street, a three phase signal is provided with a leading left turn phase for southbound traffic. At Twiggs, Zack, and Cass Streets, two phase signals are provided (for side street traffic at Twiggs and Cass Steets, where southbound left turns are prohibited, and for southbound left turns at Zack Street). The Tyler Street intersection provides a three phase signal with a lagging left turn phase for northbound traffic.

The present signal system is under three dial operation, however, for illustrative purposes the example problem will be limited to an evaluation of the P.M. peak hour.

Analysis of Existing Condition

The PASSER 80 model does not permit modeling of existing conditions. It is possible to model existing cycle length (by setting minimum and maximum cycle length equal to existing cycle length), phasing (by defining only existing sequence), and phase length (by setting minimum greens equal to present splits). However, there is no method to establish existing offsets in order to determine actual bandwidths, and progressive speeds.

Figure 54 shows a link-mode network for Ashley Drive. This illustrates the existing traffic volume for each movement and the distance betweens stop bars in each direction. With the information on this sketch, along with street widths, sufficient information is available to code the arterial network.

Define and Analyze Alternatives

In order to define the alternatives standard coding forms developed by the Texas SDHPT were used. Figure 55 shows the coded input data for the example problem for evaluating cycle lengths ranging between 60 and 70 seconds. It is important to note that it is possible to look at several permissible phase sequence on the areterial but only one sequence can be specified for the cross street. Figure 56 shows the output for this run. A total of seven runs were made to permit evaluation of cycle ranges between 60 seconds and 130 seconds. One run was also made to represent existing intersection signal timing but not actual offsets.

The range of 60-130 second cycle lengths was used to illustrate the MOE's for this range. However, from a practical standpoint, the range should fall between .85 of the longest cycle length and 1.5 of the shortest cycle length for optimum "isolated intersection" operation. Thus, a more practical range would fall between 70 and 90 seconds. The cycle lengths below 70 seconds and above 90 seconds would not be considered or even become of excessive delay.

PASSER II (81)(1) #3
ARTERIAL: Ashley Drive CITY Tampa, Florida
CONDITION: optimise 60-70 sec cycle
PAGE 1 OF 2
DATE 10/23/81
CODED BY: A.S. Byrne

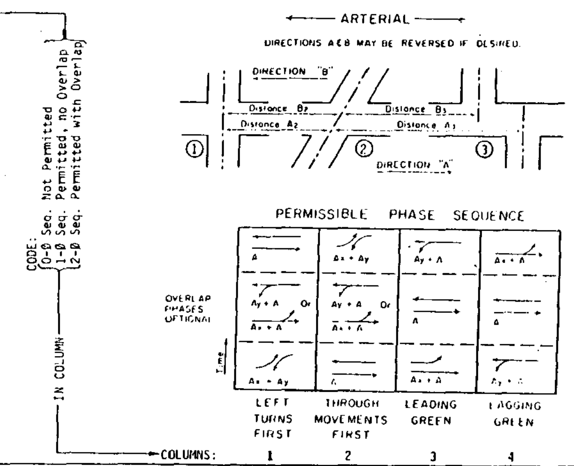
ARTERIAL HEADER CARD (ONE PER ARTERIAL)

RUN NO	NAME OF CITY	NAME OF ARTERIAL	DISTRICT	DATE (M D Y)	NO. OF INTERSECTIONS	ISOLATED	PROGRESSION	CYCLE LENGTHS LOWER	CYCLE LENGTHS UPPER	CYCLE LENGTH INCREMENT SEC.	MIN "B" DIRECTION BAND SPLIT	SPEED SEARCH	PRINTER PLOT	LINE PLOT	X-SCALE 1" = ? SEC.	Y-SCALE 1" = ? FEET	NEMA
A 2	3 A 4	6 A 4	I 2	A 2	I 2	I1	I1	I3	I3	I 2	I 2	I1	I1	I1	F2.0	F4.0	I1
3	TAMPA, FLA	ASHLEY DRIVE	1	102381	8		1	60	70	2		1	1				0

INTERSECTION HEADER CARDS (ONE PER INTERSECTION)

STREET NAME	INTS. NO.	DIST. 'A'	SPD. 'A'	DIST. 'B'	SPD. 'B'	Q-CLEAR 'A'	Q-CLEAR 'B'	Ø SEQ-ART. 1 2 3 4	Ø SEQ-XST 1 2 3 4
3A4	I2	F4.0	F2.0	F4.0	F2.0	I2	I2	4I1	4I1
JACKSON	1	0	25	0	25	0	4	9202	
KENNEDY	2	286	25	313	25	0	3	2222	9910
MADISON	3	291	25	286	25	3	3	2222	9991
TWIGGS	4	292	25	322	25	3	0	2222	9010
ZACK	5	292	25	272	25	4	2	2222	
POLK	6	237	25	338	25	0	2	2222	9910
CASS	7	348	25	243	25	3	2	2222	9001
TYLER	8	284	25	288	26	3	0	2222	9010

CODE: 0-Ø Seq. Not Permitted; 1-Ø Seq. Permitted, no Overlap; 2-Ø Seq. Permitted with Overlap — IN COLUMN / COLUMNS



PASSER II (81)(2) #3
PAGE 2 OF 2

INTERSECTION HEADER CARDS (THREE PER INTERSECTION)

VARIABLE	INTS. NO	VEH. MOVEMENTS - ARTERY* 1	2	3	4	VEH. MOVEMENTS - X STREET* 5	6	7	8
	I2	4I4				4I4			
VOLUMES	1	0	84	436	577	0	0	0	0
CAPACITIES	1	0	3590	1640	3590	0	0	0	0
MIN- GREEN	1	0	14	23	14	0	0	0	0
VOLUMES	2	0	644	0	476	0	0	516	584
CAPACITIES	2	0	3590	0	5100	0	0	2940	3420
MIN- GREEN	2	0	14	0	14	0	0	23	23
VOLUMES	3	0	333	93	1254	0	102	211	0
CAPACITIES	3	0	3590	2590	5100	0	1440	1640	0
MIN- GREEN	3	0	14	10	14	0	23	23	0
VOLUMES	4	0	926	0	1466	143	0	0	400
CAPACITIES	4	0	3590	0	5100	1640	0	0	1440
MIN- GREEN	4	0	14	0	14	23	0	0	23
VOLUMES	5	0	926	115	1634	0	0	0	0
CAPACITIES	5	0	3590	1640	5100	0	0	0	0
MIN- GREEN	5	0	14	10	14	0	0	0	0
VOLUMES	6	0	991	0	1403	40	0	0	209
CAPACITIES	6	1640	3590	0	3590	1640	0	0	1440
MIN- GREEN	6	0	14	0	14	23	0	0	23
VOLUMES	7	0	531	0	1393	0	337	229	0
CAPACITIES	7	0	3590	0	3590	0	3920	1640	0
MIN- GREEN	7	0	15	0	15	0	23	23	0
VOLUMES	8	263	895	0	1589	331	0	0	259
CAPACITIES	8	1640	3590	0	3590	3420	0	0	1440
MIN- GREEN	8	10	14	0	14	23	0	0	23

(CONTINUE ON RIGHT SIDE)

INTERSECTION HEADER CARD (CONTINUED)

INTS. NO	CONTINUATION - ARTERY* 1	2	3	4	CONTINUATION - X STREET* 5	6	7	8
I2	4I4				4I4			

VEHICLE MOVEMENTS*

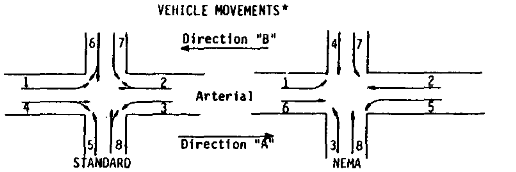


Figure 55. Coded PASSER 80 Input Data for Ashley Drive (Cycle length ranges 60 to 70 seconds)

MULTIPHASE ARTERIAL PROGRESSION PROGRAM - PASSER II-80

TAMPA, FLA ASHLEY DRIVE DISTRICT 1 10/23/81 RUN NO. 3

OPTIONS IN EFFECT ARE # 2

INPUT DATA

NUMBER OF INTERSECTIONS	LOWER CYCLE LENGTH	UPPER CYCLE LENGTH	CYCLE INCREMENT
8	60	70	2

****

***** INTERSECTION 1 JACKSON

DISTANCE 0 TO 1 0. FT SPEED 25. MPH DISTANCE 1 TO 0 0. FT SPEED 25. MPH

MAJOR ST. MINOR ST.
A SIDE QUEUE CLEARANCE 0 SEC B SIDE QUEUE CLEARANCE 4 SEC
THROUGH MOVEMENTS FIRST WITH OVERLAP
LAGGING GREEN WITH OVERLAP

MOVEMENTS

	1	2	3	4	5	6	7	8
VOLUMES	0	484	436	577	0	0	0	0
SAT. CAPACITY	0	3590	1640	3590	0	0	0	0
MINIMUM GREEN	0	14	23	14	0	0	0	0

***** INTERSECTION 2 KENNEDY

DISTANCE 1 TO 2 286. FT SPEED 25. MPH DISTANCE 2 TO 1 313. FT SPEED 25. MPH

MAJOR ST. MINOR ST.
A SIDE QUEUE CLEARANCE 0 SEC B SIDE QUEUE CLEARANCE 3 SEC

ARTERIAL PERMISSIBLE PHASE SEQUENCE CROSS ST PHASE SEQUENCE IS LEADING GREEN NO OVERLAP
LEFT TURNS FIRST WITH OVERLAP
THROUGH MOVEMENTS FIRST WITH OVERLAP
LEADING GREEN WITH OVERLAP
LAGGING GREEN WITH OVERLAP

MOVEMENTS

	1	2	3	4	5	6	7	8
VOLUMES	0	644	0	476	0	0	516	584
SAT. CAPACITY	0	3590	0	5100	0	0	2940	3420
MINIMUM GREEN	0	14	0	14	23	0	23	23

***** INTERSECTION 3 MADISON

DISTANCE 2 TO 3 291. FT SPEED 25. MPH DISTANCE 3 TO 2 286. FT SPEED 25. MPH

MAJOR ST. MINOR ST.
A SIDE QUEUE CLEARANCE 3 SEC B SIDE QUEUE CLEARANCE 3 SEC

ARTERIAL PERMISSIBLE PHASE SEQUENCE CROSS ST PHASE SEQUENCE IS LAGGING GREEN NO OVERLAP
LEFT TURNS FIRST WITH OVERLAP
THROUGH MOVEMENTS FIRST WITH OVERLAP
LEADING GREEN WITH OVERLAP
LAGGING GREEN WITH OVERLAP

MOVEMENTS

	1	2	3	4	5	6	7	8
VOLUMES	0	383	93	1254	0	102	211	0
SAT. CAPACITY	0	3590	2590	5100	0	1440	1640	0
MINIMUM GREEN	0	14	10	14	0	23	23	0

Figure 56. PASSER 80 Output Report for Ashley Drive (Cycle length 60 to 70 seconds).

CODING ERROR MESSAGES

NO APPARENT CODING ERRORS

	MINIMUM ADVISABLE CYCLE LENGTH	MAXIMUM ADVISABLE CYCLE LENGTH
INTERSECTION 1 JACKSON	34.	50.
INTERSECTION 2 KENNEDY	47.	69.
INTERSECTION 3 MADISON	38.	56.
INTERSECTION 4 TWIGGS	42.	63.
INTERSECTION 5 ZACK	34.	50.
INTERSECTION 6 POLK	47.	69.
INTERSECTION 7 CASS	34.	50.
INTERSECTION 8 TYLER	81.	100.

IF THE CYCLE LENGTH SELECTED IN THE BEST SOLUTION IS NOT WITHIN THE RANGE SHOWN ABOVE
THE MAXIMUM BAND WIDTH MAY BE PRESENT BUT UNDULY LARGE DELAY MAY BE PRESENT

MULTIPHASE ARTERIAL PROGRESSION PROGRAM - PASSER II-80

TAMPA, FLA ASHLEY DRIVE DISTRICT 1 10/23/81 RUN NO. 3

BEST SOLUTION

CYCLE LENGTH = 70 SEC. BAND A = 18 SEC. BAND B = 11 SEC. 0.21 EFFICIENCY 0.66 ATTAINABILITY
AVERAGE PROGRESSION SPEED - BAND A = 27 MPH. BAND B = 27 MPH.

****

**** INTERSECTION 1 0.0 SECONDS OFFSET ARTERIAL PHASE SEQUENCE IS THROUGH MOVEMENTS FIRST
JACKSON 0.0 % OFFSET CROSS STREET PHASE SEQUENCE IS THROUGH MOVEMENTS FIRST

	ARTERIAL				CROSS STREET			
MOVEMENTS	2+4	2+3	1+3	TOTAL MAJOR ST	6+8	6+7	5+7	TOTAL MINOR ST
GREEN TIME SECS	27.4	42.6	0.0	70.0	0.0	0.0	0.0	0.0
GREEN TIME (%)	39.1	60.9	0.0	****	0.0	0.0	0.0	0.0

----------------------- MEASURE OF EFFECTIVENESS -----------------------

MOVEMENTS	1	2	3	4	5	6	7	8
XRATIO	0.0	0.143	0.482	0.483	0.0	0.0	0.0	0.0
LEVEL OF SERVICE		A	A	A				
DELAY(SEC/VEH)	0.0	1.56	11.11	19.34	0.0	0.0	0.0	0.0
LEVEL OF SERVICE		A	A	B				
PROBABILITY OF CLEARING QUEUE	1.000	1.000	0.999	1.000	1.000	1.000	1.000	1.000
LEVEL OF SERVICE		A	A	A				

TOTAL INTERSECTION DELAY (SEC/VEH) 11.19

Figure 56. PASSER 80 Output Report for Ashley Drive (Cycle length 60 to 70 seconds) (Cont'd).

BEST SOLUTION CONTINUED

```
****************************************************************************************************************
**** INTERSECTION  2    7.2 SECONDS OFFSET    ARTERIAL PHASE SEQUENCE IS  LAGGING GREEN
KENNEDY                10.3 % OFFSET    CROSS STREET PHASE SEQUENCE IS LEADING GREEN
```

MOVEMENTS	ARTERIAL 2+3	2+4	1+4	TOTAL MAJOR ST	5+8	CROSS STREET 6+8	6+7	TOTAL MINOR ST
GREEN TIME SECS	0.0	23.8	0.0	23.8	23.0	0.0	23.2	46.2
GREEN TIME (%)	0.0	34.0	0.0	34.0	32.9	0.0	33.1	66.0

----------------------- MEASURE OF EFFECTIVENESS -----------------------

MOVEMENTS	1	2	3	4	5	6	7	8
XRATIO	0.0	0.634	0.0	0.330	0.0	0.0	0.640	0.629
LEVEL OF SERVICE		B		A			B	B
DELAY(SEC/VEH)	0.0	24.94	0.0	1.28	0.0	0.0	24.15	23.79
LEVEL OF SERVICE		B		A			B	B
PROBABILITY OF CLEARING QUEUE	1.000	0.983	1.000	1.000	1.000	1.000	0.970	0.981
LEVEL OF SERVICE		A		A			A	A

TOTAL INTERSECTION DELAY (SEC/VEH)   19.38

```
                                                           TAMPA, FLA
                                                                                  HORIZONTAL SCALE  1 INCH =  30 SECONDS
               CYCLE LENGTH =  70 SECONDS                                           VERTICAL SCALE  1 INCH = 1000 FEET

TYLER          *
 45.8S 65.4%  **=++++++       ========++++++        ========++++++        ========++++++        ========++++++        ===
CASS           *                                   . .  ..
 24.0S 34.3%   *       ===============       ===============       ===============        ===============       ==========
POLK           *
 26.2S 37.4%   *       ===============       ===============       ===============        ===============       ==========
 13.0S 18.6%   *---===================---===================---===================---===================---===============
TWIGGS        **                             .    .         .  .
  4.6S  6.6%   * ============          ============          ============          ============          ============
MADISON        *
 61.3S 87.6%   *============       ---===========        ---===========        ---===========        ---===========
  7.2S 10.3%   *  ========              ========              ========              ========              ========
JACKSON        *                      .     .                      .   .
  0.0S  0.0%  **========--------------========--------------========--------------========--------------========----------

                        "A"                        "B"
                      27 MPH                     27 MPH                     *** DUAL LEFT (1+3)        +++ LEADING GREEN (1+4)
                   18 SECOND BAND             11 SECOND BAND                === STRAIGHT THRU (2+4)    --- LAGGING GREEN (2+3)
```

Figure 56. PASSER 80 Output Report for Ashley Drive (Cycle length 60 to 70 seconds) (Cont'd).

Table 15 - Comparison of PASSER 80 Runs

RUN	CYCLE RANGE	SELECTED CYCLE	BAND A SEC	BAND A SPEED	BAND B SEC	BAND B SPEED	% EFF	TOTAL DELAY (Veh-Hrs)	AVERAGE DELAY PER VEHICLE (Sec/Veh)
1	120-130*	130	42	24	26	24	26	133.3	23.71
2	110-120*	112	36	23	22	23	26	101.76	18.10
3	100-110*	110	36	23	22	23	26	100.19	17.32
4	90-100*	100	32	25	19	25	26	92.34	16.42
5	80-90**	90	28	27	17	27	26	84.30	14.99
6	70-80**	70	18	27	11	27	21	71.45	12.71
7	60-70*	70	18	27	11	27	21	71.45	12.71
EXIST	90	90	26	27	23	27	27	88.99	15.80

*Outside range of advisable cycle length.
**Range which would be used for analysis based upon intital cycle length calculation for each intersection using Poisson method.

Evaluation of Results

Table 15 provides a summary of each of the runs. As cycle length increased the arterial delay to vehicles increased, however, bandwidth also tended to become larger, as expected.

A comparison of the existing signal timing with optimum signal timing for the same cycle length (90 sec) showed only a slight difference in total delay. This is largely due to a small change in length of each phase at some intersections, although no phasing plan was changed. (Remember that the model did not represent the existing offset but used the model's result so this is not a true comparison.)

In reviewing the results, a 90 second cycle would give the largest percent bandwidth (or efficiency of 26%) with minimum delay for that level of efficiency (84.30 vehicle hours). The optimum cycle length to minimize delay would be a 70 second cycle with a 71.45 seconds of delay or a reduction of 15%. Although not explicitly defined by the model, it would appear that the 90 second cycle minimized stops, but the length of the stops are increased.

Summary of Work Effort Reqquirements

The amount of work effort required to code, run and analyze the PASSER 80 model was minimal. The following summarizes this effort.

Data Collection - The data required for the PASSER 80 model is minimal. Turning volumes, intersection geometric and distance between stop bars on each direction are all that is required. In the case of an existing system the existing signal timing would be useful.

Data Coding - Less than one hour was required to code this arterial problem and should be typical for most problems.

Computer Time - Execution time on the IBM 360/370 varied from .26 seconds for the existing condition to .38 seconds for the highest cycle lengths investigated. All the problems were executed using 96K of storage.

REFERENCES

6.1 *Messer, C.J., et al., "A Report on the User's Manual for Progression Analysis Signal System Evaluation Routine - PASSER II," Texas Transportation Institute Research Report 165-14, August, 1974. (NTIS-PB-241582)

6.2 Texas Transportation Institute, "Signal Timing Optimization to Maximize Traffic Flow," Workshop Notes, undated.

6.3 Messer, C.J. and Fambro, D.C., "A Guide for Designing and Operating Signalized Intersections in Texas," Texas Transportation Institute, Research Report 203-1, August 1975.

6.4 Messer, C. J., et.al., "A Variable-Sequence Multi-phase Progression Optimization Program," Transportation Research Record 445, 1973, pp. 24-33.

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

6.6 Fambro, D.B. "PASSER II - Software Documentation," Texas Transportation Institute, College Station, January, 1979.

6.7 "Traffic Engineering Programs," Texas State Department of Highways and Public Transportation, Dec. 1980.

CHAPTER 7 - PASSER III (DIAMOND OPTIMIZATION MODEL)

The diamond interchange is the most common type of interchange used today in both rural and urban areas. In rural areas, this type of interchange is adaptable almost exclusively to major-minor crossings and the traffic volumes are small so that traffic signs are used to control traffic. In urban areas, diamond interchanges can handle large traffic volumes by use of storage lanes, channelization, and traffic signals at the crossroad terminals of the freeway ramps.

The signalization of diamond interchanges presents an interesting challenge to the traffic engineer. Quite often efficient movement of traffic through the interchange is critical because of the potential for traffic to back up onto the freeway. The quality of service provided is related to the physical design and type of signalization at the interchange.

There are many differences of opinion regarding the best way to signalize a diamond interchange. The computer model described in this chapter was developed to assist the traffic engineer in determining the optimal traffic signal timings for signalized diamond interchanges. The program is applicable to isolated interchanges as well as a series of interchanges through which progression is desired along one-way frontage roads. PASSER III, like PASSER II(80), was developed at the Texas Transportation Institute for use in the Dallas Corridor Project which was sponsored by the Federal Highway Administration (FHWA) and the Texas State Department of Highways and Public Transportation (SDHPT) in cooperation with the City of Dallas. PASSER III was adapted and improved upon in HPR Project 178 which was also sponsored by the Texas SDHPT and FHWA.

The Texas SDHPT maintains the model and is used extensively by its staff.

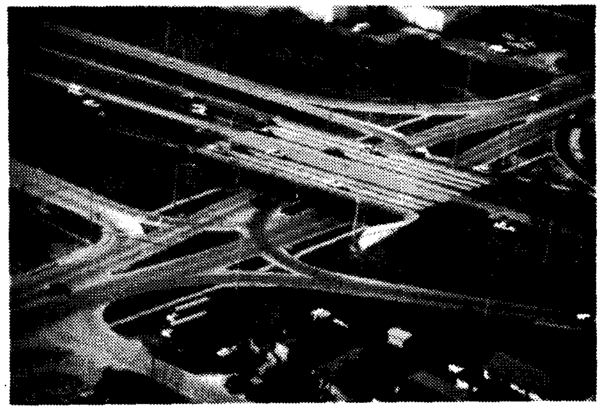


Figure 57 - Typical Signalized Diamond Interchange.

MODEL DESCRIPTION

In urban areas, most diamond interchanges are signalized at the ramp terminals, where the ramps intersect the cross street. Diamond interchanges are normally characterized by their close spacing of the ramp terminals and the resulting small storage areas between the signals. In the early 1960's the Texas Transportation Institute of Texas A&M University developed a novel signalization strategy for diamond interchanges which took into account the fact that the throughput (or capacity) of the system could be increased by allowing several potentially conflicting movements at the separate intersections to occur simultaneously for a short time (Reference 7.1). This period was termed the "overlap phase" for obvious reasons, and the underlying concept has become a standard in the profession.

PASSER III, which is an Acronym for Progressive Analysis and Signal System Evaluation

Routine, Model III (Diamond Interchange, see Reference 7.2), determines the optimal phase patterns, splits and internal offsets at single interchanges (for given cycle lengths) and additionally the optimal system cycle length and progression offsets for the frontage road progression. The physical system considered is the signalized diamond interchange, with or without thru frontage roads or a series of interconnected interchanges with progression on the parallel (frontage) road.

The computer program is written in FORTRAN IV and consists of about 3100 statements. It is estimated that machines with core storage of 168K can accommodate most problems.

INPUT REQUIREMENTS

The input data required for this program are similar to those needed by the PASSER 80 model. The program uses data that are normally collected and used for signal analysis at diamond interchanges, with some special requirements. The current program can handle up to fifteen (15) interchanges in a single run.

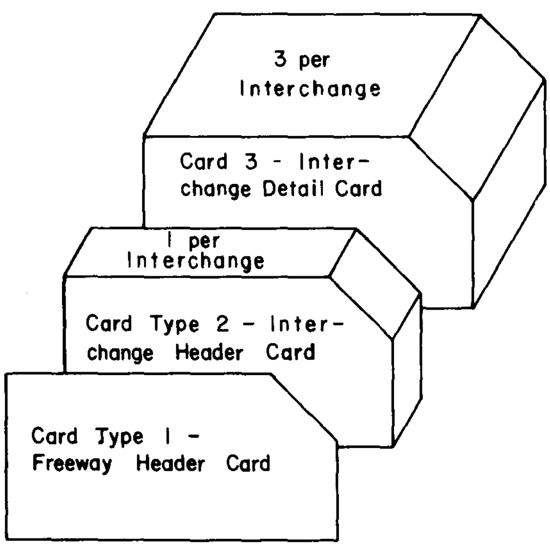


Figure 58. PASSER III Data Deck

Three types of input cards are used for PASSER III - 1) freeway header card, 2) interchange header card and 3) interchange detail card. These data are recorded using standard formats and submitted to the computer as shown in Figure 58.

Freeway Header - This card identifies the freeway and defines some general parameters and options.

Interchange Header - This card provides signalization and geometric information for each signalized interchange in the data set. Link data for the frontage road must be provided if a frontage road progression is desired. One card is required for each interchange.

Interchange Detail Cards - Three cards are required for each interchange. Card one contains traffic volumes, card two contains the effective number of lanes for each movement and card three presents the minimum green time in seconds for each signal phase.

A summary description of the input data for each of the card types are included in Table 16. A more detailed description and instructions for coding input data are included in the reference material. Standard coding forms are available for the user.

Most of the inputs are self-explanatory, but there are a few peculiarities which should be noted. PASSER III has two primary functions as noted earlier: a) isolated interchange optimization and b) coordinated progression on frontage roads. These modes can be run simultaneously for a total system analysis, but this is quite expensive. The preferred approach is to run the isolated designs first and then using these results, run the progressive analysis (if the latter is needed). Accordingly, the user has to be aware of what inputs should be included in the respective runs. The two modes are discussed briefly below, then some general remarks.

Isolated Interchange Mode

When one or more interchanges are being optimized independently the essential input requirement is to code a minus one (-1) in each of the five two column fields to cause PASSER

Table 16 - Input Requirements for PASSER III

CARD TYPE	CARD DESCRIPTION	REQUIREMENTS
Freeway Header Card (1 per freeway)	Name of City	User Choice
	Name of Freeway	User Choice
	District	User Choice
	Run Number	Arbitrary number to identify run.
	No. of Interchanges	Required
	Isolated Mode	Isolated interchange(s) or frontage road progression.
	THE FOLLOWING IS ONLY FOR FRONTAGE ROAD PROGRESSION OPTION	
	Progression Mode	To indicate frontage road analysis
	Lower Cycle Length	Smallest Cycle length.
	Upper Cycle Length	Largest Cycle length.
	Cycle Length Increment	In seconds.
	Min. "B" Direction Band Split	Percent of total bandwidth to be provided in "B" direction.
	Link Speed Search	To permit 2 mph variation (optional)
	Printer Plot	Time Space Diagram (optional)
	Line Plot	Use Line Plotter for TSD.
	X Scale	Scale for time axis.
	Y Scale	Scale for distance axis.
Intersection Header Card (1 per interchange)	Cross-Street Name	Required - User Choice
	Interchange Number	Must be sequential in "A" direction.
	THE FOLLOWING IS ONLY FOR SINGLE INTERCHANGE ANALYSIS:	
	Cycle Length	In seconds.
	Delay-Offset Analysis	User Choice
	Permissive Left Turns	To define those permitted.
	Interior Travel Time	Time required to travel from one intersection to the other.
	Interior Queue Storage	No. of vehicles that can be stored (25 feet per vehicle)
	THE FOLLOWING IS ONLY FOR PROGRESSION ANALYSIS:	
	"A" Direction Distance	Distance to next interchange.
	"A" Direction Speed	Average Speed (MPH)
	"B" Direction Distance	Distance to next interchange.
	"B" Direction Speed	Average Speed (MPH)
	Queue Clearance	"A" & "B" - amount of time the progressive band will lag.
	THE FOLLOWING IS REQUIRED FOR EITHER MODE	
	Priority Phasing	No. of seconds of directed internal offset for each phasing code.
Interchange Detail Cards (3 per interchange)	Traffic Volumes*	Traffic volumes for 18 movements
	Number of Lanes*	Effective lanes which serve each movement
	Minimum Green*	Minimum allowable green time for each approach.

*These data are placed on separate cards for each interchange.

III to determine the optimal internal offset. If analysis only is desired, code actual splits and offsets as "minimum greens" and "priority phasing" as applicable.

Progressive Frontage Road Mode

In this mode the lower and upper cycle length limits entered may be based on the results of the isolated interchange runs, but should not be more than 10 seconds difference for one run. Directional preference for the progression band may be specified for either one-way or two-way, (with or without preference to direction). The speeds input should be based on field studies under "nonstop" conditions to obtain "free speed" during the time period under study. However, if different link speeds occur and it is not desired to vary the band speed, the average speed should be used (unless it is anticipated that drivers will adjust to slightly different speeds).

General

Options input on the freeway and interchange header cards are used by PASSER III to perform the requested analysis. The volumes can be obtained from field studies or projections, but the user must be careful to obtain the appropriate counts. Just above the coding columns for this card (see Figure 59) are diagrams showing the eighteen movements required. Note that in some cases a movement must be traced through both sides of the interchange.

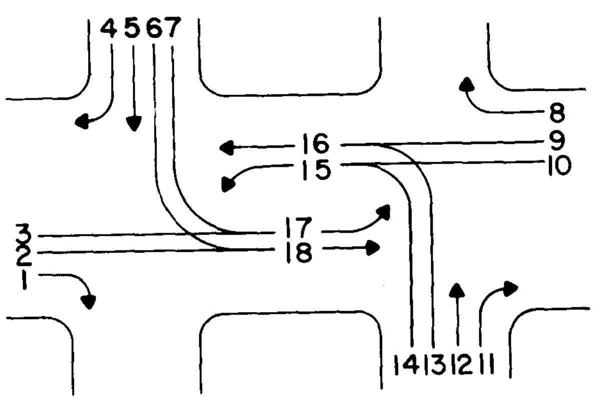


Figure 59. PASSER III Traffic Movements

The second detail card gives the equivalent number of lanes. This is how capacities are input. PASSER III uses a constant lane saturation flow of 1800 vehicles per hour of green time. This may be adjusted (for a single lane and movement) by inputting a factor in the appropriate field. The factor is found by dividing the user's desired saturation flow by 1800. For example, if a left turn lane saturation flow of 1200 vph for movement 15 (see Figure 59) is desired, enter 67. Movements which share several lanes must be assigned their proportional capacity. For example, assume the frontage road in direction "A" has three lanes and demands of 200 vph per lane with the traffic in the left lane all turning left (of which 50 make a U-turn) and 50 vehicles in the right lane turn right. The equivalent number of lanes for movements 4, 5, 6 and 7 are 0.25 (50/200), 1.75 (150/ 200 + 200/200), 0.75 (150/200) and 0.25 (50/200), respectively. These values should be carefully estimated since phase splits are based on the demand/ saturation flow ratios.

Finally, the conflicting minimum greens input must not exceed the cycle length (or minimum cycle length) specified. Minimum greens include green, amber and all-red intervals. Sufficient time must be provided for any pedestrian movements.

OPERATIONAL SUMMARY

PASSER III is a macroscopic deterministic time-based optimization model. Since the isolated interchange analysis is distinctly different from the progressive analysis on the frontage roads, it is simpler to discuss them separately.

Isolated Interchange Mode

The interchange optimization is based on the fact that there can exist at each interchange only three basic phases, or allowable greens (excluding pedestrian phases). These are shown for the left-side intersection in Figure 60. These may occur in the order of either ABC (leading left-turns) or ACB (lag-

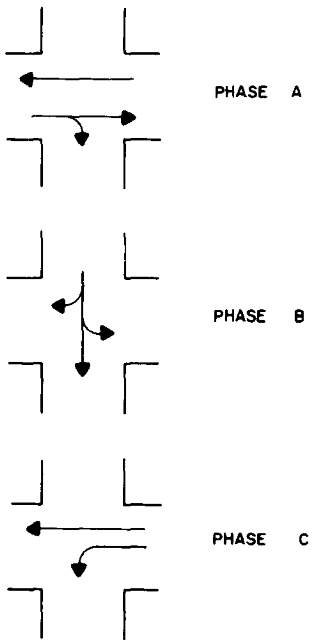


Figure 60. Three Basic Phases at Left-Side Intersection of Interchange

ging left turns), where the off-ramp traffic either leads or lags the left-turns to the on-ramp. Three similar phases are available at the right-side intersection.

Only certain movements can exist simultaneously at both intersections for any period of time. Thus, the complete set of possible patterns is four, as shown in Figure 61. The fifth code (1A) is a special case of the lead-lead pattern, discussed later. All other movements are stopped. For Phasing Code 1, queues are forming on the ramps during Phase A, in the connecting street on Phase B, and on the ramps during Phase C. When overlap is permitted, some conflicting movements can move simultaneously, as shown in Figure 62. Note that the offset is defined as the time between the beginning of Phase A on the left side to the end of Phase B on the right side.

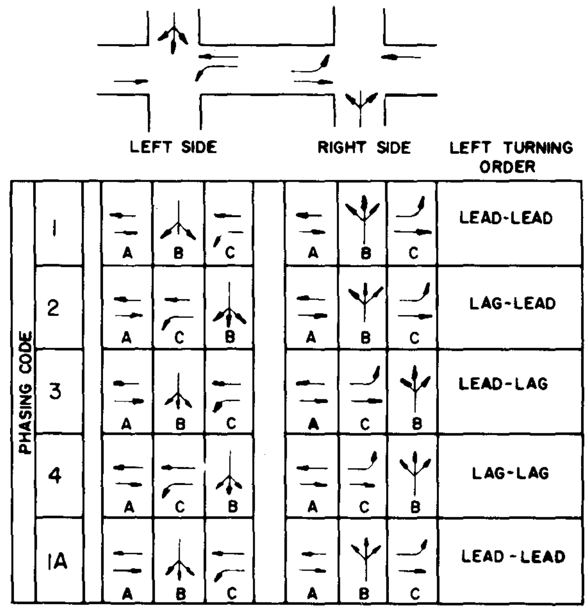


Figure 61. Phase Sequences and Phase Codes Used by PASSER III

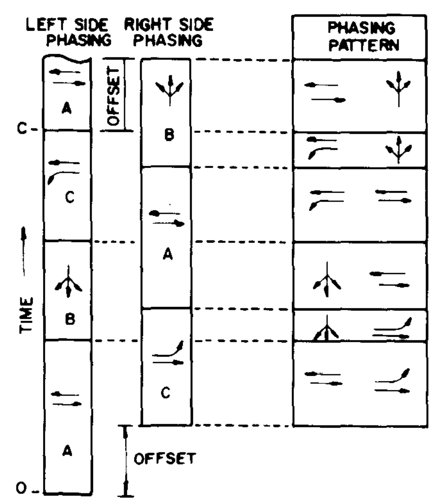


Figure 62. Development of Diamond Interchange Phasing Patterns From ABC:ABC Phasing and Offset

PASSER III examines all possible combinations of phases (i.e., patterns) and varies the offset to find the pattern and offset which results in the minimum delay in the interchange. An example of the comparison of all possible Phase Codes is shown in Figure 63. The optimal design would appear to be Phase Code #4 with an offset equal to zero or the cycle length (70 sec). Phase Code 1 also gives good results at an offset of about 20 sec. To obtain this result 350 combinations were tried (five phase codes by 70 seconds). To do this by hand would be prohibitive.

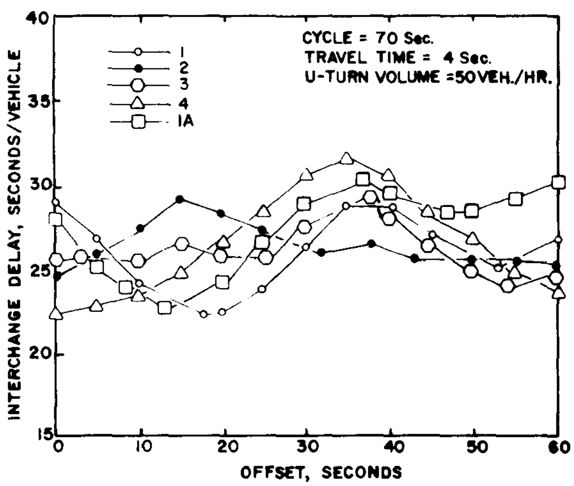


Figure 63. Variation in Interchange Delay for all Five Phase Codes

The fifth phase code (1A) shown in Figure 61 is the well-known "four phase with over-lap" pattern where the overlap is equal to the internal travel time (i.e., from the stop bar at one intersection to the stop bar of the other). In other words, perfect progression is provided for the through traffic (this may not be the case if Phase Code 1 (only) is specified).

Progressive Frontage Road Mode

The frontage road progression is independent of the interchange optimization, although the latter should be run to obtain the appropriate phasing and minimums for the progressive analysis. Both analyses may be run together, but the output is extensive and run time high, so the two step method is preferred. The optimal progression design is that which provides the largest "bandwidth efficiency", defined as the sum of the bi-directional bandwidths divided by twice the cycle length. For further discussion on the progressive optimization, see Chapter 6, PASSER II(80).

COMPUTATIONAL ALGORITHMS

The computational algorithms differ somewhat between the isolated interchange and progressive frontage road modes. In the isolated mode the green times are found using Webster's method (Reference 7.3).

$$G = \frac{y}{\Sigma y} \cdot (C-L) + \ell ; \qquad (7.1)$$

where G = green time (sec),
y = volume (vps)/saturation flow (upsg),
Σy = sum of all y at intersection
C = cycle length,
ℓ = lost time this phase (sec),
L = sum of all lost time at intersection.

When the four-phase with overlap pattern (Code 1A) is introduced, the green times are calculated using a slightly different formula. An additional term is inserted in the parenthetical expression, which is then $(C + \emptyset - L)$ and $\emptyset$ = sum of interchange overlap (offset) times.

Exterior delay is the delay to all approaches into the interchange (movements 1-14). These are calculated by Webster's method (Reference 7.3), namely,

$$d = \frac{C(1-\lambda)^2}{2(1-\lambda X)} + \frac{X^2}{2v(1-X)} - 0.65 \left(\frac{C}{v^2}\right)^{1/3} \cdot X^{(2+5\lambda)} \qquad (7.2)$$

where d = average delay per approach (sec/veh),
C = cycle length,
v = approach volume (vps)
λ = proportion of cycle green for this approach, and
χ = saturation ratio v/c (c = capacity)

The internal delay for movements 15-18 is calculated by the delay-offset technique. However, this technique is too lengthy to discuss here (interested readers are referred to Reference 7.4).

In the progressive mode the objective is to find the optimal bandwidth efficiency, or

$$\text{Maximize } E = \frac{B_A + B_B}{2C}; \tag{7.3}$$

where E = bandwidth efficiency,
B_A = bandwidth in "A" direction,
B_B = bandwidth in "B" direction, and
C = cycle length.

For further discussion of the progressive optimization, see Chapter 6, PASSER II(80).

OUTPUT REPORTS

There are a total of eight output reports available from PASSER III, but not all are produced in a single run since they vary by mode of analysis (i.e. isolated or progressive). The distinctions are included in the discussion below.

```
********************************************************************************
*                                                                              *
*  RUN NUMBER  2                                            DATE  5/14/81     *
*                                                                              *
*  I-75 OPTIMAL TIMING PM          TAMPA                    DISTRICT  1       *
*                                                                              *
********************************************************************************
*                                                                              *
*  OPTIONS -                                                                   *
*                                                                              *
*     CALCULATE GREEN SPLITS AND MEASURES OF EFFECTIVENESS --------     YES    *
*                                                                              *
*     USE DELAY-OFFSET EVALUATION TECHNIQUE -----------------------     YES    *
*                                                                              *
*     DETERMINE OPTIMAL PROGRESSION SOLUTION ----------------------      NO    *
*                                                                              *
*     SEARCH FOR OPTIMAL SOLUTION BY VARYING LINK SPEEDS ----------      NO    *
*                                                                              *
*     PRINT OPTIMAL TIME-SPACE PROGRESSION DIAGRAM ----------------      NO    *
*                                                                              *
*     PLOT OPTIMAL TIME-SPACE PROGRESSION DIAGRAM -----------------      NO    *
*                                                                              *
*  PARAMETERS - (ISOLATED INTERCHANGE ANALYSIS)                                *
*                                                                              *
*     DESIRED CYCLE LENGTH ---------------------------------------- 60 SECONDS *
*                                                                              *
*  PARAMETERS - (FRONTAGE ROAD PROGRESSION ANALYSIS)                           *
*                                                                              *
*     NUMBER OF INTERCHANGES --------------------------------------  1         *
*                                                                              *
*     LOWER CYCLE LENGTH LIMIT ------------------------------------  0 SECONDS *
*                                                                              *
*     UPPER CYCLE LENGTH LIMIT ------------------------------------  0 SECONDS *
*                                                                              *
*     CYCLE LENGTH INCREMENT --------------------------------------  0 SECONDS *
*                                                                              *
*     MINIMUM 'B' DIRECTION BAND SPLIT ----------------------------    NONE    *
*                                                                              *
********************************************************************************
```

Figure 64. PASSER III Input Data Report: Options and Parameters

INTERCHANGE INPUT DATA

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

RUN DELAY-OFFSET ANALYSIS?

CODE 1 OR LEAD-LEAD --------------------- YES
CODE 2 OR LAG-LEAD ---------------------- YES
CODE 3 OR LEAD-LAG ---------------------- YES
CODE 4 OR LAG-LAG ----------------------- YES
CODE 1A OR TTI 4-PHASE ------------------- YES

PRIORITY PHASINGS / INTERNAL OFFSET

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

PERMISSIVE LEFT TURNS ALLOWED?

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

INTERIOR TRAVEL TIME

FROM LEFT TO RIGHT ACROSS THE INTERCHANGE ------- 11 SEC.
FROM RIGHT TO LEFT ACROSS THE INTERCHANGE ------- 12 SEC.

INTERIOR QUEUE STORAGE

THROUGH MOVEMENT AT RIGHT SIDE INTERSECTION ----- 8 VEH.
LEFT TURN MOVEMENT AT RIGHT SIDE INTERSECTION --- 6 VEH.
THROUGH MOVEMENT AT LEFT SIDE INTERSECTION ------ 8 VEH.
LEFT TURN MOVEMENT AT LEFT SIDE INTERSECTION ---- 6 VEH.

MOVEMENTS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
VOLUMES	0	628	336	220	10	161	0	125	526	245	0	45	376	0	245	902	336	789
NUMBER OF LANES	0.0	1.30	0.70	1.00	0.12	1.88	0.0	0.39	1.00	0.51	0.0	0.21	1.79	0.0	1.00	2.00	1.00	2.00
MINIMUM GREEN	10	18	10	18	10	10	10	10										

Figure 65. PASSER III Input Data Report:
Interchange Data

Input Data Report

All input data are printed in well formatted tables, shown in Figures 64 and 65. These reports are output in both modes. One table of the type in Figure 65 is produced for each interchange. The contents of these reports are self-explanatory.

General Signalization Information

In both modes of operation the general intersection information shown in Figure 66 is output for each interchange. This table reports the measures of effectiveness (MOE) for each movement (phase) of the two intersections, along with a corresponding level of service. The first three phases (A, B, and C) are the normal three phases in the pattern. The forth "phase" labeled "D" is the time available for the interior thru traffic, or the sum of phases A and C.

The green time is the amount of the available cycle available for each of the phases (including amber and all-red). The volume/capacity is the ratio of demand to capacity flow in the critical lanes. Delay is the estimate of delay calculated by Webster's method or the delay-offset technique, as

GENERAL SIGNALIZATION INFORMATION

I-75 OPTIMAL TIMING PM AT BUFFALO RUN NO. 2 5/14/81

MEASURES OF EFFECTIVENESS	LEFT SIDE				RIGHT SIDE			
	A	B	C	D	A	B	C	D
GREEN TIME (SEC.)	26.7	18.0	15.3	42.0	24.9	18.0	17.1	42.0
VOLUME/CAPACITY RATIO, X	0.71	0.52	0.72	0.40	0.84	0.51	0.85	0.35
LEVEL OF SERVICE	C	A	C	A	D	A	E	A
DELAY (SEC./VEH.)	17.44	19.38	30.84	5.85	19.63	20.93	41.92	5.55
LEVEL OF SERVICE	B	B	C	A	B	B	C	A
PROBABILITY OF CLEARING QUEUE	0.89	0.98			0.62	0.98		
LEVEL OF SERVICE	C	A			D	A		
STORAGE RATIO			0.42	0.19			0.56	0.14

PHASE ORDER - ABC/ABC
INTERNAL OFFSET - 12 SECONDS
TOTAL INTERCHANGE DELAY - 16.02 VEHICLE-HOURS PER HOUR

Figure 66. PASSER III - General Signalization Report

appropriate. The probability of clearing the queue values refer to the likelihood that all queues will be cleared on a given cycle for the particular phase. These three MOE's all have a level of service associated with them. The levels of service are determined from Table 17.

The fourth MOE is only available in the isolated mode. The interior storage ratio is the ratio of the length of the maximum queue per cycle for the C and D phases to the available interior storage capacities for these phases. Storage ratio should not exceed 0.8, with 0.6 being a preferrable maximum.

Table 17 - Los Criteria for MOE'S on Signalized Movements

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

Below the table in Figure 66 are the phase orders analyzed, the interal offset identified as having the minimal delay (i.e. the optimal offset) and the total interchange delay in veh-hrs/hr.

It should be noted that the estimates of delay for the separate phases in Figure 66 do not vary with offset under isolated mode analysis for a single cycle length. While the total delay is computed as per Equation 7.2, the internal delays in this table do not reflect variation of offset. This is considered a deficiency of Passer III. For the isolated mode analysis, evaluations should always be based on total delay where a single cycle length is analyzed, days can be comparted when different cycle lengths are analyzed, rather than individual movement delays.

Phase Interval Report

A Phase Interval Report is given for each interchange which shows the complete phase pattern including overlaps and the length of the intervals. This report is shown in Figure 67. Note that the sum of the intervals is equal to the cycle length.

PHASE INTERVALS

I-75 OPTIMAL TIMING PM AT BUFFALO RUN NO. 2 5/14/81

PHASE INTERVAL NUMBER	LEFT SIDE STATUS	RIGHT SIDE STATUS	PHASE INTERVAL LENGTH(SEC.)
1	A	B	12.0
2	A	C	14.7
3	B	C	2.4
4	B	A	15.6
5	C	A	9.3
6	C	B	6.0

PHASE ORDER - ABC/ABC
INTERNAL OFFSET - 12 SECONDS

Figure 67. PASSER III Phase Interval Report

Optimal Progression Solution Report

When the frontage road progressive mode is run the afore-mentioned reports are output. Additionally an Optimal Progression Solution report such as Figure 68 is output. The report includes the optimal cycle length, the progression speed and bandwidth for each direction, the bandwidth efficiency and the attainability. The last value is the average percent of the minimum frontage road green time used in each direction for progression.

OPTIMAL PROGRESSION SOLUTION

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

CYCLE LENGTH	75	SEC.
'A' DIRECTION		
PROGRESSION SPEED	34.8	MPH.
BAND WIDTH	25.0	SEC.
'B' DIRECTION		
PROGRESSION SPEED	34.8	MPH.
BAND WIDTH	23.9	SEC.
EFFICIENCY	0.33	
ATTAINABILITY	0.93	

Figure 68. Optimal Progression Report from PASSER III

Frontage Road Progression Information

Additional internal phasing information, which is shown in Figure 67, is provided for the progression solution. The results are self explanatory. The phase orders and offsets will have been input by the user unless the delay-offset analysis was called for; but as noted earlier, it is strongly recommended that this analysis not be requested simultaneously with the progression analysis due to extreme computer run times.

FRONTAGE ROAD PROGRESSION INFORMATION

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

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

Figure 69. PASSER III Frontage Road Progression Information Report

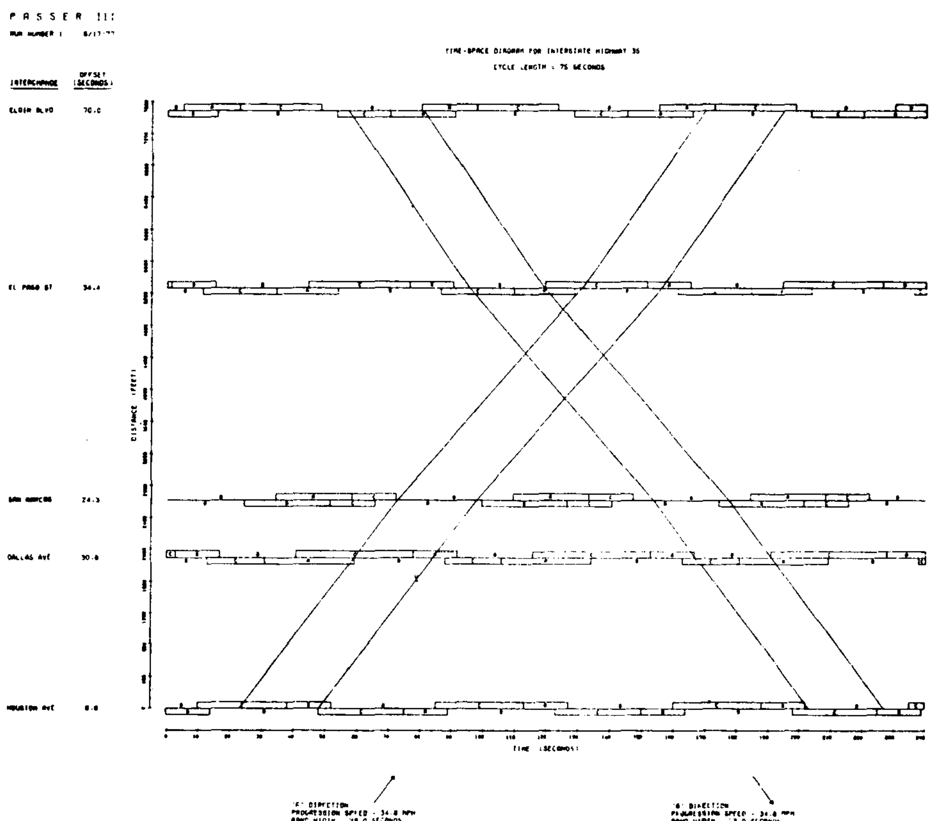


Figure 70. PASSER III Time Space Plot

Time-Space Plot

If requested, a printer or line terminal plot of the timespace diagram can be obtained. An example of a line plot is shown in Figure 70.

ADDITIONAL FEATURES

The two major options have already been mentioned: a) optimization of isolated interchanges and b) optimization of progression on parallel frontage roads.

In the isolated mode, PASSER III can analyze five phasing patterns, which were identified in Figure 61. The two most popular (but not necessarily always the "best") are the four-phase with two overlaps (Pattern 1A) and the three-phase "lag-lag" pattern (Pattern 4). This is because the interior of the interchange is always cleared in both directions after the ramp traffic has entered.

In the progressive mode the optimal cycle length is determined to maximize progression. Progression may be one-way or two-way with or without preference to one direction.

Output options include printer or line terminal plots of the time-space diagram of the progressive mode.

PASSER III can be used to evaluate alternative interchange improvements by simply changing the inputs to reflect proposed conditions, such as adding new lanes.

APPLICATIONS AND LIMITATIONS

When the isolated interchange mode is used, the results shown in Figures 64 thru 69 are output. For design purposes the interchange will operate optimally if the resulting offset is used for the particular cycle length and phase pattern specified. To examine alternative solutions, several runs may be made specifying different parameters. The "best" solution is that which results in the best overall value of the appropriate MOE, usually total delay. Other MOE's may be used to override a decision based on delay. For example, if there is a high probability that queues may not be cleared and the internal storage may be exceeded. Other improvements can be analyzed by altering inputs, such as adding lanes.

Although PASSER III is designed primarily to study fixed-time and fixed-sequence control, the delay-offset analysis can also be used to study various full-actuated phasings and to determine the effects of different interchange approach lane configurations, left turn configurations and U-turn lane provisions. Of course one must realize that such an analysis must be considered as an "average" operation.

Similarly, the progressive mode is used to design the optimal progression scheme on a system of interconnected interchanges with continuous frontage roads. In this case the optimal cycle length is computed by PASSER III, as are the offsets to obtain progression at a specified speeds (± 2 mph). Progression may be one-way or two-way depending on the input parameters. See Chapter 6 - PASSER II(80) for further discussion on the progressive mode.

As stated earlier, these two modes should not be run simultaneously, but this is not really a limitation because it is more practical to design the individual interchanges first, and "fine tune" them before proceeding to the progression design.

EXAMPLE PROBLEM

To illustrate the use of PASSER III model in the isolated mode an example problem was selected. The following paragraphs describe the problem and the results of using PASSER III.

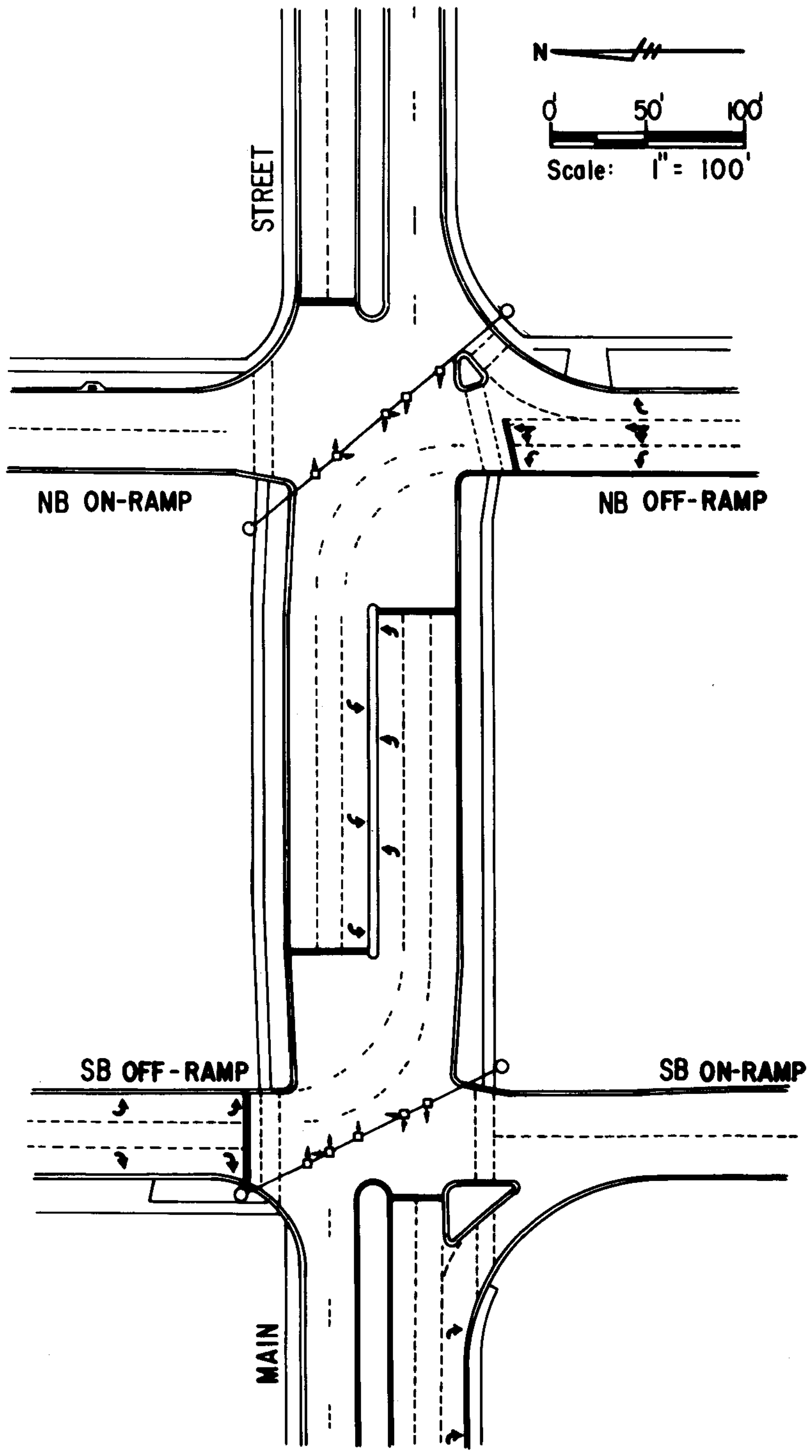


Figure 71. Diamond Interchange Example Problem

Problem Description

The diamond interchange shown on Figure 71 was used on an example problem. This interchange is located approximately two miles north of the Tampa CBD which has been used previously as example study sites.

This is a standard diamond interchange with the arterial providing a four-lane divided roadway within the interchange and having single left turn bays feeding the on-ramps to the freeway. The left turn bays are 150' long, having a nominal storage capacity of six vehicles. Right turns for northbound off-ramp and eastbound arterial are independant of signalization.

The existing signalization is presently a "lead-lead" operation similiar to Figure 62, with a six (6) second offset. Due to problems experienced previously, no permissive left turns from the arterial to the on-ramps are permitted.

Since the timing was orginally established several years ago, it is now desirable to determine if improved traffic flow can be obtained thru revised signal timing.

Analysis of Existing Conditions

With the PASSER III model it is possible to model existing conditions if signal timing is similar to one of the five phase sequences used by PASSER III. Since the operation at the example interchange meets this criteria, existing conditions were modeled.

To model existing conditions only the existing phase is coded with the offset used in the field. Minimum greens are coded to represent actual time for each phase.

The operating characteristics under existing conditions were obtained from this initial run. The results showed that Phase A (thru movements at both the signals) was inadequate to handle traffic and that unacceptable levels of services occurred, particularly for the westbound thru movement. Since this was confirmed by observation in the field, the model was accepted as calibrated. Figures 64 thru 67 previously used as illustrations showed the output from this condition.

Define and Analyze Alternatives

Each run of the model will evaluate each of the five possible phasing patterns for a specified cycle length and select the most optimal phasing and internal offset. Figure 70 shows the coding required to permit the model to select the optimal pattern for a sixty (60) second cycle. To define alternatives, it is only necessary to change the interchange header card to specify cycle length for each of the runs. For this problem, one run was made for each 10 second increment between 60 and 100 seconds. Figure 71 shows the report obtained for the input data shown on Figure 72. A similar report was obtained for the existing condition and the five cycle lengths evaluated.

Evaluation of Results

Table 18 provides a summary of the optimal results obtained for each of the alternative cycle lengths evaluated. The existing lead-lead phasing was the optimal phasing pattern for all alternatives except for the 50 second cycle. However, the 50 second cycle is not a valid alternative since the interchange became super-saturated.

As previously discussed the most meaningful measure of effectiveness is the total interchange delay. Alternative B (60 second cycle) results in the lowest total delay of 16.02 vehicle hours and represents a substantial reduction (40.6%) from existing operations. Alternative C (70 second cycle) is similar to Alternative B with 16.76 vehicle hours of delay. The criterial movement for both of these alernatives is the right side Phase C. During this phase all left turns cannot clear the interchange and frequently 3 or 4 vehicles will have to remain in the left turn storage lane between the signals. Although this queue does not affect through movements it does increase the average delay to these left turning vehicles.

It would at first appear that using Alternate C (70 seconds) the delay for these vehicles

PASSER III(1): #2
INTERCHANGE OR FREEWAY: I-75 & Buffalo CITY Tampa, Fla
CONDITION: Optimal 60 sec cycle

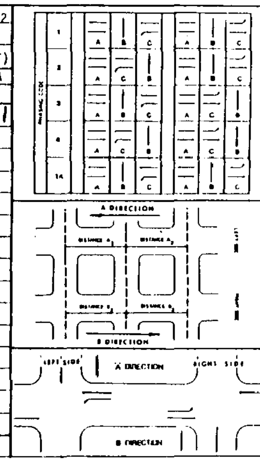
PAGE 1 OF 2
DATE 5/13/81
CODED BY: ASB

FREEWAY HEADER CARD (ONE PER FREEWAY)

NAME OF CITY	NAME OF FREEWAY	DIST. NO.	DATE MO	DATE DA	DATE YR	RUN NO.	NO. INTC.	ISOL?	PROG?	CYCLE LNTH MIN	CYCLE LNTH MAX	STEP SIZE	'B' BAND SPLIT	VAR SPD	P-PLOT	L-PLOT	X-SCALE (SEC/IN)	Y-SCALE (ft/in)	ISOL?
3A4	6A4	I2	3I2			I2	I2	I	I	2I3		I2	I2	I	I	I	I2	I4	I2
TAMPA	I-75 OPTIMAL TIMING PM	1	5	14	81	2	1	1											

INTERCHANGE HEADER CARDS (ONE PER INTERCHANGE)

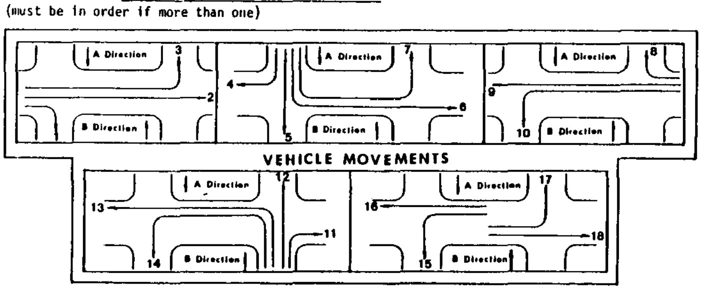
X-STREET NAME	INTC. NO.	CYCLE LNTH	DELAY-OFFSET? 1 2 3 4 1A	* PLT? L R	INT. TRAV TIME L-R R-L	INT. QUE. STOR. R-SIDE T L	INT. QUE. STOR. L-SIDE T L	'A' DIRECT. DIST	'A' DIRECT. SPD	'B' DIRECT. DIST	'B' DIRECT. SPD	Q-CLEAR 'A' 'B'	INT. PHASING? (OFFSET) 1 2 3 4 1A
3A4	I2	I3	5I1	2I1	2I2	4I2		F4.0	F2.0	F4.0	F2.0	2I2	5I2
BUFFALO	1	60	1 1 1 1 1		1 1 1 2	8 6	8 6						-1 -1 -1 -1 -1

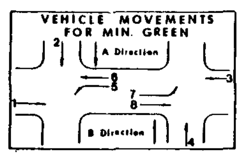


* PLT= Permissive Left Turns Left and Right sides

PASSER III (2): #2
INTERCHANGE(S): I-75 & Buffalo
(must be in order if more than one)

PAGE 2 OF 2





INTERCHANGE DATA CARDS (THREE PER INTERCHANGE)

MOVEMENTS (SEE DIAGRAM)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	18F4.0																	
VOLUME	0	628	336	220	10	161	0	185	526	245	0	45	376	0	245	902	336	789
NO. LANES	0	1.30	0.70	1.00	0.12	1.88	0	9.39	1.90	0.51	0	0.21	1.79	0	1.00	2.00	1.00	2.00
MIN. GRN.	10	18	10	18	10	10	10	10										
VOLUME																		
NO. LANES																		
MIN. GRN.																		
VOLUME																		
NO. LANES																		
MIN. GRN.																		

Figure 72. PASSER III Coded Input Data for 60 Second Cycle at I-275 Interchange into Buffalo Ave.

```
RUN NUMBER  2                                                DATE  5/14/81
I-75 OPTIMAL TIMING PM            TAMPA                      DISTRICT  1

OPTIONS -
   CALCULATE GREEN SPLITS AND MEASURES OF EFFECTIVENESS --------     YES
   USE DELAY-OFFSET EVALUATION TECHNIQUE -----------------------     YES
   DETERMINE OPTIMAL PROGRESSION SOLUTION ----------------------      NO
   SEARCH FOR OPTIMAL SOLUTION BY VARYING LINK SPEEDS ----------      NO
   PRINT OPTIMAL TIME-SPACE PROGRESSION DIAGRAM ----------------      NO
   PLOT OPTIMAL TIME-SPACE PROGRESSION DIAGRAM -----------------      NO
PARAMETERS - (ISOLATED INTERCHANGE ANALYSIS)
   DESIRED CYCLE LENGTH --------------------------------------- 60 SECONDS
PARAMETERS - (FRONTAGE ROAD PROGRESSION ANALYSIS)
   NUMBER OF INTERCHANGES --------------------------------------  1
   LOWER CYCLE LENGTH LIMIT ------------------------------------  0 SECONDS
   UPPER CYCLE LENGTH LIMIT ------------------------------------  0 SECONDS
   CYCLE LENGTH INCREMENT --------------------------------------  0 SECONDS
   MINIMUM 'B' DIRECTION BAND SPLIT ----------------------------    NONE
```

INTERCHANGE INPUT DATA

```
                  *          DISTANCE          *     PROGRESSION SPEED      *        QUEUE CLEARANCE
INTERCHANGE  1    *                            *                            *
 BUFFALO          *  FROM  1 TO  2 ---   0 FT. *  FROM  1 TO  2 ----  0 MPH. *  'A' DIRECTION -----  0 SEC.
                  *  FROM  2 TO  1 ---   0 FT. *  FROM  2 TO  1 ----  0 MPH. *  'B' DIRECTION -----  0 SEC.

         RUN DELAY-OFFSET ANALYSIS?               *           PERMISSIVE LEFT TURNS ALLOWED?

                                                  *  AT LEFT SIDE INTERSECTION ---------------------------  NO
CODE 1  OR LEAD-LEAD --------------------- YES    *  AT RIGHT SIDE INTERSECTION --------------------------  NO
CODE 2  OR LAG-LEAD ---------------------- YES    *
CODE 3  OR LEAD-LAG ---------------------- YES    *                 INTERIOR TRAVEL TIME
CODE 4  OR LAG-LAG ----------------------- YES    *
CODE 1A OR TTI 4-PHASE ------------------- YES    *  FROM LEFT TO RIGHT ACROSS THE INTERCHANGE ------- 11 SEC.
                                                  *  FROM RIGHT TO LEFT ACROSS THE INTERCHANGE ------- 12 SEC.
      PRIORITY PHASINGS / INTERNAL OFFSET         *
                                                  *                 INTERIOR QUEUE STORAGE

CODE 4  OR LAG-LAG ------------      NONE         *  THROUGH MOVEMENT AT RIGHT SIDE INTERSECTION -----  8 VEH.
CODE 3  OR LEAD-LAG -----------      NONE         *  LEFT TURN MOVEMENT AT RIGHT SIDE INTERSECTION ---  6 VEH.
CODE 2  OR LAG-LEAD -----------      NONE         *  THROUGH MOVEMENT AT LEFT SIDE INTERSECTION ------  8 VEH.
CODE 1  OR LEAD-LEAD ----------      NONE         *  LEFT TURN MOVEMENT AT LEFT SIDE INTERSECTION ----  6 VEH.

   MOVEMENTS     *   1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16   17   18

    VOLUMES      *    0  628  336  220   10  161    0  125  526  245    0   45  376    0  245  902  336  789
NUMBER OF LANES  * 0.0  1.30 0.70 1.00 0.12 1.88 0.0  0.39 1.00 0.51 0.0  0.21 1.79 0.0  1.00 2.00 1.00 2.00
 MINIMUM GREEN   *   10   18   10   18   10   10   10   10
```

Figure 73. PASSER III Output Report for 60 Second Cycle length at I-275 Interchange with Buffalo Ave.

GENERAL SIGNALIZATION INFORMATION

I-75 OPTIMAL TIMING PM AT BUFFALO RUN NO. 2 5/14/81

MEASURES OF EFFECTIVENESS	LEFT SIDE A	LEFT SIDE B	LEFT SIDE C	LEFT SIDE D	RIGHT SIDE A	RIGHT SIDE B	RIGHT SIDE C	RIGHT SIDE D
GREEN TIME (SEC.)	26.7	18.0	15.3	42.0	24.9	18.0	17.1	42.0
VOLUME/CAPACITY RATIO, X	0.71	0.52	0.72	0.40	0.84	0.51	0.85	0.35
LEVEL OF SERVICE	C	A	C	A	D	A	E	A
DELAY (SEC./VEH.)	17.44	19.38	30.84	5.85	19.63	20.93	41.92	5.55
LEVEL OF SERVICE	B	B	C	A	B	B	C	A
PROBABILITY OF CLEARING QUEUE	0.89	0.98			0.62	0.98		
LEVEL OF SERVICE	C	A			D	A		
STORAGE RATIO			0.42	0.19			0.56	0.14

PHASE ORDER - ABC/ABC
INTERNAL OFFSET - 12 SECONDS
TOTAL INTERCHANGE DELAY - 16.02 VEHICLE-HOURS PER HOUR

PHASE INTERVALS

I-75 OPTIMAL TIMING PM AT BUFFALO RUN NO. 2 5/14/81

PHASE INTERVAL NUMBER	LEFT SIDE STATUS	RIGHT SIDE STATUS	PHASE INTERVAL LENGTH(SEC.)
1	A	B	12.0
2	A	C	14.7
3	B	C	2.4
4	B	A	15.6
5	C	A	9.3
6	C	B	6.0

PHASE ORDER - ABC/ABC
INTERNAL OFFSET - 12 SECONDS

Figure 73. PASSER III Output Report for 60 Second Cycle length at I-275 Interchange with Buffalo Ave. (Continued)

Table 18 - Comparison of PASSER III Alternatives

Alternate	Cycle Length	Phase Pattern	Internal Offsets	Total Delay (Veh. Hrs)	Critical Movement Phase	V/C Ratio	Delay (sec per hr)
Existing	90	lead lead	6	26.98	A(Rt.)	1.05	(Super saturated)
A	50	lead lead	36		(INTERCHANGE SUPER SATURATED)		
B	60	lead lead	12	16.02	C(Rt.)	.85	41.92
C	70	lead lead	13	16.76	C(Rt.)	.77	32.76
D	80	lead lead	14	18.67	C(Rt.)	.71	31.94
E	90	lead lead	9	20.72	B(Rt.)	.77	40.56
F	100	lead lead	9	22.78	B(Rt.)	.78	45.57

would be reduced with little increase in total delay. However, as previously pointed out, the estimate of delay for the separate phases did not vary with offset, therefore, these figures should not be used except as a general order of magnitude.

Based upon the results of these alternatives it could appear substantial improvement in traffic flow can be obtained by reducing the cycle length. Additional runs for 60 to 80 seconds using a 10 or 11 second internal off-set with overlap values may result in further improvements.

Summary of Work Effort Required

The following paragraphs summarize the work effort required for the example problem.

Data Collection - All data required were readily available from the traffic engineering office. This included a 1" = 20' scale geometric plan of the interchange, recent turning movement counts and existing signal timing.

Data Coding - With the information on hand little time was required to code the data necessary to run the model. Coding is straightforward except for internal travel time. However, guidelines are available in table form in the User's Manual. A little over one hour was required to code the initial runs (existing and optimal runs).

Computer Requirements - The time required to run existing conditions was .33 second of CPU while the optimization runs required .68 second for the 60 second cycle to 1.45 seconds for the 100 second cycle. All the runs required 150 K of storage for the IBM 370.

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CHAPTER 8 - SUB (ARTERIAL BUS SIMULATION MODEL)

The evaluation of traffic operations on urban arterial highways is the subject of a number of computer models described in this Handbook. Traffic flow is simulated (e.g., analyzed) according to a variety of techniques and acceptable results may be obtained from several models, depending upon the analyst's specific interests.

One facet of urban traffic which is not expressly considered in most traffic operations models is bus traffic, either as to how buses operate under various transit management strategies, or the effect of general traffic on bus operations. In some urban areas, buses constitute a major part of the traffic demand. Even more significantly, buses may carry over 70% of the urban vehicular passengers in larger metropolitan areas.

Figure 74. Urban Bus Stop

Urban arterials serve the dual purpose of providing a relatively efficient route for the movement of traffic, as well as servicing the abutting land. In the case of general (primarily automobile) traffic, this is accomplished by appropriate geometrics and traffic controls which enable the smooth flow of through traffic and access/egress to adjacent properties and cross streets.

In the case of buses, the efficient flow is an important concern, but of equal concern is the efficient servicing of the abutting properties to board and discharge passengers. The necessity of buses to make (largely scheduled) stops at designated bus stops may - depending on the type, location and duration of stops-cause perturbations in the traffic stream. Likewise, general traffic may interfere with the movement of the buses, causing delays or extending scheduled travel times.

The analysis of bus-related traffic management strategies is clearly a significant need, for both the traffic engineer and the transit operator. Few existing models adequately address this aspect. In Washington, D.C., the need to consider bus impacts was recognized and some facilities for analyzing bus flow were incorporated into the Urban Traffic Control System (UTCS-1, later NETSIM, see Chapter 11). These facilities were minimal, however, and detailed analysis of some of the bus-related characteristics noted above could not be adequately addressed.

In order to provide transit operators with a tool for evaluating bus operations along an arterial, and the effect of various bus stop strategies on their performance, the SUB model developed by FHWA has been included in this Handbook and is the subject of this chapter.

MODEL DESCRIPTION

SUB is an acronym for Simulation of Urban Buses. The program is written in FORTRAN IV and contains nine modules with a total length of approximately 1300 FORTRAN statements, plus comments. The program requires only about 90k of core, thus, should run on most IBM OS/360 or higher computers. Efficiency is high, although run time varies with the specific simulation requirements. Time compression of up to 50 time units of simulated time per unit of computer time may be realized.

The simulation model treats buses and general traffic differently. Bus traffic is analyzed by a microscopic, deterministic and stochastic simulation submodel with event scan updating. That is, all events are calculated and projected ahead and updates are made only upon occurrence of the projected events (e.g., bus travel from point to point, stop, depart, etc.).

Automobile traffic, on the other hand, is processed by a macroscopic, deterministic simulation submodel with periodic time scan updating. Input volumes are the only random element in this submodel. Traffic is treated as homogeneous groups or platoons on each block and these are propagated along the route according to common analytical expressions, subject to control status, and turning movements.

Only one direction of travel is simulated; however, the effect of opposing traffic on left-turns is considered. Traffic signal control is considered simplistically by a two-phase (for the single approach to each intersection) operation, namely green or not green.

The arterial model analyzed by SUB involves two-lanes of arterial highway, broken into separate links (by block) with either signal or stop/ yield sign control at the nodes.

A number of bus-related strategies are available to minimize the mutual interference of buses and general traffic, such as location of stops (e.g., far-side vs. near-side), type of stop (e.g., pull-outs vs. on-street bus stops) and restricted lanes for buses.

Inputs to SUB include the geometric and traffic control characteristics of the study section, traffic volumes and turning movements, bus routes and schedules, bus stops, passenger demands and other bus-related data.

Outputs are measures of effectiveness of bus operations, such as bus travel times, passenger waiting times and bus dwell times. MOE on general traffic are not produced, however.

INPUT REQUIREMENTS

There are four basic types of input data required by SUB. These are arterial descriptors, bus data, traffic data and other exogeneous data, such as parameters and standard values.

Additionally, there are certain embedded data which are automatically used by the program. These latter include the following, which may be changed by the user to reflect local characteristics by changing the appropriate "DATA" statements and recompiling the program:

- o Minimum acceptable gap for bus driver to change lanes
- o Bus driver reaction time
- o Factors representing the variability of passenger and bus arrivals, bus passenger service time and bus speed.

The data input by the user are contained on 14 types of cards, which are described in Table 19. A typical data deck stack is shown in Figure 75.

The inputs are mostly self-explanatory, with several exceptions, which are discussed briefly below. However, it should be noted that extreme care must be utilized in coding and keypunching the data. There is no edit routine to check the number of cards or validity of the cards. The program simply

Table 19 - Input Requirements for SUB

CARD TYPE	CARD DESCRIPTION	REQUIREMENTS
TITLE (1 per run)	Provides Title for Simulation Run	Arbitrary Information
SIMULATION CONTROL (1 per run)	Define parameters to control the simulation	Seed for random number, number of links, simulation time, number of time periods, time scan interval and clock time
TRAFFIC PARAMETER (1 per run)	Define traffic parameters which are constant for entire run	Headways, vehicle & bus lengths and bus operational characteristics (acceleration & deceleration rates, cruise speed and average "lateness" of bus arrival)
PASSENGER SERVICE TIME (1 per run)	Defines the time require to service passenger	Service time, load time, unload time and interaction time between loading passengers
TRAFFIC DEMAND (1 per run)	Define the traffic volumes (excluding buses)	Vehicles per hour entering first link for each simulation period (max. 13 periods)
BUS ROUTE (1 per run)	Defines bus routes and number of buses on each route	Number of bus routes and number of buses on each route (max. 18 routes)
LINK (1 per link)	Define bus stop characteristics of each link of arterial	Link length, number and type of bus stop, distance to stop line and capacity of bus stop
BUS ARRIVAL (1 per route)	Define bus arrival times	Scheduled time of day at entry link of each bus
COMMON DEMAND (1 per route)	Define common loading, and unloading demand between bus routes	Routes with shared ridership and proportion of demand
SIGNAL (1 per link per period)	Define arterial signal timing for each study period	Cycle length, green interval, lead time (if appropriate) and offset
SPEED & VOLUME (1 per link per period)	Define traffic speeds and distribution of volumes for each study period	Average free speed and lane distribution of thru traffic as well as turning volumes
PASSENGER DEMAND (1 per stop per period)	Define passenger demand at each bus stop for each period	Number of passengers loading and unloading by route
PASSENGER LOAD (1 per period)	Define expected passenger load for buses of each route	Number of passengers aboard buses of each route at entry link
PASSENGER CAPACITY (1 per period)	Define bus capacity for each period	Maximum number of passengers per bus by route

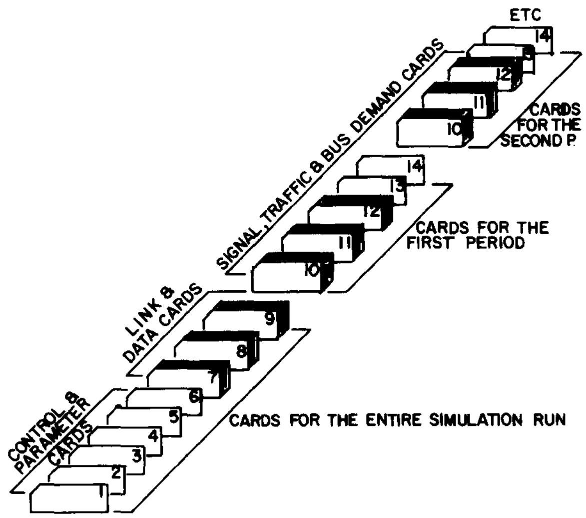

Figure 75. SUB Data Deck

reads in the data and attempts to execute the data. If any error exists considerable computer time can be wasted.

All input volumes are indicated for the entry link only. Thereafter, flows are adjusted by adding or subtracting traffic on each link by turns onto the link and cars leaving parking and/or turns from the artery or parking, respectively.

Different simulation periods should be input to reflect changing conditions, such as traffic control, vehicular or passenger demand, and bus schedule changes.

One of the more confusing aspects of the inputs is the common demand among routes. Often more than one route may serve a passenger for his trip. Thus, passengers may have some choice as to which route to use on the facility being simulated. For example, route 1 may expect to load 200 passengers in the section of interest, while route 2 expects to load 100. If 20 of these may use either route, the common loading is 0.1 (20/200) between routes 1 and 2 and 0.2 (20/100) between routes 2 and 1. For the two individual routes, "common" loadings are 0.9 (180/200) for route 1 and 0.8 (80/100) for route 2. Unloadings are calculated similarly. This facility allows for diversion to other routes when bus capacities are threatened. Exact measures of these factors are virtually impossible to obtain; however, the model developers suggest that estimates are better than ignoring the common demand.

Finally, inputs for traffic signal control assume fixed-timed, single through phase, coordinated control. If the study section has actuated controllers, "average" values for cycle length and green intervals should be input. If the system is not coordinated for progession, offsets should be entered which approximate the random variation in the start time of the cycle. Since uncoordinated fixed-time signals will operate with reasonable stability for short periods of time, this is not an unreasonable assumption. For most accurate results, however, these "offsets" should be determined by field measurements.

OPERATIONAL SUMMARY

As noted previously, there are two separate simulation submodels in the SUB program, but there are certain common operational characteristics and interactions between the simulation submodels. The logical operation is described briefly in the following subsections. Figure 76 gives an overview of the model operation.

Initialization and Inputs

The initial period of simulation is the "priming" period, during which the system is loaded with traffic and buses. Data gathered during this period is not meaningful.

Inputs to the system occur on Link 1, which is the entry link to the system in the direc-

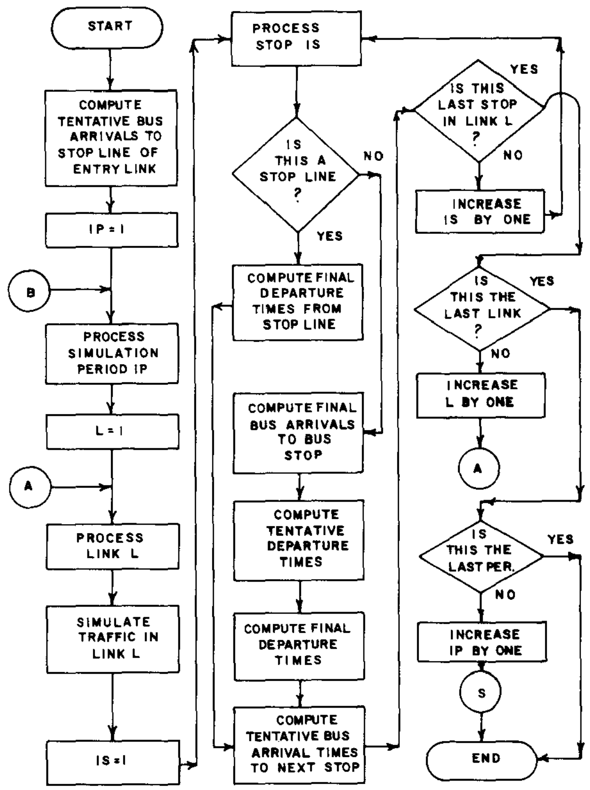

Figure 76. General Logic Flow for SUB Model

tion of travel being simulated. These inputs (both buses and general traffic) are propograted downstream by their respective simulator with traffic demands varying according to turns onto and from the artery. MOE's calculated for the entry link are also meaningless.

Macroscopic Traffic Simulator

Traffic operations are updated at fixed-time intervals (from 5 to 15 seconds) on each link, beginning with the entry link. Random arrivals are generated using the Poisson distribution to simulate the number of new arrivals in each period. Depending on the type of control, and control status, the new arrivals are either added to a queue or discharged to the next link. Subsequent links are treated similarly, but with the upstream inputs adjusted by randomly generated arrivals from side streets or midblock locations, or departures to side streets or parking. Each platoon is propogated to the tail of the next successive link.

When a queue of stopped vehicles is set in motion, the discharge time of each vehicle is considered, but in terms of the number of vehicles discharged during the time interval. Link travel times in motion are assumed to be constant for each link.

Traffic is regulated at each node according to the type of control. If the signal is green, or if the intersection is sign controlled (on the cross street), arterial traffic advances, with two constraints:

1. If there exists a queue, traffic moving downstream joins the queue and is discharged later.
2. If vehicles turn left, they must wait for suitable gaps in the opposing traffic stream.

This procedure is done for the entire length of a simulation period, by link, by time step. At each time step, the link occupancy (vehicles/link), queue length in each lane and number of vehicles discharged to the next link (by lane) are calculated for each link and stored for interfacing with the bus model.

Microscopic Bus Simulator

The bus simulator is entered for each link for each simulation period. The traffic simulation will have been completed for the entire period at this point. Now an event scan simulation is used. For each bus, several event times are recorded, namely the arrivals at stop lines and bus stops, departures from these and completion of a passenger service operation. Each bus has an "ID" number to key to its statistics and a sequence number which indicates its relative position in the bus stream at any given time.

Bus arrivals are initially input at times dictated by the scheduled arrival time, modified by a stochastic process to reflect variations in arrivals. Buses are then propogated link by link as follows:

1. A tentative arrival time is estimated for each stop on the link, based on its departure time from the upstream link.

2. Intra-link travel is based on a deterministic traffic flow rule (discussed in the next section).

3. At the "tentative" arrival time at a bus stop, the conditions are checked to see if the bus can "reach" the stop (e.g., is the stop blocked by other buses or a traffic queue?). Only other buses can block a protected bus stop. Once the obstruction clears, the "final" arrival time is set.

4. Passenger service time is based on loading and off-loading demands and the "tentative" departure times is calculated.

5. If a bus is blocked from leaving the stop (e.g., another bus with a longer passenger service time), a pass is attempted, which depends on the availability of a gap in the adjacent traffic stream. If a pass occurs, the sequence numbers of the buses are switched. If a pass cannot occur, the "final" departure time is set to the departure time of the preceeding bus, plus driver reaction time.

6. At stop lines, the conditions are checked at the "tentative" arrival time. Depending on the signal-sequence status, buses may "depart" at that time or be delayed. Final arrival and departure times are calculated accordingly.

This process is repeated, as appropriate, for each stop on each link for the current simulated period.

COMPUTATIONAL ALGORITHMS

There are three computational algorithms of interest in the SUB model. These are the traffic flow, bus flow and passenger service models.

The traffic flow model is quite simple. Groups of passenger cars are propagated at constant speed if not queued. If entering a queue, the traffic is assumed to join the queue instantaneously (since delays are not calculated). The queue length varies according to the number of arrivals and departures. Discharges are also calculated simply. At the start of green at a signal, the number of initial departures are based on the input discharge headways. At each time step, so many vehicles are released, until the queue has dissipated. From this point stop line departures equal arrivals.

The bus travel model is somewhat more sophisticated. All buses have their "tentative" travel times from stop to stop estimated by an acceleration-cruise-deceleration model. The variables that control this cycle are distance and cruise speed. The latter is determined to be the lesser of the desired bus cruise speed or the speed of traffic. If traffic density exceeds a threshold value, the bus speed will be reduced proportionately to the degree of excess density. Once the cruise speed is determined (for individual buses), the "delays" due to acceleration and deceleration are determined and the projected travel times is summed. Bus travel times are given a random variation by the model. "Tentative" arrival times mentioned above are thus calculated. Finally, the bus passenger service time (BPST) is based on the following relationship:

$$BPST = RT + (LIT \times PL) + (UIT \times PU) - (ILU \times PL \times PU) \qquad (8.1)$$

where RT = residual (lost) time for servicing passengers

LIT = incremental time for loading one passenger

PL = passengers loaded

UIT = incremental time for unloading one passenger

PU = passengers unloaded

ILU = interaction between loading and unloading

As in the case of most simulation models, the main complexity of SUB is the logical decision-making which occurs at each time interval (for the macroscopic simulation) or event (for the microscopic simulation).

The recursive technique used in SUB perhaps loses some accuracy, but is highly efficient from the computational size and time perspectives.

OUTPUT REPORTS

The SUB model produces three basic types of output reports. These are discussed separately below.

Input Data Reports

The program gives a listing of the input data in two formatted reports. The first is a summary of input data for the entire simulation run: then, prior to the results of each simulation period, a second report shows the data peculiar to that time period. Samples of these reports are shown in Figure 77.

ORIGIN OF RANDOM NUMBERS :251671 - PROCESSING INTERVAL : 10

QUEUE DISCHARGE HEADWAYS = 5.3 4.0 3.2 2.7 2.5 2.4

CAR LENGTH = 22. FT BUS LENGTH = 45. FT. BUS TRAF. FACTOR = 2.0
BUS ACCELERATION = 2.2 MPH/SEC - BUS DECELERATION = 3.0 MPH/SEC
BUS CRUISING SPEED = 20. MPH - AVERAGE BUS DELAY = 90 SEC

SERVICE TIME IN SEC = 4.50 + 2.70 PL + 1.00 PU - 0.05 PL.PU + DEV.

TRAFFIC DEMANDS, VPH :
868 960 1188 984

LINK NO.	LENGTH FEET	BUS STOP NO. 1 DIST FEET	BUS STOP NO. 1 CAP BUS	BUS STOP NO. 1 TYPE	BUS STOP NO. 2 DIST FEET	BUS STOP NO. 2 CAP BUS	BUS STOP NO. 2 TYPE	BUS STOP NO. 3 DIST FEET	BUS STOP NO. 3 CAP BUS	BUS STOP NO. 3 TYPE
1	291.	0.	0	0						
2	292.	292.	2	0						
3	292.	292.	2	0						
4	237.	237.	2	0						
5	348.	348.	2	0						
6	284.	284.	2	0						

EXPECTED BUS ARRIVALS TO FIRST STOP LINE IN HOURS & MINUTES

ROUTE	ARRIVALS :
1	1635 1645 1655 1705 1715 1725
2	1635 1650 1705 1720
3	1630 1642 1654 1706 1718
4	1630 1645 1700 1715

PERCENT OF BUS COMMON PASSENGER DEMAND

BETWEEN ROUTE 1
AND ROUTES : 1 3
COMMON LOADING 80 20
COMMON UNLOAD. 80 20

BETWEEN ROUTE 2
AND ROUTES : 2 4
COMMON LOADING 50 50
COMMON UNLOAD. 50 50

BETWEEN ROUTE 3
AND ROUTES : 1 3
COMMON LOADING 70 30
COMMON UNLOAD. 70 30

BETWEEN ROUTE 4
AND ROUTES : 2 4
COMMON LOADING 50 50
COMMON UNLOAD. 50 50

-------- FOR SIMULATION PERIOD 1 - FROM 16:30 TO 16:45 --------

TRAFFIC SIGNALS SETTING IN SECONDS

LINK NUMBER	CYCLE LENGTH	GREEN PHASE	ADVANCED GREEN	OFFSET
1	90	47	0	40
2	90	52	0	41
3	90	63	0	39
4	90	48	10	59
5	90	64	0	63
6	90	48	0	52

TRAFFIC SPEEDS AND VOLUMES

LINK NUMB	SPEED MPH	VOLUME FROM SIDE ST VPH LEFT	VOLUME FROM SIDE ST VPH RIGHT	OPPOS. VOLUME VPH	MDBLCK DEMAND VPH	TURNING PROBABILITY LEFT	TURNING PROBABILITY RIGHT	LANE DISTRIBUTION ONE	LANE DISTRIBUTION TWO
1	25.	148	0	1058	0	0.0	0.37	0.53	0.47
2	25.	0	200	926	0	0.0	0.0	0.65	0.35
3	25.	0	0	1041	0	0.0	0.50	0.63	0.37
4	25.	0	108	992	0	0.0	0.0	0.77	0.23
5	25.	0	0	931	0	0.0	1.00	0.79	0.21
6	25.	0	165	1029	0	0.0	0.0	0.99	0.01

BUS PASSENGER DEMAND

BUS STP	ROUTE 1 PL	ROUTE 1 PU	ROUTE 2 PL	ROUTE 2 PU	ROUTE 3 PL	ROUTE 3 PU	ROUTE 4 PL	ROUTE 4 PU	ROUTE PL	ROUTE PU	PL	PU
2	6	1	-1	0	-1	0	-1	0				
4	2	0	3	1	2	0	4	0				
6	8	2	6	1	4	0	8	1				
8	4	1	3	0	2	0	5	1				
10	6	2	5	0	6	1	8	1				

BUS PASSENGER LOAD AND CAPACITY

ROUTE	LOAD	CAPACITY
1	20	65
2	26	65
3	24	65
4	18	65

Figure 77. SUB Summary of Input Data Report

BUS STATISTICS

BUS NUMBER :	1	2	3	4	5	6	7
ROUTE NO. :	4	3	1	2	3	1	4
-LINK NUMBER 1							
STOP LINE							
ARRIVAL TIME	16:31	16:33	16:36	16:37	16:43	0: 0	0: 0
DEPARTURE TIME	16:31	16:33	16:36	16:37	16:43	0: 0	0: 0
-LINK NUMBER 2							
BUS STOP NO. 1							
ARRIVAL TIME	16:32	16:33	16:36	16:37	16:43	0: 0	0: 0
PASS. LOADED	0	0	3	0	0	0	0
PASS. UNLOADED	0	0	0	0	0	0	0
SERVICE TIME, SEC	0	0	6	0	0	0	0
DEPARTURE TIME	16:32	16:33	16:36	16:37	16:43	0: 0	0: 0
STOP LINE							
ARRIVAL TIME	16:32	16:33	16:36	16:37	16:43	0: 0	0: 0
DEPARTURE TIME	16:32	16:33	16:37	16:37	16:43	0: 0	0: 0
-LINK NUMBER 3							
BUS STOP NO. 1							
ARRIVAL TIME	16:32	16:33	16:37	16:37	16:44	0: 0	0: 0
PASS. LOADED	0	0	1	2	2	0	0
PASS. UNLOADED	0	0	0	0	0	0	0
SERVICE TIME, SEC	0	0	3	9	7	0	0
DEPARTURE TIME	16:32	16:33	16:37	16:37	16:44	0: 0	0: 0
STOP LINE							
ARRIVAL TIME	16:32	16:33	16:37	16:37	16:44	0: 0	0: 0
DEPARTURE TIME	16:32	16:33	16:37	16:37	16:44	0: 0	0: 0
-LINK NUMBER 4							
BUS STOP NO. 1							
ARRIVAL TIME	16:32	16:33	16:37	16:38	16:44	0: 0	0: 0
PASS. LOADED	0	1	3	3	4	0	0
PASS. UNLOADED	0	0	1	0	1	0	0
SERVICE TIME, SEC	0	6	16	10	12	0	0
DEPARTURE TIME	16:32	16:33	16:37	16:38	16:44	0: 0	0: 0
STOP LINE							
ARRIVAL TIME	16:32	16:33	16:37	16:38	16:44	0: 0	0: 0
DEPARTURE TIME	16:32	16:33	16:37	16:38	16:44	0: 0	0: 0

Figure 78. Bus Itinerary and Summary Statistics Report

Bus Itinerary and Summary Statistics

The first of the reports on the results of the simulation run is the bus itinerary and summary statistics report, shown in Figure 78. The arrival and departure times of each bus at each bus stop is shown, along with the passenger loading/unloading and the passenger service time. These are reported by link and for the entire section. Additionally, the average overall speed is shown for the entire section. This report is issued for each simulation time period.

ROUTE STATISTICS

ROUTE NUMBER	1	2	3	4
TOTAL P. LOADED	10	11	14	0
TOTAL P. UNLOADED	2	0	2	0
TOTAL S. TIME, MIN	47	43	62	0
MEAN SPEED, MPH	8.4	13.0	15.0	15.0
P. WAIT. TIME, MIN	87	70	0	128
MEAN P W TIME, MIN	8.7	6.4	0.0	0.0

SUMMARY STATISTICS

TOTAL PASSENGERS LOADED =	35	TOTAL PASSENGERS UNLOADED =	4
TOTAL SERVICE TIME, MIN =	152	MEAN OVERALL BUS SPEED, MPH=	13.3
PASS WAITING TIME, MIN =	285	MEAN PASS. WAIT. TIME, MIN =	8.1

Figure 79. Route Statistics and Summary Report

Route Statistics and Summary Statistics

Finally, at the conclusion of the simulation run, the loading/unloading, service times, mean speed and total and average passenger waiting time are reported by route, and for the entire run. An example of this report is shown in Figure 79. The regularity of bus arrivals at stops, mean speed and passenger waiting time are the significant MOE for the system simulated.

ADDITIONAL FEATURES

The "standard" analysis options available in the SUB model enable the analyst to consider the following design characteristics:

- o Changes in types of buses
- o Locations of bus stops
- o Type of bus stops
- o Route and schedule changes
- o Changes in passenger or vehicle demand
- o Changes in fare collection techniques

By proper manipulation of input data, these additional traffic management strategies may be studied.

- o Restricted lane for buses
- o Coordination of traffic signals to favor passage of buses at signalized intersections

Finally, it is possible to represent buses that enter and/or exit the arterial at intermediate points within the study section. This is done by treating them as part of the general traffic on the links in which they do not actually travel.

The SUB model only analyzes. No design is "recommended" by the model; however, by making successive runs with varied control conditions, the user can evaluate the alternative strategies and by comparison of the results simulated, select the "best" solution.

APPLICATIONS AND LIMITATIONS

The SUB model is designed to analyze bus operations on signalized arterial streets. Considered are the impacts of bus stop strategies and the affect of general traffic on bus operations. The reverse, or the impact of buses on general traffic is not considered, mainly because other models can already perform this function. NETSIM (Chapter 11) is the prime example of this capability.

The limitation of two lanes in SUB is, in reality, not a serious limitation. Most buses normally use the curb lane, in order to service stops, or the adjacent lane, to pass. Since total traffic impacts are not assessed, it is only necessary to deal with these two lanes. If a system actually has more lanes and/or left-turn bays, it can be modeled by simply omitting the traffic that will not impact on bus operations.

The treatment of traffic signals is somewhat simplistic in SUB. The binary control function, green or not green, limits the study of traffic signal strategies somewhat. Also, in this regard, bus preemption is becoming an increasingly considered method of improving bus operations. This type of control cannot be simulated by SUB.

The limitations notwithstanding, SUB is a unique model in the traffic engineer's arsenal of traffic operations models. It is also a valuable tool for the transit operator and can be used by both the traffic agency and the operator to evaluate improved traffic/transit management strategies.

EXAMPLE APPLICATION

An example problem was developed to illustrate the use of SUB to evaluate alternative bus stop locations and design. The example is based upon the same arterial street used previously for illustrative purposes. The following paragraphs describe the use of SUB for this model.

Problem Description

Ashley Drive is the major arterial route serving the downtown area. At the present time four bus routes are served by this facility with a maximum hourly volume of 19 buses per hour for all routes. None of the buses now stop and pick up passengers on Ashley Drive. However, there is some consideration of the need of adding bus stops to serve the adjacent office buildings as well as a multipurpose center on the west side of the street which is frequently used during the daytime for convention and industrial shows.

The purpose of this example problem is to evaluate the use of nearside unprotected bus stops at each street, which the driver and transit company prefers, or to install two protected midblock bus stops as desired by

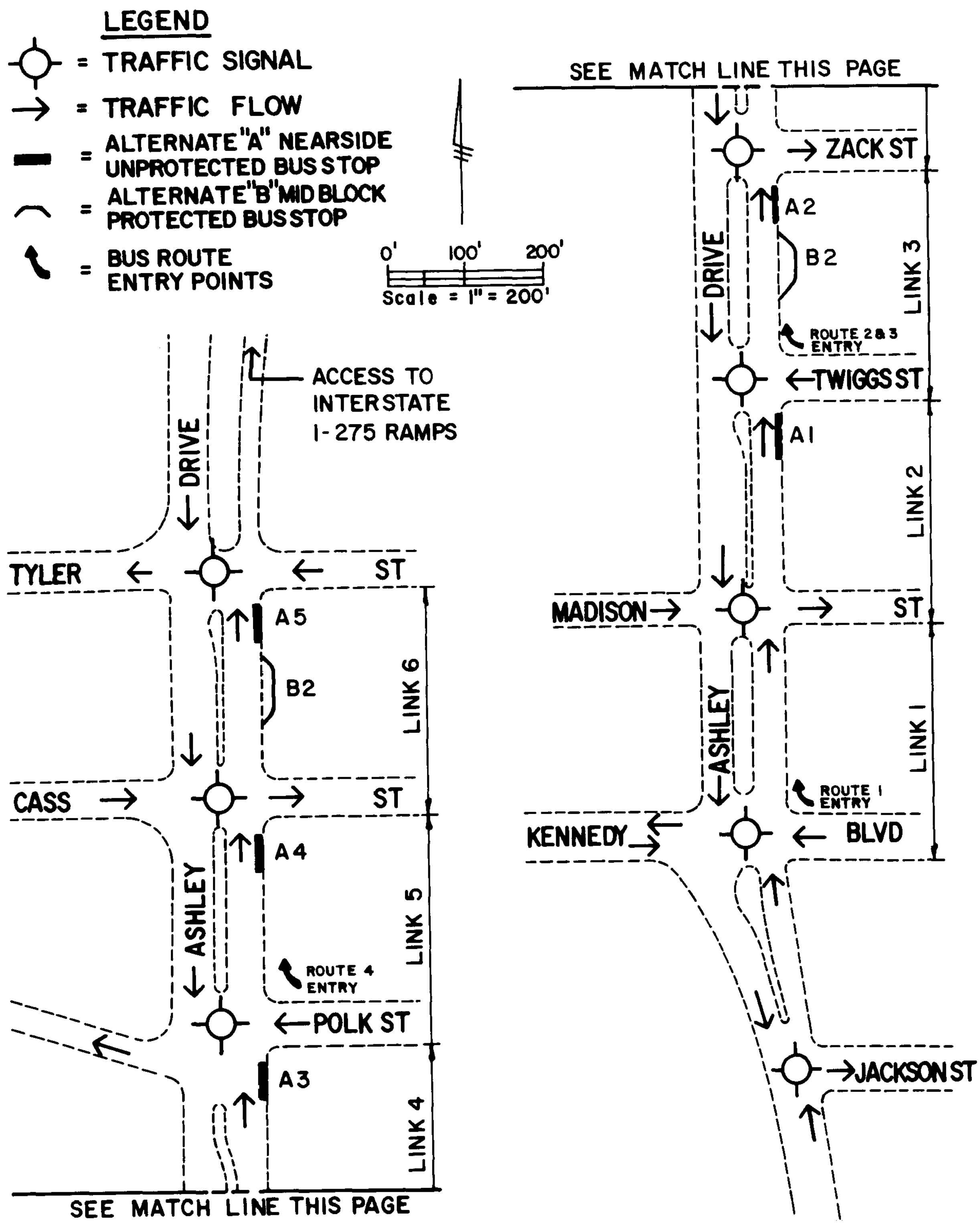

Figure 80. SUB Arterial Example - Ashley Drive

the city traffic engineer. Figure 80 illustrates these two alternatives.

Analysis of Existing Conditions

Since this is a proposal to evaluate two alternative methods of serving potential passenger demand on this route no existing condition is modeled.

Define and Analyze Alternatives

In order to define each of the alternatives it is necessary to code information on various parameters (vehicle characteristics and passenger service characteristics) which are representative of local conditions. Since these were not readily available for the local area, guidelines suggested in the User's Manual were utilized.

Since there are no special coding forms the information was coded on standard forms and keypunched. Figure 81 shows a comparison of input data for both alternatives from the output reports.

The only change between the two alternatives is location of bus stops, capacity and type. For Alternative A five unprotected bus stops

```
                    *** THE SUB MODEL ***
                SIMULATION OF URBAN BUSES
  ASHLEY DR BUS OPERATIONS(PM)- PROPOSED  5 UNPROTECTED NEAR S


  ORIGIN OF RANDOM NUMBERS :251671   -  PROCESSING INTERVAL : 10

      QUEUE DISCHARGE HEADWAYS =  5.3 4.0 3.2 2.7 2.5 2.4

CAR LENGTH = 22. FT   BUS LENGTH = 45. FT.  BUS TRAF. FACTOR = 2.0
BUS ACCELERATION =  2.2 MPH/SEC - BUS DECELERATION = 3.0 MPH/SEC
BUS CRUISING SPEED  = 20. MPH    -    AVERAGE BUS DELAY =   90 SEC

SERVICE TIME IN SEC = 4.50 + 2.70 PL + 1.00 PU - 0.05 PL.PU + DEV.

TRAFFIC DEMANDS, VPH :
    868    960    1188    984

LINK  LENGTH   BUS STOP NO. 1    BUS STOP NO. 2    BUS STOP NO. 3
 NO.   FEET    DIST  CAP  TYPE   DIST  CAP  TYPE   DIST  CAP  TYPE
               FEET  BUS         FEET  BUS         FEET  BUS


  1   291.       0.   0    0
  2   292.     292.   2    0
  3   292.     292.   2    0
  4   237.     237.   2    0
  5   348.     348.   2    0
  6   284.     284.   2    0

   EXPECTED BUS ARRIVALS TO FIRST STOP LINE IN HOURS & MINUTES

ROUTE          ARRIVALS :

   1  1635 1645 1655 1705 1715 1725

   2  1635 1650 1705 1720

   3  1630 1642 1654 1706 1718

   4  1630 1645 1700 1715
               PERCENT OF BUS COMMON PASSENGER DEMAND

 BETWEEN ROUTE  1

    AND ROUTES :  1  3

 COMMON LOADING  80 20
 COMMON UNLOAD.  80 20

 BETWEEN ROUTE  2

    AND ROUTES :  2  4

 COMMON LOADING  50 50
 COMMON UNLOAD.  50 50

 BETWEEN ROUTE  3

    AND ROUTES :  1  3

 COMMON LOADING  70 30
 COMMON UNLOAD.  70 30

 BETWEEN ROUTE  4

    AND ROUTES :  2  4

 COMMON LOADING  50 50
 COMMON UNLOAD.  50 50
```

```
                    *** THE SUB MODEL ***
                SIMULATION OF URBAN BUSES
  ASHLEY DR BUS OPERATIONS(PM -ALTERNATE 2 PROT MID BLOCK BUS


  ORIGIN OF RANDOM NUMBERS :251671   -  PROCESSING INTERVAL : 10

      QUEUE DISCHARGE HEADWAYS =  5.3 4.0 3.2 2.7 2.5 2.4

CAR LENGTH = 22. FT   BUS LENGTH = 45. FT.  BUS TRAF. FACTOR = 2.0
BUS ACCELERATION =  2.2 MPH/SEC - BUS DECELERATION = 3.0 MPH/SEC
BUS CRUISING SPEED  = 20. MPH    -    AVERAGE BUS DELAY =   90 SEC

SERVICE TIME IN SEC = 4.50 + 2.70 PL + 1.00 PU - 0.05 PL.PU + DEV.

TRAFFIC DEMANDS, VPH :
    868    960    1188    984

LINK  LENGTH   BUS STOP NO. 1    BUS STOP NO. 2    BUS STOP NO. 3
 NO.   FEET    DIST  CAP  TYPE   DIST  CAP  TYPE   DIST  CAP  TYPE
               FEET  BUS         FEET  BUS         FEET  BUS


  1   291.       0.   0    0
  2   292.       0.   0    0
  3   292.       0.   0    0
  4   237.     150.   3    1
  5   348.       0.   0    0
  6   284.     150.   3    1

   EXPECTED BUS ARRIVALS TO FIRST STOP LINE IN HOURS & MINUTES

ROUTE          ARRIVALS :

   1  1635 1645 1655 1705 1715 1725

   2  1635 1650 1705 1720

   3  1630 1642 1654 1706 1718

   4  1630 1645 1700 1715
               PERCENT OF BUS COMMON PASSENGER DEMAND

 BETWEEN ROUTE  1

    AND ROUTES :  1  3

 COMMON LOADING  80 20
 COMMON UNLOAD.  80 20

 BETWEEN ROUTE  2

    AND ROUTES :  2  4

 COMMON LOADING  50 50
 COMMON UNLOAD.  50 50

 BETWEEN ROUTE  3

    AND ROUTES :  1  3

 COMMON LOADING  70 30
 COMMON UNLOAD.  70 30

 BETWEEN ROUTE  4

    AND ROUTES :  2  4

 COMMON LOADING  50 50
 COMMON UNLOAD.  50 50
```

Figure 81. Comparison of Summary Input Data for Alternatives

Alternative "A"

-------- FOR SIMULATION PERIOD 1 - FROM 16:30 TO 16:45 --------

TRAFFIC SIGNALS SETTING IN SECONDS

LINK NUMBER	CYCLE LENGTH	GREEN PHASE	ADVANCED GREEN	OFFSET
1	90	47	0	40
2	90	52	0	41
3	90	63	0	39
4	90	48	10	59
5	90	64	0	63
6	90	48	0	52

TRAFFIC SPEEDS AND VOLUMES

LINK NUMB	SPEED MPH	VOLUME FROM SIDE ST VPH LEFT	RIGHT	OPPOS. VOLUME VPH	MDBLCK DEMAND VPH	TURNING PROBABILITY LEFT	RIGHT	LANE DISTRIBUTION ONE	TWO
1	25.	148	0	1058	0	0.0	0.37	0.53	0.47
2	25.	0	200	926	0	0.0	0.0	0.65	0.35
3	25.	0	0	1041	0	0.0	0.50	0.63	0.37
4	25.	0	108	992	0	0.0	0.0	0.77	0.23
5	25.	0	0	931	0	0.0	1.00	0.79	0.21
6	25.	0	165	1029	0	0.0	0.0	0.99	0.01

BUS PASSENGER DEMAND

BUS STP	ROUTE 1 PL	PU	ROUTE 2 PL	PU	ROUTE 3 PL	PU	ROUTE 4 PL	PU	ROUTE PL	PU	PL	PU
2	6	1	-1	0	-1	0	-1	0				
4	2	0	3	1	2	0	4	0				
6	8	2	6	1	4	0	8	1				
8	4	1	3	0	2	0	5	1				
10	6	2	5	0	6	1	8	1				

BUS PASSENGER LOAD AND CAPACITY

ROUTE	LOAD	CAPACITY
1	20	65
2	26	65
3	24	65
4	18	65

- O U T P U T S -

BUS STATISTICS

BUS NUMBER :	1	2	3	4	5	6	7
ROUTE NO. :	4	3	1	2	3	1	4

-LINK NUMBER 1

STOP LINE

ARRIVAL TIME	16:31	16:33	16:36	16:37	16:43	0: 0	0: 0
DEPARTURE TIME	16:31	16:33	16:36	16:37	16:43	0: 0	0: 0

-LINK NUMBER 2

BUS STOP NO. 1

ARRIVAL TIME	16:32	16:33	16:36	16:37	16:43	0: 0	0: 0
PASS. LOADED	0	0	3	0	0	0	0
PASS. UNLOADED	0	0	0	0	0	0	0
SERVICE TIME, SEC	0	0	6	0	0	0	0
DEPARTURE TIME	16:32	16:33	16:36	16:37	16:43	0: 0	0: 0

STOP LINE

ARRIVAL TIME	16:32	16:33	16:36	16:37	16:43	0: 0	0: 0
DEPARTURE TIME	16:32	16:33	16:37	16:37	16:43	0: 0	0: 0

-LINK NUMBER 3

BUS STOP NO. 1

ARRIVAL TIME	16:32	16:33	16:37	16:37	16:44	0: 0	0: 0
PASS. LOADED	0	0	1	2	2	0	0
PASS. UNLOADED	0	0	0	0	0	0	0
SERVICE TIME, SEC	0	0	3	9	7	0	0
DEPARTURE TIME	16:32	16:33	16:37	16:37	16:44	0: 0	0: 0

STOP LINE

ARRIVAL TIME	16:32	16:33	16:37	16:37	16:44	0: 0	0: 0
DEPARTURE TIME	16:32	16:33	16:37	16:37	16:44	0: 0	0: 0

Alternative "B"

-------- FOR SIMULATION PERIOD 1 - FROM 16:30 TO 16:45 -------

TRAFFIC SIGNALS SETTING IN SECONDS

LINK NUMBER	CYCLE LENGTH	GREEN PHASE	ADVANCED GREEN	OFFSET
1	90	47	0	40
2	90	52	0	41
3	90	63	0	39
4	90	48	10	59
5	90	64	0	63
6	90	48	0	52

TRAFFIC SPEEDS AND VOLUMES

LINK NUMB	SPEED MPH	VOLUME FROM SIDE ST VPH LEFT	RIGHT	OPPOS. VOLUME VPH	MDBLCK DEMAND VPH	TURNING PROBABILITY LEFT	RIGHT	LANE DISTRIBUTION ONE	TWO
1	25.	148	0	1058	0	0.0	0.37	0.53	0.47
2	25.	0	200	926	0	0.0	0.0	0.65	0.35
3	25.	0	0	1041	0	0.0	0.50	0.63	0.37
4	25.	0	108	992	0	0.0	0.0	0.77	0.23
5	25.	0	0	931	0	0.0	1.00	0.79	0.21
6	25.	0	165	1029	0	0.0	0.0	0.99	0.01

BUS PASSENGER DEMAND

BUS STP	ROUTE 1 PL	PU	ROUTE 2 PL	PU	ROUTE 3 PL	PU	ROUTE 4 PL	PU	ROUTE PL	PU	PL	PU
4	16	3	9	2	6	0	12	1				
7	10	3	8	0	8	1	13	2				

BUS PASSENGER LOAD AND CAPACITY

ROUTE	LOAD	CAPACITY
1	20	65
2	26	65
3	24	65
4	18	65

- O U T P U T S -

BUS STATISTICS

BUS NUMBER :	1	2	3	4	5	6	7
ROUTE NO. :	4	3	1	2	3	1	4

-LINK NUMBER 1

STOP LINE

ARRIVAL TIME	16:31	16:33	16:36	16:37	16:43	0: 0	0: 0
DEPARTURE TIME	16:31	16:33	16:36	16:37	16:43	0: 0	0: 0

-LINK NUMBER 2

STOP LINE

ARRIVAL TIME	16:32	16:33	16:36	16:37	16:44	0: 0	0: 0
DEPARTURE TIME	16:32	16:33	16:36	16:37	16:44	0: 0	0: 0

-LINK NUMBER 3

STOP LINE

ARRIVAL TIME	16:32	16:33	16:36	16:38	16:44	0: 0	0: 0
DEPARTURE TIME	16:32	16:33	16:36	16:38	16:44	0: 0	0: 0

Figure 82. Comparison of Bus Itinerary and Bus and Route Summary Statistics for 1st Simulation Period

Alternative "A"

-LINK NUMBER 4

BUS STOP NO. 1

ARRIVAL TIME	16:32	16:33	16:37	16:38	16:44	0: 0	0: 0
PASS. LOADED	0	1	3	3	4	0	0
PASS. UNLOADED	0	0	1	0	1	0	0
SERVICE TIME, SEC	0	6	16	10	12	0	0
DEPARTURE TIME	16:32	16:33	16:37	16:38	16:44	0: 0	0: 0

STOP LINE

ARRIVAL TIME	16:32	16:33	16:37	16:38	16:44	0: 0	0: 0
DEPARTURE TIME	16:32	16:33	16:37	16:38	16:44	0: 0	0: 0

-LINK NUMBER 5

BUS STOP NO. 1

ARRIVAL TIME	16:32	16:33	16:38	16:38	16:44	0: 0	0: 0
PASS. LOADED	0	1	1	2	1	0	0
PASS. UNLOADED	0	0	0	0	0	0	0
SERVICE TIME, SEC	0	10	7	9	10	0	0
DEPARTURE TIME	16:32	16:33	16:38	16:38	16:44	0: 0	0: 0

STOP LINE

ARRIVAL TIME	16:32	16:33	16:38	16:38	16:44	0: 0	0: 0
DEPARTURE TIME	16:32	16:33	16:38	16:38	16:44	0: 0	0: 0

-LINK NUMBER 6

BUS STOP NO. 1

ARRIVAL TIME	16:32	16:33	16:38	16:38	16:44	0: 0	0: 0
PASS. LOADED	0	2	2	4	3	0	0
PASS. UNLOADED	0	0	1	0	1	0	0
SERVICE TIME, SEC	0	11	15	15	6	0	0
DEPARTURE TIME	16:32	16:33	16:38	16:38	16:44	0: 0	0: 0

STOP LINE

ARRIVAL TIME	16:32	16:33	16:38	16:38	16:44	0: 0	0: 0
DEPARTURE TIME	16:32	16:34	16:38	16:38	16:44	0: 0	0: 0

TOTAL P. LOADED	0	4	10	11	10	0	0
TOTAL P. UNLOADED	0	0	2	0	2	0	0
TOTAL S TIME, SEC	0	27	47	43	35	0	0
OVERALL SPEED MPH	15.0	15.0	8.4	13.0	15.0	0.0	0.0

ROUTE STATISTICS

ROUTE NUMBER	1	2	3	4
TOTAL P. LOADED	10	11	14	0
TOTAL P. UNLOADED	2	0	2	0
TOTAL S. TIME, MIN	47	43	62	0
MEAN SPEED, MPH	8.4	13.0	15.0	15.0
P. WAIT. TIME, MIN	87	70	0	128
MEAN P W TIME, MIN	8.7	6.4	0.0	0.0

SUMMARY STATISTICS

TOTAL PASSENGERS LOADED = 35 TOTAL PASSENGERS UNLOADED = 4

TOTAL SERVICE TIME, MIN = 152 MEAN OVERALL BUS SPEED, MPH= 13.3

PASS WAITING TIME, MIN = 285 MEAN PASS. WAIT. TIME, MIN = 8.1

Alternative "B"

-LINK NUMBER 4

BUS STOP NO. 1

ARRIVAL TIME	16:32	16:33	16:36	16:38	16:44	0: 0	0: 0
PASS. LOADED	1	1	5	5	8	0	0
PASS. UNLOADED	0	0	1	1	1	0	0
SERVICE TIME, SEC	3	12	9	16	37	0	0
DEPARTURE TIME	16:32	16:33	16:36	16:38	16:44	0: 0	0: 0

STOP LINE

ARRIVAL TIME	16:32	16:33	16:37	16:38	16:45	0: 0	0: 0
DEPARTURE TIME	16:33	16:34	16:37	16:39	16:45	0: 0	0: 0

-LINK NUMBER 5

STOP LINE

ARRIVAL TIME	16:33	16:34	16:37	16:39	0: 0	0: 0	0: 0
DEPARTURE TIME	16:33	16:34	16:37	16:39	0: 0	0: 0	0: 0

-LINK NUMBER 6

BUS STOP NO. 1

ARRIVAL TIME	16:33	16:34	16:37	16:39	0: 0	0: 0	0: 0
PASS. LOADED	3	3	2	5	0	0	0
PASS. UNLOADED	0	1	1	0	0	0	0
SERVICE TIME, SEC	11	9	7	17	0	0	0
DEPARTURE TIME	16:33	16:34	16:37	16:39	0: 0	0: 0	0: 0

STOP LINE

ARRIVAL TIME	16:33	16:34	16:38	16:39	0: 0	0: 0	0: 0
DEPARTURE TIME	16:33	16:34	16:38	16:39	0: 0	0: 0	0: 0

TOTAL P. LOADED	4	4	7	10	8	0	0
TOTAL P. UNLOADED	0	1	2	1	1	0	0
TOTAL S TIME, SEC	14	21	16	33	37	0	0
OVERALL SPEED MPH	9.6	8.6	10.0	7.6	6.6	0.0	0.0

ROUTE STATISTICS

ROUTE NUMBER	1	2	3	4
TOTAL P. LOADED	7	10	12	4
TOTAL P. UNLOADED	2	1	2	0
TOTAL S. TIME, MIN	16	33	58	14
MEAN SPEED, MPH	10.0	7.6	7.6	9.6
P. WAIT. TIME, MIN	84	46	33	165
MEAN P W TIME, MIN	12.0	4.6	2.8	41.3

SUMMARY STATISTICS

TOTAL PASSENGERS LOADED = 33 TOTAL PASSENGERS UNLOADED = 5

TOTAL SERVICE TIME, MIN = 121 MEAN OVERALL BUS SPEED, MPH= 8.5

PASS WAITING TIME, MIN = 328 MEAN PASS. WAIT. TIME, MIN = 9.9

Figure 82. Comparison of Bus Itinerary and Bus and Route Summary Statistics for 1st Simulation Period (Continued)

(Code 0) with capacity for 2 buses each were coded for links 2, 3, 4, 5, and 6. For Alternative B two protected bus stops (Code 1) with capacity of 3 buses each were coded for links 4 and 6.

Figure 82 shows a comparison between the bus itinerary and summary statistics for one of the simulation periods (4:30 PM to 4:45 PM). The only difference in the input data was the bus passenger demand for each bus stop and route. Following this input data information is printed out for each bus simulated showing it's route number, arrival and departure time at each stop bar, as well as at each bus stop. For each bus stop the passengers loaded and unloaded and the service time is shown.

Figure 82 also compares the route statistics and summary statistics for the simulation period.

Evaluation of Results

The reports for each period provides a comparison of statistics. The most useful data are the overall average bus speed and passenger waiting time. Table 20 provides a summary of the results for each of the four 15 minute simulation periods and for the total hour.

Review of each of the simulation periods, indicates that for the 1st period Alternative B results in higher speeds and lower average passenger waiting time. However, as the simulation continues Alternative A appears to be more advantageous. For the entire peak hour the total bus service time and the mean passenger waiting time is lower for Alternate A.

From the bus operators standpoint Alternate A would minimize bus travel time and passenger

Table 20 - Comparison of MOE'S for Alternative Bus Stop Configuration

Summary Statistics	Alternative A					Alternative B				
	1	2	3	4	Peak Hour	1	2	3	4	Peak Hour
Total Passengers Loaded	33	79	60	59	231	35	71	79	36	221
Total Passengers Unloaded	5	14	9	12	40	4	15	9	3	31
Total Service Time (Min)	121	241	238	233	833	152	291	345	140	928
Mean Overall Bus Speed (MPH)	8.5	8.0	5.8	6.3	7.2	13.3	7.6	4.4	5.6	7.7
Passenger Waiting Time (Min)	328	220	384	204	1136	292	298	222	504	1316
Mean Passenger Waiting Time (Min)	9.9	2.8	6.4	3.5	4.9	8.3	4.2	2.8	14.0	6.0

wait time. However, a study of the effect of bus stops in the traffic lane would expect to show a significant reduction in capacity and increased delay time for other motorists.

The increase in mean passenger waiting time from 4.9 minutes to 6.0 minutes would not appear to be significant. However, the increase in service time from 833 minutes to 928 minutes (1.6 hours) of vehicle operating time would result in higher operating costs and must be considered by the transit operators.

Summary of Work Effort Required

The following summarizes the work effort required for the example problem.

Data Collection - Data was readily available for the arterial geometrics, traffic volumes and signal operations, as well as the number of buses per hour by route. Data on passenger demand was not available since no bus stop existed. The data used were based upon estimates by the author for illustrative purposes only. Data were also not available on bus passenger service time and it was necessary to use the guidelines in the User's Manual. In actual practice it would be desirable to obtain data on local characteristics if they were not available, and considerable data collection effort may be required.

Data Coding - Once the data were obtained (or basic assumptions made) the coding was straightforward. Some difficulty was experienced in obtaining an executable input deck since the model has no edit checks or error messages, however, this was resolved by repeated runs. Approximately two (2) hours were required to code the data once it was obtained (or created in this example).

Computer Time - The SUB model required less than one second of CPU time for Alternate A and for Alternate B. Each alternate required 98 K bytes of core storage.

REFERENCE

*8.1 Radelat, G., "Simulation of Urban Bus Operation on Signalized Arterials", Report No. FHWA-RD-74-6, Federal Highway Administration, December, 1973. FB-237795.

CHAPTER 9 - TRANSYT-7F (NETWORK OPTIMIZATION MODEL)

The efficient movement of traffic through a grid network of signalized intersections can improve the capacity of the system and reduce adverse effects of traffic, such as annoying stops and delays. The quality of the environment and excess fuel consumption can be reduced as well. Such efficiency can only be achieved by interconnecting the signals and operating them in such a manner that minimizes the delay and stops in the system. Numerous computer programs have been written to assist engineers in determining how the signals should be timed and several on-line control programs are available as well.

One of the most widely used design models is the TRAffic Network StudY Tool - TRANSYT - developed by Dennis Robertson of the Transport and Road Research Laboratory in England (References 9.1 thru 9.3). Since the original model was introduced in 1968, numerous improvements have been made and new versions issued. The version discussed here is TRANSYT-7F (Reference 9.4). An early version TRANSYT-6C, is available from FHWA (See Chapter 14). A later version (TRANSYT-8) is available on a license basis (Reference 9.5)

MODEL DESCRIPTION

The TRANSYT model is a macroscopic, deterministic, time scan optimization model. It is used for optimizing the signalization on arterials and grid networks. The program was originally written in machine language for use on a Marconi Myrid Computer and later rewritten in Fortran IV for more universal use. The TRANSYT-7F model will operate on an IBM 370, CDC 7700, VAX and Honeywell computers. On the IBM 370 the core requirements for TRANSYT-7F is 278k. The program contains 7650 lines of code with approximately ten (10)% used for comments.

The physical characteristics of a system considered by TRANSYT-7F is a coordinated network of up to 50 intersections (nodes) with up to 250 directional links. Only signalized intersections are normally modeled, but facilities exist for modeling sign controlled intersections and "bottleneck" locations. Signal control is fixed-time, two to seven-phase (including pedestrian movements) and fixed sequential phasing. Stoplines may be "shared" by several movements and priority lanes may be designated for buses.

Figure 83. Urban Arterial Network Congestion

Signal timings are printed in a format that is directly implemented in the field for pretimed controllers and time-space diagrams may be printed for selected routes.

INPUT REQUIREMENTS

There are 14 major types of input cards for TRANSYT-7F, some of which have single cards, others multiple cards. A complete deck stack is shown in Figure 84. A summary of the input data is shown in Table 21. The basic inputs fall into four functional categories, namely, data which:

a. Are common to the entire network (e.g. cycle length,

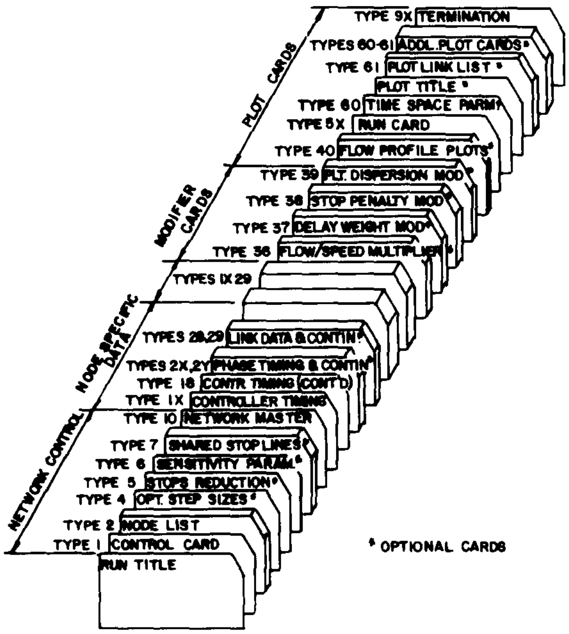

Figure 84. Typical TRANSYT-7F Data Deck

b. Control the optimization process,

c. Specify signal timing, and

d. Specify traffic data.

Input cards are numbered by card type and are input with all node-specific data grouped by intersection. Standard coding sheets are available to assist the user in preparing input cards. Some of the salient points about TRANSYT-7F inputs are covered below (refer to Table 21).

Run Title Card

The run title card gives a name to the run and the card may contain any alphanumeric data. This must always be the first card in the deck.

Control Card (Type 1)

This card applies to the entire network. In addition to the cycle length in seconds, the number of steps in the cycle is an important input because signal timing, flow and queue variations are calculated with a time resolution determined by the number of steps. The stop penalty is the parameter that the user may use to specify the relative importance of stops and delay. The objective function includes both and the number of stops/second is multiplied by this parameter before being added to the delay.

The effective green displacements are used to calculate delays by using an "effective green" equal to the start of green plus beginning lag (i.e. startup lost time) and the end of green plus end lag (i.e., to account for vehicles that use the yellow).

The remaining inputs on this card are control options. The options available are summarized as follows:

1. Initial timings: user input or computer generated.

2. Units of measure: English (gallons, feet and mph) or metric (liters, meters and km/hr).

3. Timing units: seconds or percent of cycle.

4. Speed units: speed or travel time.

5. Output level: various levels of outputs.

Optimization Node List (Type 2)

Despite the limit of 50 nodes, they may be numbered from 1 to 9999. Nodes are entered in the sequence which they will be optimized in the hill climb process. If it is desired to group nodes so that they are optimized together (e.g. their relative offset and splits remain fixed, but their offset in the system is allowed to vary), a negative sign is placed before the secondary node number to indicate grouping with the next positive numbered node, which is the primary node. Any nodes that are not to be optimized are left off this list. As many cards as necessary are used to number all nodes.

Table 21 - Input Requirements for TRANSYT-7F

CARD TYPE	CARD NAME	PURPOSE	DATA REQUIREMENTS
NETWORK CONTROL (1 each per run)	TITLE	Provide title for run	Arbitrary information
	CONTROL CARD	Define network-wide parameters and input-output options.	Cycle length, no. of steps per cycle, stop penalty, simulation period, start-up lost time, end effective green time, output requirements, type of units and volume scale.
	NODE LIST	Define intersections in order which they are to be optimized.	List of node numbers in the order which the user would like them optimized.
	HILL-CLIMB CONTROL (Optional)	Define the step sizes for the optimization hill-climbing process.	The number and size of each increment to be used in process (default values can be used).
	STOPS REDUCTION (Optional)	Define amount of delay which will be considered a "stop".	Percent for seconds of delay which is to be considered a stop (default values can be used).
	SENSITIVITY PARAMETER (Optional)	Provide parameter which will limit affect of a node on the downstream node.	Percent of change in flow profile at node which downstream node should be recalculated (default values can be used).
	SHARED STOPLINE (Optional)	Define links which have different types of turning movements or vehicles (buses normally) that have different operating characteristics for which MOE's are desired separately.	Link numbers of links which share the same stopline.
	NETWORK MASTER	Define other network-wide parameters.	Node number to reference all offsets, saturation flow rate and platoon dispersion factor to be used for all links.
NODE SPECIFIC DATA (1 set per node)	CONTROLLER TIMING (1 per controller)	Define controller offset and interval lengths at each intersection.	Number of phases and length of each interval (max. 11) offset or yield point can be coded if existing; code can also indicate double cycling.
	CONTROLLER TIMING CONTINUATION (Optional)	Define additional controller intervals.	Duration of intervals 12-25.

Table 21 - Input Requirements for TRANSYT-7F (Continued)

CARD TYPE	CARD NAME	PURPOSE	DATA REQUIREMENTS
NODE SPECIFIC DATA (Continued)	PHASE TIMING (1 per phase)	Define intervals for each phase and links which move on green.	Interval which starts green for this phase, variable interval, yellow interval, all red interval, min. Ø duration and links (max. 8) which move on this phase.
	PHASE TIMING CONTINUATION (Optional)	Define additional links in phase.	Additional links which move on green.
	LINK DATA (1 per link)	Identify link geometric and traffic flow.	Length, number lanes (or saturation flow), traffic volumes, turning traffic from 3 links and speeds.
	LINK DATA CONTINUATION (Optional)	Identify additional link characteristics.	Additional lost time/or clearance utilization on link and/or traffic from a 4th link.
MODIFIER CARDS (optional)	FLOW/SPEED MULTIPLIER (Optional)	To permit modifications to link traffic volumes and/or speeds.	Percent of flow rate and/or speeds are to be changed from original, by link.
	DELAY WEIGHT MODIFIER (Optional)	To provide factors which multiply the effect of delay in performance index (PI).	Link number and factor to be applied.
	STOP PENALTY MODIFIER (Optional)	To provide factors which multiply the effect of stops in PI.	Link number and factor to be applied.
	PLATOON DISPERSION MODIFIER (Optional)	To change the platoon dispersion factor for specific links.	Link number and new factor for platoon dispersion.
PLOT AND RUN CARDS	FLOW PROFILE PLOT (Optional)	To identify links which flow profile plots are to be output.	Link number and placement on output.
	RUN CARD (Required)	To instruct program as to what type of run to execute.	Simulation or optimization run and type.
	TIME SPACE PARAMETER (Optional)	To provide instructions for time-space plots.	Number of nodes, time (or %) and distance axis scales.
	TIME SPACE TITLE (Optional)	Provide title for time-space plot.	Arbitrary information.
	TIME SPACE LINKS (Optional)	To identify links to be printed on plot.	Link numbers in order to be plotted.
	TERMINATION (Required)	To mark end of a run.	Indicate if end of this run and if an additional run follows.

Hill-Climb Control (Type 4, Optional)

This card controls the size of the increments made to the signal timings by the "hill-climb" process. Variations of the values on this card can be used to trade off run time for sufficiency of the optimization process, which in large networks may be desirable. Defaults are available for this card.

Stops per Delay (Type 5, Optional)

This card allows more realistic estimates of stops vs. delay. TRANSYT normally assigns one stop per delay, no matter how small. Since very short delays are likely to be slow downs rather than stops, this card may be used to simulate such characteristics more realistically. Defaults are available for this card.

Sensitivity Parameters (Type 6, Optional)

This card controls the accuracy of the simulation process at each hill-climb optimization step. If the change in the departure pattern is less than the percentage values input on this card from one set of signal timings to the next, the simulation of downstream links is terminated. This feature permits significant reductions in computer run time compared to prior versions. Large sensitivity parameters (e.g. 10%) are normally used initially, then the parameters decrease to 0.01% as the optimal solution is approached. Defaults are also available for these parameters.

Shared Stopline Links (Type 7, Optional)

If two or more links share a stopline (i.e., use the same roadway at the stopline) they can be "grouped" using this card. Shared stopline links will move on the same phases and have a common saturation flow. The links are reported separately in the outputs, however.

Network Master Card (Type 10)

The network master card is required, although all data fields are optional (i.e., this card signals the use of TRANSYT-7F inputs rather than the earlier TRANSYT-7 inputs. The data fields include the designation of a master controller and several system-wide traffic flow model parameters. If a master controller is identified, all offsets will be referenced to this controller, otherwise the system time reference base is arbitrary. The traffic flow parameters are saturation flow per lane, a parameter to calibrate the platoon dispersion model and the approach speed on external links. All parameters have defaults available.

Controller Timing Card (Type 1X)

This card provides the node number, controller offset or yield point value, yield point reference interval number and all interval lengths. The value "X" indicates the number of phases at the node, with a maximum of seven. Up to 25 intervals may be used, but if there are more than 11 intervals, a continuation card (Type 18) must be used for the additional intervals. Interval lengths may be input in seconds or percent, as set on Card Type 1. If the data are to be optimized and no analysis of initial settings is desired, only the fixed interval lengths (e.g., clearances, minimum walk, etc.) need be coded.

A double cycle flag is set if the signal is to operate on one-half the system cycle length. In this case only three phases are permitted.

A Card Type 1X must be provided for each node and Card Types 2X through 29 must follow <u>immediately</u> for each intersection (see Figure 84).

Phase Timing Card (Type 2X)

The phase timing cards establish the specific phase sequence and identifies the intervals in each phase. In this case the "X" refers to the phase number and there must be as many Card Types 2X as the number of phases specified on the preceeding Card Type 1X.

For each phase (i.e., each Card Type 2X for the current node) the interval starting the green, the variable interval (i.e., the only interval that may be changed in the optimization), the yellow interval and the red interval (if used) are identified by numbers. These data define the phases and phase splits.

The phase sequence is specified by listing each link having the right-of-way in each phase. Overlap phasing is indicated by listing the appropriate links(s) in more than one phase. If a link has 100% green, it is linked on all Card Types 2X. If in the unlikely event that more than eight links move in a phase, a continuation card is available.

Link Data Cards (Types 28, 29)

For each link listed on the Card Types 2X for the current node, a link data card (Type 28) and, if needed a continuation (Type 29) are required. The link specific data include link length, stopline saturation flow rate (or equivalent number of lanes), total flow (vph), mid-block source flow and the upstream input link data. For these upstream source links, the link numbers, input flows and free speed (or travel time) are coded. Card Type 28 allows for three input links. If a fourth link is required Card Type 29 is used.

The coding of traffic volumes between nodes (intersections) is straightforward when only one link is used to represent traffic. The traffic entering the link from each upstream link is directly obtained from intersection turning movements. However, when two or more links are used (i.e., one link for left turns from exclusive lane and one link for thru and right turns) the determination of the input volumes are more involved. It is now necessary to code the number of vehicles from each turning movement at the upstream intersection which uses each of these links. Since this data is difficult to obtain in the field it is necessary to estimate the proportion of traffic going to each link from the turning movement. The User's Manual (Ref. 9.4) describes a method of estimating these volumes. However, some additional time and effort is required to estimate these volumes.

Card Type 29 also serves a second purpose. It enables the user to code additional delay at the start of effective green (or, if negative, to reduce the amount of start-up lost time coded in Card Type 1) and additional extension of effective green.

The input flows need not sum to the total (output) flow, thus data may be collected on different days and not require manual balancing.

If a link is a bus link, the speed input is coded in such a way that both bus cruise speed and bus stop dwell time are included. Thus the non-signal delay to buses may be modeled.

Flow/Speed Scaling (Type 36, Optional)

These cards allow flows and/or speeds on a link to be altered by specified multiplying factors. Their primary use is in sensitivity analysis, that is, initial data cards (Type 28) need not be changed.

Delay Weight Modifier Card (Type 37, Optional)

This card enables the user to prioritize individual links by assigning a higher relative weight to the delay on these selected links. Conversely, the weighting factor may be used to decrease or eliminate given links from consideration in the optimization. If a zero weight is coded, the affected link will also be eliminated from the fuel consumption estimate.

Stop Penalty Modifier Card (Type 38, Optional)

This card is similar to the previous one, except that it is for stops.

Platoon Dispersion Modifier Card (Type 39, Optional)

The roadway characteristics may suggest a different platoon dispersion factor (see below) be used than the system value (coded in Card Type 10, or the program default). If so, the factor may be changed using this card to list all such links and new values of the dispersion coefficient.

Flow Profile Plot Card (Type 40, Optional)

This control card is used to specify the order of links for plotting composite arrival/departure profiles plotted. Four graphs are plotted per page and they may be arranged to follow progression down or up the pages.

Run Card (Types 50-53)

This card is used to conveniently make simulation or optimization runs. Card Type 50 requires the user to specify an optimization step size listed on Card Type 4 (or simulate). Card Type 51 indicates simulation only. Card Types 52 and 53 indicate optimization with a normal hill-climb list and a "quick" list, respectively (see below).

Time-Space Parameter Card (Type 60, Optional)

This card indicates the number of nodes to be included in the current time-space diagram. Other inputs are various units and scaling parameters for the plot. A Card Type 60 must be first in each group of Card Types 60-61 for each separate plot.

Time-Space Diagram Title Card (Optional)

This card is similar to the run title card, except this card provides the title for the current plot.

Time-Space Link List Card (Type 61, Optional)

For each time-space diagram, the list of links for both directions must be provided in pairs. This is necessary since the user may select routes in any convenient fashion. One-way streets may be plotted by leaving the second field in each pair blank.

Termination Card (Type 90,91)

This card signals the end of the data for the current run. If "90" is used, the job terminates. If the card is numbered "91," another <u>complete</u> data deck will be processed.

OPERATIONAL SUMMARY

TRANSYT-7F is a macroscopic, deterministic optimization model with independent time scan. It has a moderately structured organization with a master program which calls other subroutines as the analysis progresses.

Input cards are read and checked for apparent accuracy and if errors are detected the erroneous card is printed out with the detected error underlined, and a message is printed. TRANSYT-7F may calculate initial splits if these were not supplied by the user. Thus after satisfactorily reading the input data and, if necessary, computing the initial splits, the program execution begins. The execution of TRANSYT-7F is controlled by the optimization model.

Hill-climbing is accomplished by varying offsets and splits in small, medium or large steps and calculating the resulting traffic effects. To accomplish the latter, it is necessary to determine the behavior of traffic within a link. These are based on the manipulation of the following:

a. The "IN" pattern is the periodic flow rate of traffic that arrives at the stopline (downstream) if the traffic was not empeded by the signal.

b. The "OUT" pattern is the periodic traffic flow rate leaving a link.

c. The "GO" pattern is the periodic traffic flow rate that leaves the stopline if there was enough traffic to saturate the green.

The word "pattern" refers to the fact that TRANSYT-7F does not deal with individual vehicles, but rather platoons in histogram form (see Figure 85).

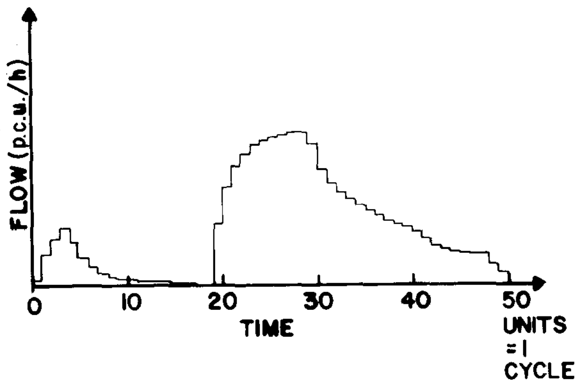

Figure 85. TRANSYT-7F Traffic Flow Histogram

The inflows of one link are obtained from the outflows of the upstream link(s). These flow characteristics are computed for each link for each iteration and the delays are calculated, as discussed in the next section.

With this background, the full process may now be described. The first step is to calculate the performance index (PI) for the initial timings. Then the offset of one signal is altered by the number of time units (steps) input on Card 4 and recalculate the PI. If the PI is reduced, the offset is changed successively in the same direction until a minimum PI is reached. If the first alteration increased the PI, the search was made in the opposite "direction"

Each signal is adjusted in a similar manner in the order specified on Card Type 2 until the network minimum PI is reached. This process is repeated for each hill-climb value on Card Type 4 (or in the default list). This is offset optimization.

TRANSYT-7F also optimizes splits. It does this by altering the start of each phase and recalculating the PI as before.

It is obvious that the length of a run will be largely dependent on how many iterations of the model are required. Another factor is that if the number of steps used to alter the particular timing is too small, the solution may be "trapped" into a local optimum which is not global. To compensate for these concerns the recommended step sizes to locate "a good" optimum are given in Table 22, along with the type of optimizations which will occur at each step. These are generated internally by TRANSYT-7F, but other lists may be input on Card Type 4.

If a "quick optimization" is desired, the user may specify a hill-climb sequence which may not result in the "best" PI, but will be reasonably good. Such a sequence is 15, 40, 15, 1, -1, 1. Another option allows optimization to include only those links directly connected to the present link, rather than the entire network. This is done by adding 100 to the values above (e.g. 115, 140, 115, 101, -101, 101). This reduces run time considerably but the resulting PI may be a few percent worse than the normal method.

Table 22 - Optimization Sequence

	TO OPTIMIZE OFFSETS ONLY		FOR TOTAL OPTIMIZATION	
STAGE	% CYCLE	OPTIMIZATION	% CYCLE	OPTIMIZATION
1	15	Offsets	15	Offsets
2	40	Offsets*	40	Offsets*
3	15	Offsets	-1	Splits
4	40	Offsets*	15	Offsets
5	15	Offsets	40	Offsets*
6	1	Offsets (fine tune)	1	Offsets (fine tune)
7	1	Offsets (fine tune)	-1	Splits (fine tune)
8			1	Offsets (fine tune)

*Starred steps insure that the optimization is not trapped in a local optimum. (Source 9.2.)

COMPUTATIONAL ALGORITHMS

The major algorithms in TRANSYT-7F are the objective function and the calculations of traffic characteristics. The objective function is called the "performance index", or "PI", and it is defined as follows:

$$\text{Minimize PI} = \sum_{i}^{n} [W(D)_i d_i + kW(S)_i s_i] \qquad (9.1)$$

where d_i = delay on the i^{th} link of network (veh-hr/hr),
s_i = average number of stops per second on link i,
k = the weighting factor for stops entered on Card Type 1, and
W = weighting factors for delay (D) and stops (S) for link i.

This objective function is minimized by an iterative search procedure where the signal timings are changed and the resulting flow and travel characteristics are recalculated.

The link patterns discussed in a previous section are found as follows, for the i^{th} link at time step t:

$$IN_{it} = \sum_{j} F_{ij} (P_{ij} \times OUT_{jt}); \qquad (9.2)$$

where F_{ij} = the smoothing process from link j to i (see below);
P_{ij} = the proportion of OUT_j which feeds link i, and
OUT_{jt} = the OUT pattern of link j_t at time t.

The number of vehicles (m_t) held at the stopline during time interval t is found by:

$$m_t = \max[(m_{t-1} + q_t - s_t) \text{ or } (0)]; \qquad (9.3)$$

where q_t = the number of vehicles arriving in interval t, given by the IN pattern, and
s_t = the number of vehicles allowed to leave in interval t, given by the out pattern.

The number of vehicles leaving in interval t is $m_{t-1} + q_t - m_t$ and these figures are used to derive the OUT pattern.

The average delay is calculated in two parts which are added together. The first is the average queue length over the cycle (times the cycle length) and the second is the delay due to random variations of arrivals and saturation. The second component for each link is found by,

$$d_{rs} = \left[\left(\frac{B_n}{B_d}\right)^2 + \frac{X^2}{B_d}\right]^{1/2} - \frac{B_n}{B_d} \qquad (9.4)$$

where d_{rs} = random and saturation delay;

$B_n = 2(1-X) = ZX;$

$B_d = 4Z - Z^2;$

$Z = (2x/v * 60/T;$

X = degree of saturation;

V = volume on the link; and

T = simulation time.

Since TRANSYT-7F assumes that traffic disperses as it travels downstream, the smoothing function (F) used in equation (9.2) is used to more realistically represent this dispersion of vehicles. F is calculated by,

$$F = \frac{1}{1 + \alpha \beta t}; \qquad (9.5)$$

where α = smoothing parameter (usually assumed to be 0.35 but it may be varied), and

β = a coefficient which "shifts" the effective travel time (set to 0.8), and

t = link travel time.

The number of stops is simply equal to the number of vehicles delayed. Since some de-

INPUT DATA REPORT FOR RUN 1

ASHLEY DRIVE ARTERIAL ANALYSIS - TRANSYT-7F- OPT 112 SEC CYCLE PM PEAK

CARD NO.	CARD TYPE	CYCLE LENGTH	STEPS PER CYC.	STOP PENALTY	PERIOD LENGTH	LOST TIME	GREEN EXTEN	CONTROL FLAGS: INITIAL TIMINGS	SPEED/ T-TIME	OUTPUT LEVEL	ENGLISH/ METRIC	SEC/ PERCENT			FLOW SCALE	
1	1	112	56	25	60	2	3	1	0	2	0	0	0	0	0	0

+++ 102 +++ WARNING + INITIAL TIMINGS HAVE BEEN REQUESTED IN FIELD 8.
TRANSYT-7F WILL IGNOR ANY OFFSET AND VARIABLE INTERVAL VALUES
CODED ON CARD TYPES 1X AND 18.
AN OPTIMIZATION RUN IS EXPECTED.

LIST OF NODES TO BE OPTIMIZED

CARD NO.	CARD TYPE															
2	2	1	2	3	4	5	6	7	8	0	0	0	0	0	0	0

SYSTEM MASTER DATA

CARD NO.	CARD TYPE	MASTER NODE	SYSTEM SATFLOW	SYSTEM PDF	EXTERNAL SPEED	FUEL FACTOR										
3	10	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

--- PROGRAM NOTE --- INPUT UNITS WERE SPECIFIED AS FOLLOWS:

SPEED/TRAVEL TIME IN SPEED
ENGLISH/METRIC UNITS IN ENGLISH
TIMING UNITS IN SECONDS

INTERSECTION 1

CONTROLLER TIMING DATA

CARD NO.	CARD TYPE	NODE NO.	OFFSET	OFFSET REF INT	INTERVAL DURATIONS (SECS. OR PERCENT) INT1	INT2	INT3	INT4	INT5	INT6	INT7	INT8	INT9	INT10	INT11	DOUBLE CYCLE
4	12	1	0	1	5	6	4	8	8	4	0	0	0	0	0	0

PHASE TIMING DATA

CARD NO.	CARD TYPE	NODE NO.	START INT	VARIAB. INT	YELLOW INT	ALL-RED INT	MINIM. SECS.	LINKS MOVING IN THIS PHASE								CONT. FLAG
5	21	1	1	1	3	0	15	101	103	0	0	0	0	0	0	0
6	22	1	4	4	6	0	20	104	103	0	0	0	0	0	0	0

LINK DATA

CARD NO.	CARD TYPE	LINK NO.	LINK LENGTH	SAT. FLOW	TOTAL VOL.	MID-BLK. VOL.	FIRST INPUT LINK NO.	VOL.	SPD/TT	SECOND INPUT LINK NO.	VOL.	SPD/TT	THIRD INPUT LINK NO.	VOL.	SPD/TT	
7	28	101	0	3270	572	0	0	0	0	0	0	0	0	0	0	0
8	28	104	313	1640	436	0	208	21	25	203	305	25	211	110	25	0
9	28	103	313	3270	484	0	211	121	25	203	339	25	208	24	25	0

--- PROGRAM NOTE --- TRANSYT-7F NOW BEGINS FINAL PROCESSING AFTER ALL INTERSECTIONS HAVE BEEN INPUT.

GRAPH PLOT CARDS

CARD NO.	CARD TYPE	LINK NO.	LINK NO.	LINK NO.	LINK NO.	LINK NO	LINK NO.	LINK NO.	LINK NO.							
74	40	101	104	201	203	301	303	401	403	0	0	0	0	0	0	0
75	40	501	503	601	603	701	703	801	803	0	0	0	0	0	0	0

RUN CARD

CARD NO.	CARD TYPE															
76	52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

--- PROGRAM NOTE --- A CARD TYPE 52 CAUSES RUN TO BE OPTIMIZED USING THE DEFAULT NORMAL OPTIMIZATION STEP SIZES.
IF CARD TYPE 4 WAS INPUT, IT IS IGNORED.

--- PROGRAM NOTE --- THERE ARE A TOTAL OF 8 NODES AND 42 LINKS (INCLUDING BOTTLENECKS, IF ANY) IN THIS RUN.

--- PROGRAM NOTE --- THERE WERE A TOTAL OF 1 WARNING MESSAGES ISSUED IN THE ABOVE REPORT.

ASHLEY DRIVE ARTERIAL ANALYSIS - TRANSYT-7F- OPT 112 SEC CYCLE PM PEAK 112 SECOND CYCLE 56 STEPS

--- PROGRAM NOTE --- THIS IS THE INPUT DATA REPORT FOR TIME-SPACE DIAGRAM NO. 1

TIME-SPACE DIAGRAM DATA

CARD NO.	CARD TYPE	NO. NODES	TIME FLAG	TIME SCALE	DIST. SCALE											
77	60	8	0	0	67	0	0	0	0	0	0	0	0	0	0	0

PLOT TITLE CARD

CARD NO.	TITLE
78	ASHLEY DRIVE - OPTIMUM CYCLE

PLOT LINK STREAM CARD

CARD NO.	CARD TYPE	LINK PAIRS ALTERNATING BY DIRECTION DOWN	AND UP	DOWN	AND UP	DOWN	AND UP	DOWN	AND UP	DOWN	AND UP	DOWN	AND UP	DOWN	AND UP	
79	61	101	104	201	203	301	303	401	403	501	503	601	603	701	703	0
80	61	801	803	0	0	0	0	0	0	0	0	0	0	0	0	0

TERMINATION CARD

CARD NO.	CARD TYPE															
81	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

--- PROGRAM NOTE --- END OF JOB!

Figure 86. Typical TRANSYT-7F Input Data Report

lays may only be slow downs and not full stops, the calculation of stops may be adjusted by entering the appropriate parameters on Card Type 5. The recommended values found to be valid in England are as follows:

Seconds of Delay:	1	2	3	4	5	6	7	8	9	10	>10
% of Stops:	20	50	65	76	83	88	93	95	97	99	100

OUTPUT REPORTS

There are five basic outputs available from a successful TRANSYT-7F run (i.e., no errors detected).

Input Data Report

The input data are echoed in essentially the same format they were input, with column headings to identify each data item. An example is shown in Figure 86.

Traffic Performance Tables

Traffic performance estimates are produced for each set of timings, normally initial and/or final. An example of the final performance table is shown in Figure 87. The initial has the identical format, but is labeled "initial".

Below the title, the link data are given, along with several measures of effectiveness (MOE) and green periods (in seconds). The link MOE's are subtotaled by node to enable rapid identification of critical intersec-

ASHLEY DRIVE ARTERIAL ANALYSIS - TRANSYT-7F- OPT 112 SEC CYCLE PM PEAK   112 SECOND CYCLE 56 STEPS

FINAL SETTINGS OBTAINED WITH STEP SIZES : 8 22 -1 8 22 1 -1 1

NODE NO	LINK NO	FLOW (VEH/H)	SAT FLOW (VEH/H)	DEGREE OF SAT (%)	TOTAL TRAVEL (VEH-MI/H)	TOTAL TIME (VEH-H/H)	UNIFORM DELAY (VEH-H/H)	RANDOM DELAY (VEH-H/H)	TOTAL DELAY (VEH-H/H)	UNIFORM STOPS (VEH/H;%)	MAX BACK OF QUEUE (VEH)	FUEL CONSUM (GAL/H)	GREEN START (SEC)	PERIOD LENGTH (SEC)	LINK NO
1	101	572	3270	36	0.0	2.746	2.697	0.049	2.746	327.5(57%)	10	3.73	102	54	101
1	103	484	3270	15	28.57	1.121	0.0	0.0	0.0	0.0(0%)	0	1.39	0	112	103
1	104	436	1640	58	25.74	2.523	1.309	0.204	1.513	234.9(54%)	8	3.23	48	50	104
1:		1492	MAX =	58	54.31	6.391	4.006	0.253	4.259	562.4(38%)	10(M)	8.35	NODE PI =		8.2
2	201	496	4860	24	26.81	3.567	2.495	0.020	2.514	399.3(81%)	13	4.63	26	46	201
2	203	644	3270	47	34.81	4.329	2.859	0.104	2.963	318.5(49%)	10	4.79	26	46	203
2	206	516	2950	85	0.0	7.190	6.008	1.181	7.190	476.7(92%)	15	6.89	0	22	206
2	207	584	3270	61	0.0	5.600	5.367	0.233	5.600	478.4(82%)	15	6.18	76	32	207
2	208	45	1440	11	0.0	0.355	0.352	0.003	0.355	31.4(70%)	1	0.40	76	32	208
2	210	423	1440	45	22.87	1.777	0.787	0.092	0.879	107.7(25%)	3	2.10	0	72	210
2	211	231	1640	27	0.0	0.927	0.903	0.024	0.927	118.6(51%)	4	1.32	76	58	211
2	212	276	1440	65	0.0	2.877	2.577	0.300	2.877	229.7(83%)	7	3.05	76	32	212
2:		3215	MAX =	85	84.49	26.622	21.348	1.957	23.305	2160.3(67%)	15(M)	29.36	NODE PI =		38.3
3	301	1428	4860	45	78.97	4.956	2.111	0.092	2.203	381.3(27%)	14	7.25	2	72	301
3	303	582	3270	24	35,44	1.569	0.159	0.019	0.178	29.7(5%)	1	1.97	104	82	303
3	304	93	2590	57	5.66	2.053	1.639	0.191	1.831	92.7(100%)	3	1.62	104	6	304
3	305	165	3270	25	0.0	1.692	1.672	0.020	1.692	132.9(81%)	4	1.78	78	22	305
3	306	211	1640	63	0.0	2.588	2.327	0.260	2.588	184.6(87%)	6	2.58	78	22	306
3	310	383	1640	32	23.32	1.057	0.105	0.036	0.142	19.7(5%)	1	1.31	104	82	310
3:		2862	MAX =	63	143.40	13.914	8.014	0.619	8.633	840.8(29%)	14(M)	16.50	NODE PI =		14.5
7	701	1382	3270	67	91.03	5.992	2.086	0.333	2.419	320.8(23%)	12	7.29	10	70	701
7	702	230	1640	22	15.15	0.883	0.273	0.016	0.288	39.1(17%)	1	1.08	10	70	702
7	703	931	5100	29	50.91	2.259	0.232	0.029	0.261	35.3(4%)	1	2.79	10	70	703
7	705	407	4430	29	0.0	3.243	3.213	0.031	3.243	291.4(72%)	9	3.69	84	34	705
7	706	229	1640	45	0.0	1.997	1.907	0.090	1.997	174.2(76%)	6	2.23	84	34	706
7	709	226	1640	22	14.89	0.757	0.157	0.015	0.172	16.7(7%)	1	0.89	10	70	709
7:		3405	MAX =	67	171.97	15.131	7.868	0.513	8.381	877.5(26%)	12(M)	17.97	NODE PI =		14.5
8	801	1578	3270	67	85.31	5.038	1.356	0.334	1.690	225.0(14%)	7	6.15	4	80	801
8	802	263	1640	72	14.22	3.312	2.303	0.451	2.754	231.8(88%)	7	3.21	60	24	802
8	803	1029	5100	43	0.0	5.461	5.382	0.079	5.461	637.1(62%)	21	7.32	4	52	803
8	807	295	1800	73	0.0	3.737	3.238	0.499	3.737	262.7(89%)	8	3.69	88	24	807
8	808	36	1640	10	0.0	0.341	0.338	0.003	0.341	27.1(75%)	1	0.36	88	24	808
8	812	259	1640	71	0.0	3.243	2.821	0.422	3.243	227.8(88%)	7	3.20	88	24	812
8:		3460	MAX =	73	99.52	21.132	15.438	1.788	17.226	1611.4(47%)	21(M)	23.94	NODE PI =		28.4

TOTAL DISTANCE TRAVELED (VEH-MI/H)	TOTAL TRAVEL TIME (VEH-H/H)	TOTAL UNIFORM DELAY (VEH-H/H)	TOTAL RANDOM DELAY (VEH-H/H)	TOTAL DELAY (VEH-H/H)	TOTAL UNIFORM STOPS (VEH/H)	TOTAL FUEL CONSUM (GAL/H)	PERFORMANCE INDEX	SPEED (MI/H)
970.97	115.506	71.525	6.216	77.741	7681.8	133.81	131.09	8.41

Figure 87. Typical TRANSYT-7F Traffic Performance Table

tions. Starred (*) links are bus links. The "system" MOE's are shown at the bottom of the table.

Flow Profile Plots (Optional)

Figure 88 shows a typical flow pattern plot for a link that enters an intersection which is double cycled (i.e., the controller completes two identical cycles in the time alloted for one system cycle). The flow patterns use symbols to enable the user to "see" what is happening over the signal cycle. The following symbols are used:

a. Flow that queues at the stopline, normally on red (I).

b. Flow leaving the stopline on green which clears the queue(s).

c. Arrivals on green that may or not be delayed, as explained below (o).

The symbol (S) represents queue discharge and is generally at the saturation flow rate. The symbol (O) represents arrivals and when below the (S), indicates those vehicles which join the back of the queue when the "O's" appear without the "S's" above them, these are undelayed arrivals/departures.

The flows are overlayed so the distortion caused by red/green periods are easily observed. The horizontal scale is always constant and equal to the cycle length in steps. The vertical scale is always flow rate, but the scale depends on the maximum flow. The saturation flow always extends to the top of the respective plot (i.e., 24 lines).

These plots are intended to be used to verify field conditions by merely observing whether the intersection approaches actually perform as predicted.

The Mean Modules of Error (MME) printed with the graph is a measure of how much the profile of the arrival flow deviates from the mean value. It is an index from 0 to 1. If the inflow as exactly uniform the MME would equal zero, while a high MME would indicate a link on which the flow is strongly platooned and would particularly benefit from progression. The MME (in Figure 89/0.62) indicates a moderately high potential for progression.

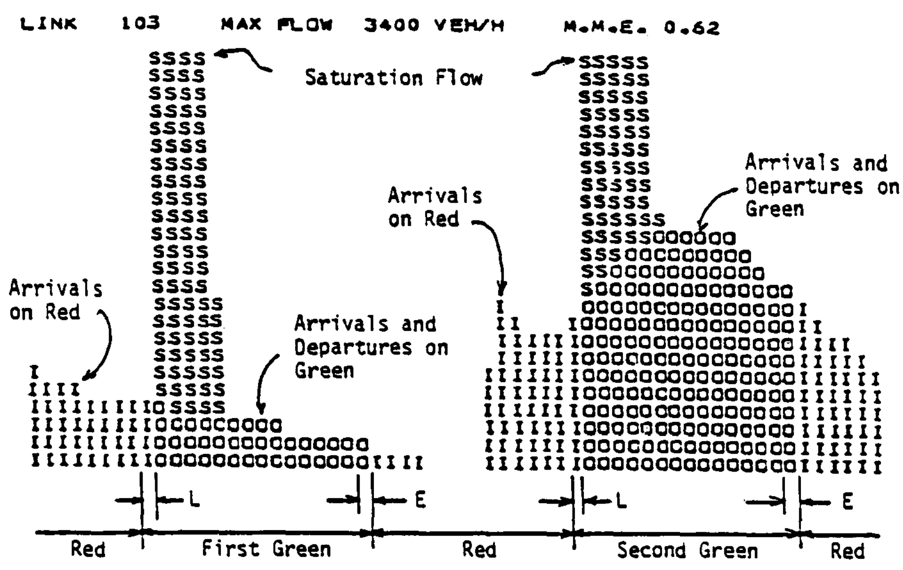

Figure 88. Explanation of TRANSYT-7F Flow Profile Plots

Values approaching 1.0 indicate the link can definitely benefit from progression.

Signal Timing Tables

TRANSYT-7F produces a unique output of signal settings, as shown Figure 89. For pretimed controllers, these timings may be readily implemented in the field with no further manual manipulation, so long as the offsets do not fall within a clearance (or on another pin in the case of electro-mechanical controllers). Warnings are issued in the event of either of these conflicts.

Time-Space Diagrams

TRANSYT-7F will print a time-space diagram for any selected route of up to 50 nodes. The route need not be linear, and many plots

```
ASHLEY DRIVE ARTERIAL ANALYSIS - TRANSYT-7F- OPT 112 SEC CYCLE  PM PEAK          112 SECOND CYCLE  56 STEPS

-------------------------------------
TRANSYT-7F SIGNAL CONTROLLER SETTINGS
-------------------------------------


-------------------------------
NETWORK-WIDE SIGNAL TIMING DATA
-------------------------------

SYSTEM CYCLE LENGTH =  112 SECONDS

MASTER OFFSET REFERENCE LOCATION = INTERSECTION NO.    1

ALL OFFSETS ARE REFERENCED TO THE START OF INTERVAL NO. 1 AT THIS SIGNAL.


--------------------------------
INTERSECTION CONTROLLER SETTINGS
--------------------------------


-------------------------
INTERSECTION NUMBER     1
-------------------------

INTERVAL NUMBER:        1    2    3    4    5    6

LENGTH (SEC):          48    6    4   42    8    4

LENGTH (%):            43    5    4   37    7    4

PIN SETTINGS (%):   100/0   43   48   52   89   96

PHASE START (PH #):     1             2

VARIABLE INT.(PH #):    1             2

OFFSET =   0 SEC.   0 %.

THIS IS THE MASTER CONTROLLER.

+++ 137 +++ WARNING + THE OFFSET FALLS WITHIN 1% OF AN INTERVAL CHANGE POINT AT THE START OF INTERVAL NO.  1
```

Figure 89. TRANSYT-7F Signal Timing Table

may be printed. The symbols of the diagram shown on Figure 90 are as follows:

a. "+" green in the direction of increasing distance from the origin (down the page).

b. "-" green in the direction of decreasing distance (up the page).

c. "blank" green on the route in both directions.

d. "*" red on the route.

Although through bands are not explicitly plotted, the scaling allows convenient use of such tools as triangles and protractors to plot the bands. A speed protractor is available in the TRANSYT-7F User's Manual (Reference 9.4).

ADDITIONAL FEATURES

TRANSYT-7F has a number of options, most of which are handled by control cards as discussed in an earlier section. It has already been noted that buses can be modeled separately by including bus links. These can either be separate lanes or shared lanes. In addition, pedestrians can be modeled by treating them as "vehicles" on separate links. Care must be taken to insure that pedestrians do not interchange with vehicles in the flow patterns. Pedestrian links should have zero stop penalty and delay weights if it is desired to exclude them from the PI and fuel calculations.

TRANSYT-7F can be used to design larger networks by subdividing the networks into sections that can be handled by the present

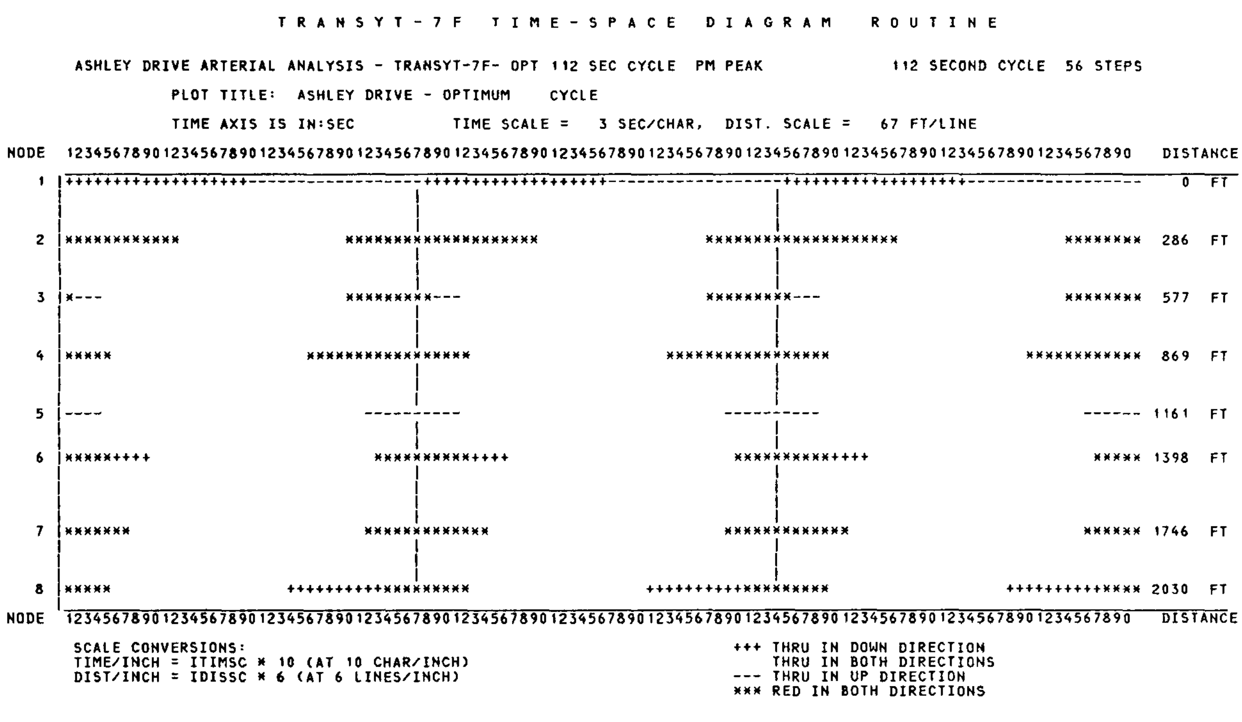

Figure 90. TRANSYT-7F Time-Space Diagram Plot

program (i.e., 50 nodes and 250 links). The boundary nodes are fixed from section to section so that their timings are not changed in the subsequent analysis. In this manner, sections can be "stacked" such that they will always share one or more nodes whose timings will be optimized in one section then remain fixed in the subsequent section.

Additionally, bottlenecks and unsignalized intersections can be considered. At intersections governed by a fixed priority rule (e.g. stop sign on cross-street) the main route traffic incurs no delay. The inflow from the side road is given a "GO" pattern proportionate to its actual capacity which is a function of the main street traffic.

While TRANSYT-7F is the most current version of TRANSYT readily available in the U.S., TRRI has also written version 8 which improves upon the current version (Reference 7.5); however, this version is only available on a license basis (i.e., only "end" users may purchase the program).

APPLICATIONS AND LIMITATIONS

In addition to designing the optimal signalization of coordinated networks, TRANSYT-7F can analyze existing (or any preset) conditions by simply inputting Card Type 51 (Run Card).

TRANSYT-7F does not explicitly optimize the cycle length or phase sequences; however, these can be "optimized" by multiple runs with varying values of the cycle length input in Card Type 1 or phase sequences on Card Types 2X. A manual approach similar to the hill climb technique explained earlier should be used (probably with the "quick optimization" procedure used in the initial trials and the normal optimization used for "fine tuning").

The shortcomings listed in the above paragraphs are clearly limitations present in this version; however, TRANSYT-7F is sufficiently realistic to design many network configurations, and can be extremely useful to the local traffic agency.

Other limiting assumptions are listed below:

a. All major intersections in the network have traffic signals, although sign-controlled intersections and other mid-block bottlenecks can be modeled.

b. Traffic entering the network from the outside does so at a constant uniform rate on each approach. This is not unrealistic over a long period such as an hour.

c. The volumes and proportions of turns remain constant at each approach for the entire period of analysis.

d. Traffic dispersion is assumed to be uniform for the period of analysis.

The last three are probably the most serious of limitations; although the platoon dispersion model is far more realistic than a simpler assumption of uniform platoons.

EXAMPLE APPLICATION

In order to illustrate the use of TRANSYT-7F the arterial problem previously utilized for PASSER 80 was selected. The following describes this example application of TRANSYT-7F.

Problem Description

Ashley Drive has eight signals interconnected as part of a downtown signal system. Previous analysis has indicated that the existing phasing is adequate. However, the city does desire to determine if an improved operation can occur by changing the cycle lengths, splits, and offsets. TRANSYT-7F, will be utilized to develop and evaluate alternative signal timing.

Analysis of Existing Conditions

The first step in the evaluation process is to use TRANSYT-7F to represent existing conditions. This condition is the basis for evaluating other alternatives.

In order to code data for TRANSYT-7F properly a link-node map with pertinent information is essential. Figure 91 illustrates one method of preparing such a map. This map shows link number, lane usage, volumes, distance between stop bars, and intersection numbers. The only additional information that would be required is existing signal timing. To code existing conditions, information is required on offsets, phasing, and interval lengths for vehicle and pedestrian signal displays. Figure 92 illustrates the coded input data for existing conditions. A total of 82 cards were required to represent the eight nodes and 42 links.

The input data were keypunched and submitted to the computer for execution. Figure 94 illustrates part of the input data report obtained from this run.

Review of the traffic performance table on Figure 94 for each of the links, permits a ready identification of existing problems The _01 links for each node (signal) are the major northbound thru movements. Information on degree of saturation, stops and maximum back of queue can be quickly identified for these links as well as identification of other problems.

For instance, the approach with the highest degree of saturation is link 206, the eastbound dual turn at node 2, Kennedy Blvd. For this links 91% of all approaching traffic must stop.

On the other hand, link 201 (the northbound thru approach) requires only 3% of the traffic to stop, indicating that the offset between beginning of green at Jackson Street and beginning of green at Kennedy Street for this movement is virtually ideal.

At the bottom of Figure 95 are the measures of effectiveness for the network as a whole. These are not as meaningful as the link statistics for evaluating a specific run. However, they can be extremely useful when compared to other alternatives as will be seen during the evaluation of alternatives.

The determination of the number of vehicles stopping on the approach can be more clearly seen on the flow profile plots on Figure 95. Link 101 (the upper left plot) is an entry link with uniform arrivals throughout the cycle. However, for link 201 (the middle left plot) we can see few arrivals on red (the III symbols). Virtually all movements (97%) are arrivals and departures on green (the 000 symbols).

Figure 96 is an example of the signal timing output obtained. Since this is an existing conditions run, their settings should represent actual field settings.

The last report obtained from the existing conditions run is the time space plot shown on Figure 97. This graphically displays the green time available in both directions. However, no statistics on bandwidth and progressive speed are available. The user must make the calculations for these parameters. For the existing conditions there is a bandwidth of approximately 26 seconds at a speed of 34 miles per hour (four mph over the speed limit) or for the average travel speed of 25 mph the bandwidth would be 20 seconds. There is no bandwidth in the opposing (southbound) direction.

Define and Analyze Alternatives

The TRANSYT-7F model can be utilized to develop optimal signal timing settings for given cycle lengths and phasing. In order to define these alternatives it is only necessary to change a few cards.

Basically these changes include the control card (to specific cycle length, steps and automatic generation of initial timings) and

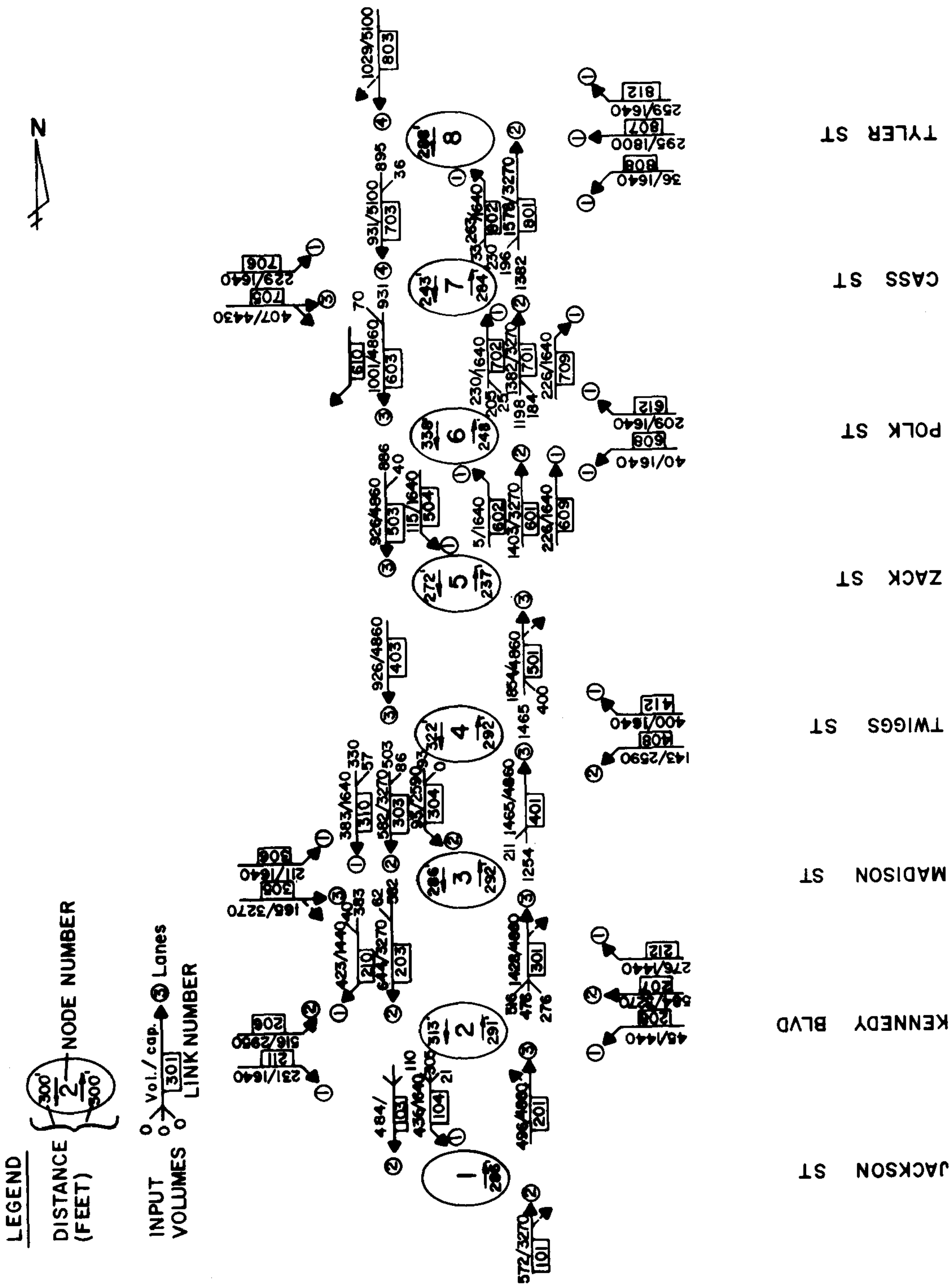

Figure 91. TRANSYT-7F Link Node Network-Ashley Drive

TRANSYT-7F CONTROL CARDS CITY TAMPA PAGE 1 OF 7

NETWORK ASHLEY DRIVE DATE 8/17/81

CONDITION EXISTING CODED BY ASB

CC	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
Field	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Run Title	ASHLEY DRIVE ARTERIAL ANALYSIS - TRANSYT-7F OPT 70 SEC CYCLE PM PEAK															
Control Card	Card Type	Cycle Length (sec)	Cycle Length (steps)	Stop Penalty	Time Simulated (mins)	Start-Lost Time	Green Exten.	Init. Settings	Speed (0) Trv.T. (1)	Output Level	Engl. (0) Metric (1)	Sec (0) Perc (1)	Not Used	Not Used	Percent Scale all Vol.	Not Used
	1	70	35	25	60	2	3	1	0	2	0	0				
Node List Cards	2	1	2	3	4	5	6	7	8							
	2															
	2															
	2															
	2															
Hill-Climb Step Sizes	4															
Stops per Delay	5															
Sensitivity Parameters	6															
Shared Stoplines	7															
	7															
	7															
	7															
Network Master	10	1														
Field	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

5 - 12

DATA SET NAME

TRANSYT-7F INTERSECTION CARDS CITY TAMPA PAGE 2 OF 7

NETWORK ASHLEY DRIVE DATE 8/17/81

CONDITION EXISTING CODED ASB

CC	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
Field	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Card Types																
Controller Card	Type 1X (x=#φ)	Node No.	Off-set	Off-set Ref. Int.	Interval Durations (Intervals 1-11): 1	2	3	4	5	6	7	8	9	10	11	Double Cycle (1)
Cont. Card	Type 18	Node No.	Interval Durations (Intervals 12-25): 12	13	14	15	16	17	18	19	20	21	22	23	24	25
Phase Card	Type 2X (x=φ#)	Node No.	Ph.Start Int. No.	Variab. Int. No.	Yellow Int. No.	All-Red Int. No.	Min. Length	Links Moving During This Phase								Cont. Flag (1)
Cont. Card	Type 2Y (y=φ#)	Node No.	Additional Links Moving During This Phase													Cont. Flag (2)
Link Card	Type 28	Link No.	Link Length	Sat. Flow	Total Vol.	Mid-blk Vol.	1st Input Link: No.	Vol.	Speed	2nd Input Link: No.	Vol.	Speed	3rd Input Link: No.	Vol.	Speed	Not Used
Cont. Card	Type 29	Link No.	Additional Lost Time	Additional Clear. Util.	Not used		4th Input Link: No.	Vol.	Speed	Not Used						
Data	12	1	00	1	5	6	4	8	8	4						
	21	1	1	1	3	0	15	101	103							
	22	1	4	4	6	0	20	104	103							
	28	101	0	3270	572	0										
	28	104	313	1640	436	0	208	21	25	203	305					
	28	103	313	3270	484	0	211	121	25	203	339					
Field	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

5 - 13

DATA SET NAME

Figure 92. TRANSYT-7F Coded Input Data Forms for Ashley Drive Existing Conditions.

TRANSYT-7F CONTINUATION OF CARD(S) CITY TAMPA PAGE 3 OF 7
NETWORK ASHLEY DRIVE DATE 8/17/81
CONDITION EXISTING CODED BY ASB

Field	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
CC	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
Data	13	2	00	1	7	10	4	5	10	4	5	10	4			
	21	2	1	1	3	0	21	201	203	210						
	22	2	4	4	6	0	19	211	208	207	212					
	23	2	7	7	9	0	19	206	211	210						
	28	201	286	4860	496	0	101	496	25							
	28	203	286	3270	694	0	303	582	25	305	62	25				
	28	210	286	1990	423	0	310	383	25	305	40	25				
	28	206	0	2950	516	0										
	28	211	0	1690	231	0										
	28	207	0	3270	584	0										
	28	208	0	1990	45	0										
	28	212	0	1440	276	0										
	13	3	00	1	1	10	4	9	10	4	6	4				
	21	3	1	1	3	0	15	301	303	310						
	22	3	4	4	6	0	23	305	306							
	23	3	7	7	8	0	10	304	303	310						
	28	301	291	4860	1428	160	206	516	25	201	476	25	212	276	25	
	28	303	322	3270	582	0	403	503	25	408	86	25				
	28	304	322	2590	93	0	403	93	25							
	28	310	322	1640	383	0	403	330	25	408	57	25				

DATA SET NAME

TRANSYT-7F CONTINUATION OF CARD(S) CITY TAMPA PAGE 4 OF 7
NETWORK ASHLEY DRIVE DATE 8/17/81
CONDITION EXISTING CODED BY ASB

Field	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
CC	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
Data	28	305	0	3270	165	0										
	28	305	0	1690	211	0										
	12	4	00	1	1	10	4	9	10	4						
	21	4	1	1	3	0	15	401	403							
	22	4	4	4	6	0	23	408	412							
	28	401	292	4860	1465	0	301	1254	25	306	211	25				
	28	403	272	4860	926	0	503	926	25							
	28	408	0	2590	143	0										
	28	412	0	1640	400	0										
	12	5	00	1	1	10	4	9	10	4						
	21	5	1	1	3	0	15	501	503							
	22	5	4	4	6	0	23	504	503							
	28	501	292	4860	1854	0	401	1465	25	412	400	25				
	28	503	338	4860	926	0	603	886	25	608	40	25				
	28	504	338	1640	115	0	603	115	25							
	13	6	00	1	1	10	4	9	10	4	6	4				
	21	6	1	1	3	0	15	601	602	609	603					
	22	6	4	4	6	0	23	608	612							
	23	6	7	7	8	0	10	602	601	609						
	28	601	237	3270	1403	0	501	1403	25							

DATA SET NAME

Figure 92. TRANSYT-7F Coded Input Data Forms for Ashley Drive Existing Conditions (Continued).

TRANSYT-7F CONTINUATION OF CARD(S) CITY TAMPA PAGE 5 OF 7

NETWORK ASHLEY DRIVE DATE 8/17/81

CONDITION EXISTING CODED BY ASB

CC	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
Field	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Data	28	602	237	1640	10	0	501	10	25							
	28	609	237	1640	226	0	501	226	25							
	28	603	243	4860	1001	0	703	931	25	705	70	25				
	28	608	0	1640	40	0										
	28	612	0	1640	209	0										
	12	7	00	1	1	0	4	9	10	4						
	21	7	1	1	3	0	15	701	702	709	703					
	22	7	4	4	6	0	23	705	706							
	28	701	348	3270	1382	0	601	1198	25	612	184	25				
	28	702	348	1640	230	0	601	205	25	612	25	25				
	28	709	348	1640	226	0	609	226	25							
	28	703	288	5100	931	0	803	895	25	808	36	25				
	28	705	0	4430	407	0										
	28	706	6	1640	229	0										
	13	8	00	1	1	10	4	11	4	9	10	4				
	21	8	1	1	3	0	15	801	803							
	22	8	4	4	5	0	15	801	802							
	23	8	6	6	8	0	23	807	808	812						
	28	801	284	3270	1578	0	701	1392	25	706	196	25				
	28	802	284	1640	263	0	702	230	25	706	33	25				
Data	28	803	0	5100	1049	0										
	28	807	0	1800	295	0										
	28	808	0	1640	36	0										
	28	812	0	1640	259	0										
CC	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
Field	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

DATA SET NAME

Card Types

Card Types	Type									
Profile Plots	Type 40	Link Numbers To Be Plotted: T. Lft.	T. Rt.	B. Lft.	B. Rt.	T. Lft.	T. Rt.	B. Lft.	B. Rt.	Not Used
Run Card	Type 5X	Not Used — X: 0 = As Indicated Above; 1 = Simulate Only; 2 = Optimize (long); 3=Optimize (short)								
Plot Param.	Type 60	No. Nodes	Time Units	Time Scale	Dist. Scale					
Plot Title	Any Alphanumeric Information									
Link List	Type 61	Links To Be Plotted In Pairs (Each Pair Must End At The Same Node)								Not Used
Term. Card	Type 9X	Not Used — X: 0 = End; 1 = Read A New Data Deck								

Data																
	40	101	104	201	203	301	303	401	403							
	40	501	503	601	603	701	703	801	803							
	52															
	60	8			67											
	ASHLEY	DRIVE -	OPTIMUM	CYCLE												
	51	101	104	201	203	301	303	401	403	501	503	601	603	701	703	
	51	801	803													
	90															
Field	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

DATA SET NAME

Figure 92. TRANSYT-7F Coded Input Data Forms for Ashley Drive Existing Conditions (Continued).

T R A N S Y T - 7 F -- T R A F F I C S I G N A L S Y S T E M O P T I M I Z A T I O N P R O G R A M

RELEASE 1 AUG, 1981 VERSION 7.0

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OFFICE OF TRAFFIC OPERATIONS

DEVELOPED BY:
TRANSPORT AND ROAD RESEARCH LABORATORY
UNITED KINGDOM AND
TRANSPORTATION RESEARCH CENTER
UNIVERSITY OF FLORIDA

I N P U T D A T A R E P O R T F O R R U N 1

ASHLEY DRIVE ARTERIAL ANALYSIS - TRANSYT-7F- EXISTING CONDITION PM PEAK

CARD NO.	CARD TYPE	CYCLE LENGTH	STEPS PER CYC.	STOP PENALTY	PERIOD LENGTH	LOST TIME	GREEN EXTEN.	INITIAL TIMINGS (CONTROL FLAGS)	SPEED/ T-TIME	OUTPUT LEVEL	ENGLISH/ METRIC	SEC/ PERCENT			FLOW SCALE	
1	1	90	45	25	60	2	3	0	0	2	0	0	0	0	0	0

LIST OF NODES TO BE OPTIMIZED

CARD NO.	CARD TYPE															
2	2	1	2	3	4	5	6	7	8	0	0	0	0	0	0	0

SYSTEM MASTER DATA

CARD NO.	CARD TYPE	MASTER NODE	SYSTEM SATFLOW	SYSTEM PDF	EXTERNAL SPEED	FUEL FACTOR										
3	10	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

--- PROGRAM NOTE --- INPUT UNITS WERE SPECIFIED AS FOLLOWS:

SPEED/TRAVEL TIME IN SPEED
ENGLISH/METRIC UNITS IN ENGLISH
TIMING UNITS IN SECONDS

INTERSECTION 1

CONTROLLER TIMING DATA

CARD NO.	CARD TYPE	NODE NO.	OFFSET	OFFSET REF INT	INT1	INT2	INT3	INT4	INT5	INT6	INT7	INT8	INT9	INT10	INT11	DOUBLE CYCLE
4	12	1	47	1	16	6	4	52	8	4	0	0	0	0	0	0

INTERVAL DURATIONS (SECS. OR PERCENT)

PHASE TIMING DATA

CARD NO.	CARD TYPE	NODE NO.	START INT	VARIAB. INT	YELLOW INT	ALL-RED INT	PHASE MINIM. SECS.	LINKS MOVING IN THIS PHASE								CONT. FLAG
5	21	1	1	1	3	0	15	101	103	0	0	0	0	0	0	0
6	22	1	4	4	6	0	20	104	103	0	0	0	0	0	0	0

LINK DATA

CARD NO.	CARD TYPE	LINK NO.	LINK LENGTH	SAT. FLOW	TOTAL VOL.	MID-BLK. VOL.	FIRST INPUT LINK.... NO.	VOL.	SPD/TT	SECOND INPUT LINK.... NO.	VOL.	SPD/TT	THIRD INPUT LINK.... NO.	VOL.	SPD/TT	
7	28	101	0	3270	572	0	0	0	0	0	0	0	0	0	0	0
8	28	104	313	1640	436	0	208	21	25	203	305	25	211	110	25	0
9	28	103	313	3270	484	0	211	121	25	203	339	25	208	24	25	0

INTERSECTION 2

Intersections 2 thru 8 similar

68	28	801	284	3270	1578	0	701	1382	25	706	196	25	0	0	0	0
69	28	802	284	1640	263	0	702	230	25	706	33	25	0	0	0	0
70	28	803	0	5100	1029	0	0	0	0	0	0	0	0	0	0	0
71	28	807	0	1800	295	0	0	0	0	0	0	0	0	0	0	0
72	28	808	0	1640	36	0	0	0	0	0	0	0	0	0	0	0
73	28	812	0	1640	259	0	0	0	0	0	0	0	0	0	0	0

--- PROGRAM NOTE --- TRANSYT-7F NOW BEGINS FINAL PROCESSING AFTER ALL INTERSECTIONS HAVE BEEN INPUT.

GRAPH PLOT CARDS

CARD NO.	CARD TYPE	LINK NO.	LINK NO.	LINK NO.	LINK NO.	LINK NO.	LINK NO.	LINK NO.	LINK NO.							
74	40	101	104	201	203	301	303	401	403	0	0	0	0	0	0	0
75	40	501	503	601	603	701	703	801	803	0	0	0	0	0	0	0

RUN CARD

CARD NO.	CARD TYPE															
76	51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

--- PROGRAM NOTE --- A CARD TYPE 51 CAUSES JOB TO BE EXECUTED AS A SIMULATION RUN,
DELETING ANY OPTIMIZATION VALUES INPUT.

--- PROGRAM NOTE --- THERE ARE A TOTAL OF 8 NODES AND 42 LINKS (INCLUDING BOTTLENECKS, IF ANY) IN THIS RUN.

Figure 93. TRANSYT-7F Input Data Report for Existing Conditions on Ashley Drive

ASHLEY DRIVE ARTERIAL ANALYSIS - TRANSYT-7F- EXISTING CONDITION PM PEAK 90 SECOND CYCLE 45 STEPS

INITIAL SETTINGS

NODE NO	LINK NO	FLOW (VEH/H)	SAT FLOW (VEH/H)	DEGREE OF SAT (X)	TOTAL TRAVEL (VEH-MI/H)	TOTAL TIME (VEH-H/H)	UNIFORM DELAY (VEH-H/H)	RANDOM DELAY (VEH-H/H)	TOTAL DELAY (VEH-H/H)	UNIFORM STOPS (VEH/H;X)	MAX BACK OF QUEUE (VEH)	FUEL CONSUM (GAL/H)	GREEN START (SEC)	PERIOD LENGTH (SEC)	LINK NO
1	101	572	3270	68	0.0	5.030	4.660	0.369	5.030	484.0(85%)	12	5.96	48	22	101
1	103	484	3270	15	28.57	1.121	0.0	0.0	0.0	0.0(0%)	0	1.39	0	90	103
1	104	436	1640	39	25.74	2.375	1.302	0.063	1.365	352.1(81%)	9	3.80	74	60	104
1:		1492	MAX =	68	54.31	8.526	5.962	0.432	6.394	836.1(56%)	12(M)	11.15	NODE PI =	12.2	
2	201	496	4860	37	26.81	1.339	0.233	0.053	0.286	13.5(3%)	0	1.51	52	24	201
2	203	644	3270	71	34.81	3.922	2.126	0.429	2.556	323.1(50%)	11	4.63	52	24	203
2	206	516	2950	83	0.0	5.708	4.733	0.976	5.708	468.4(91%)	12	6.15	30	18	206
2	207	584	3270	43	0.0	3.054	2.971	0.083	3.054	388.9(67%)	10	4.34	80	36	207
2	208	45	1440	8	0.0	0.197	0.195	0.002	0.197	25.1(56%)	1	0.28	80	36	208
2	210	423	1440	56	22.87	1.472	0.394	0.180	0.575	68.5(16%)	3	1.75	30	46	210
2	211	231	1640	21	0.0	0.390	0.376	0.015	0.390	81.9(35%)	2	0.80	80	58	211
2	212	276	1440	47	0.0	1.527	1.426	0.102	1.527	186.7(68%)	5	2.11	80	36	212
2:		3215	MAX =	83	84.49	17.609	12.453	1.840	14.293	1556.0(48%)	12(M)	21.57	NODE PI =	25.1	
3	301	1428	4860	59	78.97	7.062	4.100	0.209	4.310	796.6(56%)	22	11.09	40	44	301
3	303	582	3270	27	35.44	2.230	0.813	0.025	0.839	157.8(27%)	4	2.97	26	58	303
3	304	93	2590	29	5.66	1.614	1.361	0.031	1.392	92.7(100%)	2	1.42	26	10	304
3	305	165	3270	18	0.0	1.112	1.102	0.010	1.112	117.7(71%)	3	1.40	88	24	305
3	306	211	1640	46	0.0	1.632	1.532	0.100	1.632	164.5(78%)	4	1.99	88	24	306
3	310	383	1640	36	23.32	1.520	0.556	0.049	0.605	104.8(27%)	3	1.98	26	58	310
3:		2862	MAX =	59	143.40	15.171	9.466	0.424	9.889	1434.0(50%)	22(M)	20.85	NODE PI =	19.8	
4	401	1465	4860	55	81.02	5.357	2.005	0.171	2.177	228.7(16%)	6	6.19	42	48	401
4	403	926	4860	35	47.76	8.864	6.942	0.047	6.990	721.8(78%)	19	9.45	42	48	403
4	408	143	2590	14	0.0	0.691	0.685	0.006	0.691	86.1(60%)	2	0.97	4	34	408
4	412	400	1640	63	0.0	2.645	2.382	0.262	2.645	301.1(75%)	8	3.49	4	34	412
4:		2934	MAX =	63	128.77	17.556	12.015	0.487	12.501	1337.7(46%)	19(M)	20.10	NODE PI =	21.8	
5	501	1854	4860	58	102.53	6.468	2.241	0.202	2.443	392.4(21%)	10	8.25	40	58	501
5	503	926	4860	19	59.27	2.326	0.0	0.0	0.0	0.0(0%)	0	2.89	0	90	503
5	504	115	1640	25	7.36	0.771	0.461	0.021	0.482	101.2(88%)	3	1.13	12	24	504
5:		2895	MAX =	58	169.16	9.565	2.702	0.223	2.925	493.6(17%)	10(M)	12.27	NODE PI =	6.4	
6	601	1403	3270	65	62.77	2.898	0.125	0.309	0.434	16.1(1%)	0	3.34	46	58	601
6	602	10	1640	1	0.45	0.019	0.001	0.0	0.001	0.1(1%)	0	0.05	46	58	602

ASHLEY DRIVE ARTERIAL ANALYSIS - TRANSYT-7F- EXISTING CONDITION PM PEAK 90 SECOND CYCLE 45 STEPS

NODE NO	LINK NO	FLOW (VEH/H)	SAT FLOW (VEH/H)	DEGREE OF SAT (X)	TOTAL TRAVEL (VEH-MI/H)	TOTAL TIME (VEH-H/H)	UNIFORM DELAY (VEH-H/H)	RANDOM DELAY (VEH-H/H)	TOTAL DELAY (VEH-H/H)	UNIFORM STOPS (VEH/H;X)	MAX BACK OF QUEUE (VEH)	FUEL CONSUM (GAL/H)	GREEN START (SEC)	PERIOD LENGTH (SEC)	LINK NO
6	603	1001	4860	41	46.03	2.184	0.306	0.072	0.378	71.7(7%)	6	2.81	60	44	603
6	608	40	1640	9	0.0	0.263	0.261	0.002	0.263	27.6(69%)	1	0.33	18	24	608
6	609	226	1640	21	10.11	0.431	0.020	0.014	0.034	2.6(1%)	0	0.52	46	58	609
6	612	209	1640	46	0.0	1.613	1.516	0.097	1.613	162.9(78%)	4	1.97	18	24	612
6:		2889	MAX =	65	119.35	7.407	2.228	0.494	2.722	281.0(10%)	6(M)	9.01	NODE PI =	4.7	
7	701	1382	3270	62	91.03	5.307	1.476	0.258	1.734	620.6(45%)	21	8.62	64	60	701
7	702	230	1640	21	15.15	0.724	0.115	0.013	0.129	41.3(18%)	1	1.02	64	60	702
7	703	931	5100	27	50.91	2.975	0.952	0.025	0.977	515.2(55%)	18	5.74	64	60	703
7	705	407	4430	36	0.0	3.069	3.018	0.050	3.069	316.5(78%)	8	3.80	38	22	705
7	706	229	1640	55	0.0	1.955	1.791	0.164	1.955	187.6(82%)	5	2.31	38	22	706
7	709	226	1640	20	14.89	0.658	0.060	0.013	0.073	33.6(15%)	1	0.94	64	60	709
7:		3405	MAX =	62	171.97	14.687	7.413	0.523	7.937	1714.8(50%)	21(M)	22.43	NODE PI =	19.8	
8	801	1578	3270	67	85.31	4.951	1.266	0.336	1.602	337.6(21%)	9	6.73	52	64	801
8	802	263	1640	53	14.22	2.152	1.441	0.153	1.594	214.5(82%)	6	2.59	0	26	802
8	803	1029	5100	52	0.0	5.944	5.805	0.140	5.944	731.5(71%)	19	8.25	52	34	803
8	807	295	1800	78	0.0	3.326	2.669	0.657	3.326	262.6(89%)	7	3.51	30	18	807
8	808	36	1640	10	0.0	0.283	0.280	0.003	0.283	27.3(76%)	1	0.34	30	18	808
8	812	259	1640	75	0.0	2.872	2.328	0.544	2.872	230.1(89%)	6	3.05	30	18	812
8:		3460	MAX =	78	99.52	19.529	13.789	1.833	15.622	1803.5(52%)	19(M)	24.47	NODE PI =	28.1	

TOTAL DISTANCE TRAVELED (VEH-MI/H)	TOTAL TRAVEL TIME (VEH-H/H)	TOTAL UNIFORM DELAY (VEH-H/H)	TOTAL RANDOM DELAY (VEH-H/H)	TOTAL DELAY (VEH-H/H)	TOTAL UNIFORM STOPS (VEH/H)	TOTAL FUEL CONSUM (GAL/H)	PERFORMANCE INDEX	SPEED (MI/H)
970.97	110.050	66.028	6.256	72.284	9456.7	141.85	137.96	8.82

Figure 94. TRANSYT-7F Traffic Performance Table for Existing Conditions on Ashley Drive.

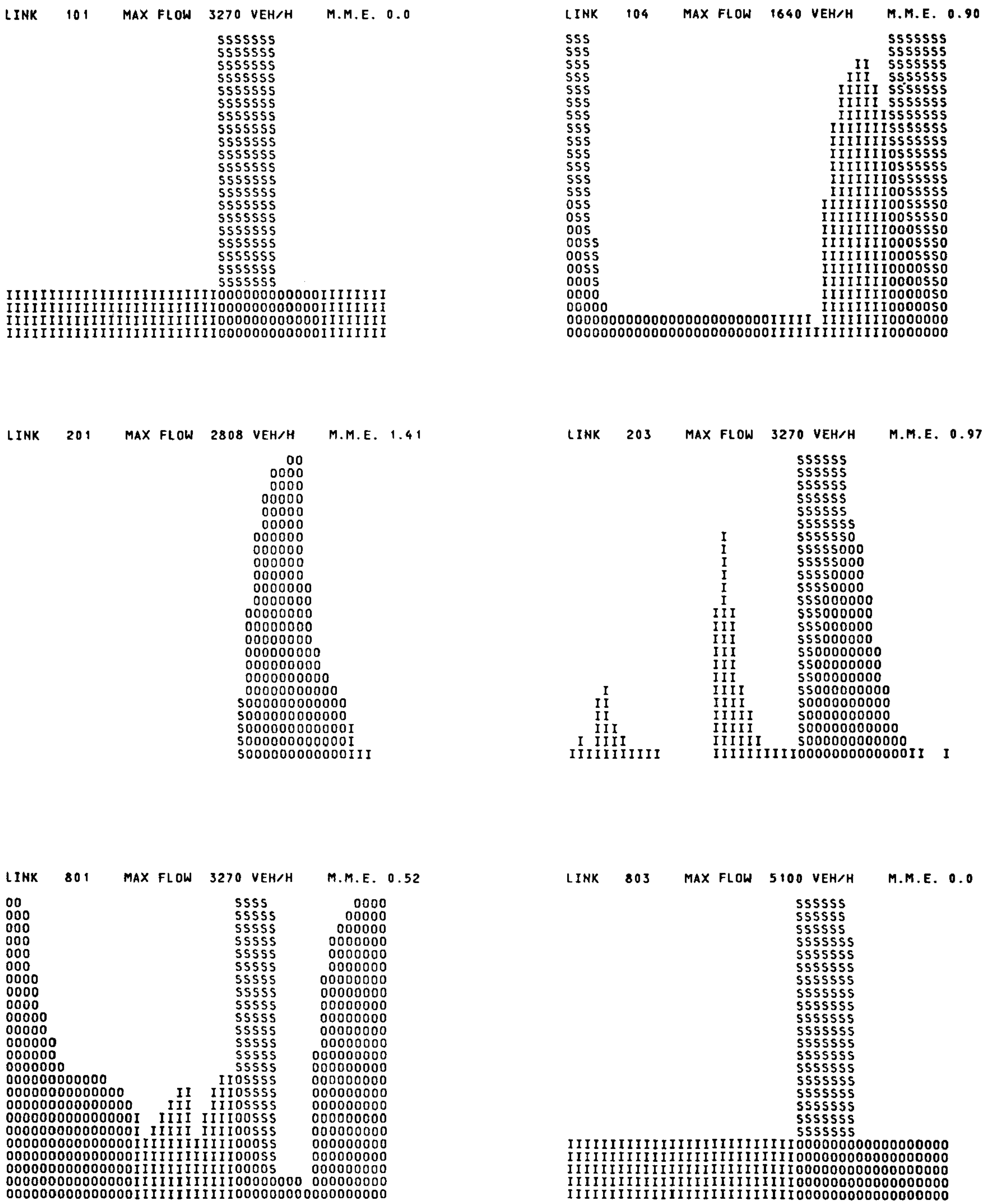

Figure 95. TRANSYT-7F Flow Profile Plots for Existing Conditions on Ashley Drive.

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ASHLEY DRIVE ARTERIAL ANALYSIS - TRANSYT-7F- EXISTING CONDITION PM PEAK            90 SECOND CYCLE  45 STEPS

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TRANSYT-7F SIGNAL CONTROLLER SETTINGS
-------------------------------------


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NETWORK-WIDE SIGNAL TIMING DATA
-------------------------------

SYSTEM CYCLE LENGTH =    90 SECONDS

MASTER OFFSET REFERENCE LOCATION = INTERSECTION NO.     1

ALL OFFSETS ARE REFERENCED TO THE START OF INTERVAL NO.  1 AT THIS SIGNAL.

--------------------------------
INTERSECTION CONTROLLER SETTINGS
--------------------------------



-------------------------
INTERSECTION NUMBER     1
-------------------------

INTERVAL NUMBER:        1   2   3   4   5   6
LENGTH (SEC):          16   6   4  52   8   4
LENGTH (%):            18   7   4  58   9   4
PIN SETTINGS (%):   100/0  18  25  29  87  96
PHASE START (PH #):     1           2
VARIABLE INT.(PH #):    1           2
OFFSET =    0 SEC.    0 %.
THIS IS THE MASTER CONTROLLER.
+++ 137 +++ WARNING + THE OFFSET FALLS WITHIN 1% OF AN INTERVAL CHANGE POINT AT THE START OF INTERVAL NO.  1


-------------------------
INTERSECTION NUMBER     2
-------------------------

INTERVAL NUMBER:        1   2   3   4   5   6   7   8   9
LENGTH (SEC):          14  10   4  26  10   4   8  10   4
LENGTH (%):            16  11   4  30  11   4   9  11   4
+++ 129 +++ WARNING + DUE TO ROUNDOFF, INTERVAL NO.  4 HAD TO BE ADJUSTED BY  0 SEC AND/OR   1%.
PIN SETTINGS (%):   100/0  16  27  31  61  72  76  85  96
PHASE START (PH #):     1           2           3
VARIABLE INT.(PH #):    1           2           3
OFFSET =    4 SEC.    4 %.
+++ 137 +++ WARNING + THE OFFSET FALLS WITHIN 1% OF AN INTERVAL CHANGE POINT AT THE START OF INTERVAL NO.  9
```

Intersections 3 thru 7 similar

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INTERSECTION NUMBER     8
-------------------------

INTERVAL NUMBER:        1   2   3   4   5   6   7   8
LENGTH (SEC):          24  10   4  26   4   8  10   4
LENGTH (%):            27  11   4  30   4   9  11   4
+++ 129 +++ WARNING + DUE TO ROUNDOFF, INTERVAL NO.  4 HAD TO BE ADJUSTED BY  0 SEC AND/OR   1%.
PIN SETTINGS (%):   100/0  27  38  42  72  76  85  96
PHASE START (PH #):     1           2       3
VARIABLE INT.(PH #):    1           2       3
OFFSET =    4 SEC.    4 %.
+++ 137 +++ WARNING + THE OFFSET FALLS WITHIN 1% OF AN INTERVAL CHANGE POINT AT THE START OF INTERVAL NO.  8
```

Figure 96. TRANSYT-7F Signal Timing Tables for Existing Conditions on Ashley Drive.

```
ASHLEY DRIVE ARTERIAL ANALYSIS - TRANSYT-7F- EXISTING CONDITION PM PEAK            90 SECOND CYCLE  45 STEPS
--- PROGRAM NOTE --- THIS IS THE INPUT DATA REPORT FOR TIME-SPACE DIAGRAM NO.  1
                                                       TIME-SPACE  DIAGRAM  DATA
CARD    CARD    NO.     TIME    TIME    DIST.
 NO.    TYPE    NODES   FLAG    SCALE   SCALE
 77      60       8       0       0      67       0       0       0       0       0       0       0       0       0       0       0

                                                            PLOT  TITLE  CARD
CARD
 NO.     TITLE
 78      ASHLEY DRIVE - EXISTING TIMING
                                                        PLOT  LINK  STREAM  CARD
CARD    CARD    LINK PAIRS ALTERNATING BY DIRECTION
 NO.    TYPE    DOWN AND UP     DOWN AND UP     DOWN AND UP     DOWN AND UP     DOWN AND UP     DOWN AND UP     DOWN AND UP
 79      61     101     104     201     203     301     303     401     403     501     503     601     603     701     703       0

 80      61     801     803       0       0       0       0       0       0       0       0       0       0       0       0       0


                     T R A N S Y T - 7 F   T I M E - S P A C E   D I A G R A M   R O U T I N E

           ASHLEY DRIVE ARTERIAL ANALYSIS - TRANSYT-7F- EXISTING CONDITION PM PEAK            90 SECOND CYCLE  45 STEPS
                    PLOT TITLE:  ASHLEY DRIVE - EXISTING TIMING
                    TIME AXIS IS IN:SEC         TIME SCALE =   3 SEC/CHAR,  DIST. SCALE =   67 FT/LINE
NODE  12345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890  DISTANCE
   1 |+++++++++---------------------+++++++++---------------------+++++++++---------------------+++++++++-----------     0  FT
     |                             |                             |                             |
   2 |*          ********************          ********************          ********************          *********   286  FT
     |                             |                             |                             |
   3 |             **********----                **********----                **********----               ********   577  FT
     |                             |                             |                             |
   4 |               *************                 *************                 *************                ******   869  FT
     |                             |                             |                             |
   5 |                  ---------                     ---------                     ---------                    ---  1161  FT
     |                             |                             |                             |
   6 |++++                *********+++++                *********+++++                *********+++++               *  1398  FT
     |                             |                             |                             |
     |                             |                             |                             |
   7 |*****                      ********                      ********                      ********                 1746  FT
     |                             |                             |                             |
   8 |*             +++++++++********             +++++++++********             +++++++++********            +++++++  2030  FT
NODE  12345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890  DISTANCE
        SCALE CONVERSIONS:                                                 +++ THRU IN DOWN DIRECTION
        TIME/INCH = ITIMSC * 10 (AT 10 CHAR/INCH)                              THRU IN BOTH DIRECTIONS
        DIST/INCH = IDISSC * 6 (AT 6 LINES/INCH)                           --- THRU IN UP DIRECTION
                                                                           *** RED IN BOTH DIRECTIONS

                                                            TERMINATION  CARD
CARD    CARD
 NO.    TYPE
 81      90       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
--- PROGRAM NOTE --- END OF JOB!
```

Figure 97. TRANSYT-7F Time Space Plot for Existing Conditions on Ashley Drive.

ASHLEY DRIVE ARTERIAL ANALYSIS - TRANSYT-7F- EDFT 70 SEC CYCLE PM PEAK   70 SECOND CYCLE 35 STEPS

FINAL SETTINGS OBTAINED WITH STEP SIZES : 5 14 -1 5 14 1 -1 1

NODE NO	LINK NO	FLOW (VEH/H)	SAT FLOW (VEH/H)	DEGREE OF SAT (%)	TOTAL TRAVEL (VEH-MI/H)	TOTAL TIME (VEH-H/H)	UNIFORM DELAY (VEH-H/H)	RANDOM DELAY (VEH-H/H)	TOTAL DELAY (VEH-H/H)	UNIFORM STOPS (VEH/H;%)	MAX BACK OF QUEUE (VEH)	FUEL CONSUM (GAL/H)	GREEN START (SEC)	PERIOD LENGTH (SEC)	LINK NO
1	101	572	3270	72	0.0	4.185	3.725	0.460	4.185	488.6(85%)	10	5.61	2	18	101
1	103	484	3270	15	28.57	1.121	0.0	0.0	0.0	0.0(0%)	0	1.39	0	70	103
1	104	436	1640	40	25.74	1.327	0.252	0.065	0.317	134.3(31%)	5	2.13	22	46	104
1:		1492	MAX =	72	54.31	6.634	3.977	0.525	4.502	622.9(42%)	10(M)	9.14	NODE PI =		8.8
2	201	496	4860	34	26.81	1.211	0.114	0.044	0.158	77.4(16%)	3	1.80	12	20	201
2	203	644	3270	66	34.81	3.176	1.497	0.312	1.809	218.1(34%)	4	3.71	12	20	203
2	206	516	2950	72	0.0	3.870	3.360	0.460	3.870	440.8(85%)	9	5.08	62	18	206
2	207	584	3270	54	0.0	3.146	2.985	0.162	3.146	435.0(74%)	9	4.73	38	22	207
2	208	45	1440	10	0.0	0.200	0.197	0.002	0.200	28.4(63%)	1	0.31	36	22	208
2	210	423	1440	50	22.87	1.321	0.297	0.126	0.423	56.8(13%)	2	1.62	62	40	210
2	211	231	1640	23	0.0	0.379	0.362	0.017	0.379	89.0(39%)	2	0.85	36	42	211
2	212	276	1440	58	0.0	1.639	1.436	0.203	1.639	211.6(77%)	4	2.35	38	22	212
2:		3215	MAX =	72	84.49	14.891	10.248	1.326	11.574	1557.2(48%)	9(M)	20.45	NODE PI =		22.4
3	301	1428	4860	62	78.97	5.773	2.763	0.257	3.020	629.3(44%)	16	9.34	68	32	301
3	303	582	3270	29	35.44	1.779	0.358	0.030	0.388	102.8(18%)	2	2.46	58	42	303
3	304	93	2590	36	5.66	1.325	1.052	0.050	1.102	92.7(100%)	2	1.28	58	6	304
3	305	165	3270	17	0.0	0.808	0.799	0.008	0.808	113.6(69%)	2	1.23	34	20	305
3	306	211	1640	43	0.0	1.190	1.110	0.080	1.190	156.8(74%)	3	1.73	34	20	306
3	310	383	1640	38	23.32	1.219	0.246	0.058	0.304	69.3(18%)	2	1.65	58	42	310
3:		2862	MAX =	62	143.40	12.094	6.328	0.484	6.812	1164.4(41%)	16(M)	17.70	NODE PI =		14.9
4	401	1465	4860	60	81.02	5.338	1.929	0.229	2.158	271.7(19%)	6	6.41	2	34	401
4	403	926	4860	38	47.76	6.795	4.862	0.059	4.920	835.3(90%)	16	9.13	2	34	403
4	408	143	2590	13	0.0	0.488	0.483	0.005	0.488	81.5(57%)	2	0.84	40	28	408
4	412	400	1640	59	0.0	1.892	1.682	0.210	1.892	281.9(70%)	6	3.00	40	28	412
4:		2934	MAX =	60	128.77	14.513	8.956	0.502	9.458	1470.6(50%)	16(M)	19.39	NODE PI =		19.7
5	501	1854	4860	68	107.53	7.458	3.062	0.371	3.433	531.0(29%)	11	9.46	0	38	501
5	503	926	4860	19	59.27	2.328	0.0	0.0	0.0	0.0(0%)	0	2.89	0	70	503
5	504	115	1640	20	7.36	0.385	0.085	0.012	0.097	26.2(23%)	1	0.55	42	24	504
5:		2895	MAX =	68	169.16	10.170	3.147	0.383	3.530	557.2(19%)	11(M)	12.89	NODE PI =		7.4
6	601	1403	3270	70	62.77	3.021	0.153	0.403	0.557	105.4(8%)	9	3.89	8	42	601
6	602	10	1640	1	0.45	0.018	0.001	0.000	0.001	0.3(3%)	0	0.05	8	42	602
6	603	1001	4860	44	46.03	2.791	0.900	0.084	0.984	127.4(13%)	3	3.39	18	32	603
6	608	40	1640	8	0.0	0.192	0.190	0.002	0.192	26.4(66%)	1	0.29	54	20	608
6	609	276	1640	22	10.11	0.425	0.012	0.016	0.028	5.2(2%)	0	0.53	8	42	609
6	612	209	1640	42	0.0	1.176	1.098	0.078	1.176	155.3(74%)	3	1.71	54	20	612
6:		2889	MAX =	70	119.35	7.623	2.354	0.584	2.938	419.8(15%)	9(M)	9.85	NODE PI =		5.9
7	701	1382	3270	72	91.03	5.355	1.316	0.466	1.782	287.5(21%)	8	6.82	14	40	701
7	702	230	1640	24	15.15	0.785	0.171	0.019	0.190	33.4(15%)	1	1.01	14	40	702
7	703	931	5100	31	50.91	2.152	0.119	0.035	0.154	31.6(3%)	1	2.72	14	40	703
7	705	407	4430	28	0.0	1.916	1.889	0.027	1.916	278.9(69%)	6	2.99	58	22	705
7	706	229	1640	42	0.0	1.198	1.120	0.078	1.198	164.0(72%)	3	1.79	58	22	706
7	709	226	1640	24	14.69	0.681	0.078	0.018	0.096	11.3(5%)	0	0.83	14	40	709
7:		3405	MAX =	72	171.97	12.086	4.693	0.643	5.336	806.7(24%)	8(M)	16.15	NODE PI =		10.9
8	801	1578	3270	79	85.31	5.498	1.434	0.716	2.149	283.5(18%)	7	6.68	16	42	801
8	802	263	1640	66	14.22	2.077	1.201	0.318	1.519	214.2(81%)	4	2.56	42	16	802
8	803	1029	5100	61	0.0	5.661	5.417	0.244	5.661	793.4(77%)	16	8.60	16	22	803
8	807	295	1600	55	0.0	1.779	1.615	0.164	1.779	227.7(77%)	5	2.54	62	20	807
8	808	36	1640	7	0.0	0.173	0.171	0.001	0.173	23.7(66%)	0	0.26	62	20	808
8	812	259	1640	53	0.0	1.555	1.409	0.146	1.555	199.3(77%)	4	2.22	62	20	812
8:		3460	MAX =	79	99.52	16.742	11.247	1.589	12.836	1741.8(50%)	16(M)	22.85	NODE PI =		24.9

TOTAL DISTANCE TRAVELED (VEH-MI/H)	TOTAL TRAVEL TIME (VEH-H/H)	TOTAL UNIFORM DELAY (VEH-H/H)	TOTAL RANDOM DELAY (VEH-H/H)	TOTAL DELAY (VEH-H/H)	TOTAL UNIFORM STOPS (VEH/H)	TOTAL FUEL CONSUM (GAL/H)	PERFORMANCE INDEX	SPEED (MI/H)
970.97	94.751	50.949	6.037	56.986	8340.5	128.42	114.91	10.25

Figure 98. TRANSYT-7F Traffic Performance Table for Optional Solution on Ashley Drive.

Table 23 - Comparison of TRANSYT-7F MOE's For Alternate Cycle Lengths Ashley Drive

Alternate	Cycle Length	Total Travel Time (Veh-H/H	Total Delay Veh-H/H	Total Uniform Stops Veh/H	Total Fuel Consumption (Veh/H)	Performance Index	Speed (MPH)
Existing	90 sec.	110.050	72.284	9456.7	141.85	137.96	8.82
1	70 sec.	94.751*	56.986*	8340.5	128.42*	114.91*	10.25*
2	72 sec.	98.293	60.528	9076.8	133.46	123.56	9.88
3	74 sec.	97.871	60.105	8635.6	131.46	120.07	9.92
4	76 sec.	96.792	59.027	8784.9	131.36	120.03	10.03
5	78 sec.	97.630	59.864	8756.4	131.57	120.67	9.95
6	80 sec.	100.056	62.291	8637.8	132.33	122.28	9.70
7	82 sec.	100.880	63.114	8194.6	130.13	120.02	9.63
8	84 sec.	100.896	63.131	8449.6	131.81	121.81	9.62
9	86 sec.	102.010	64.244	8450.5	132.34	122.93	9.52
10	88 sec.	103.027	65.262	8439.2	132.79	123.87	9.42
11	90 sec.	104.474	66.708	8384.8	133.14	124.94	9.29
12	92 sec.	104.664	66.899	8019.4	130.77	122.59	9.28
13	94 sec.	105.338	67.572	7979.8	131.12	122.59	9.22
14	96 sec.	107.089	69.323	7944.4	131.45	124.49	9.07
15	98 sec.	107.442	69.676	7920.6*	131.55	124.68	9.04

* Lowest value for MOE

Controller Timing Card (to specify fixed intervals) for each intersection. If alternative phasing schemes are to be considered then the phase timing cards for each phase must be changed.

Since previous evaluation (PASSER 80) indicated the phasing was adequate it is only necessary to define alternatives by varying the cycle length. For this example an optimal signal plan was developed for each two (2) second increase in cycle length from 70 seconds to 98 seconds. This required changing 12 cards in the existing conditions run (two control cards, two title cards and eight control timing cards).

Evaluation of Results

Table 23 provides a comparison in network wide MOE's for each of the 15 alternatives. In general as cycle length increased, travel time increased, stops decreased, and speed was relatively unchanged. All of the alternative signal plans developed by TRANSYT-7F resulted in improved traffic flow.

The optimal cycle length was a 70 second cycle. Total delay would be reduced by 20% (from 72.28 veh-hrs/hr to 56.99) while stops are reduced by 12%, as well as total fuel consumption. Average operational speed is increased from 8.8 mph to 10.3 mph.

Figure 98 shows the traffic performance expected on each of the links for the optimal 70 second cycle. The degree of saturation was slightly increased on some approaches in order to provide additional time for links with higher level of saturation. The most noticable improvement on a link by link basis is that in every case the maximum queue has decreased on each link. For instance, the maximum back of queue for existing conditions was 22 vehicles for link 301. For the optimal 70 sec. cycle the maximum expected back of queue for link 301 was reduced to 16 vehicles, or 27 percent.

Summary of Work Effort Required

The following summarizes the work effort required to run the TRANSYT-7F model for this problem.

Data Collection - Very little time is required to obtain data since all the information is normally obtained by the traffic engineering office except link to link turning movement counts for street segments which used two or more links to describe traffic flow. To accurately measure these data mini-origin/destination studies would have to be conducted, however, reasonable procedures for estimating these movements are found in the User's Manual (page 5-26 to 5-93, Reference 9.4).

Data Coding - The coding of data for TRANSYT-7F does requires some time, however, the primary effort is the time required to transform data from the information on-hand (turning movements, signal timing etc.) to that required for coding. It was found to be easier to summarize this data on the link-node network prior to coding. Preparation of the link-node sketch, summarization of data and actual coding of forms required approximately four hours. An additional hour was required to review, identify and correct coding errors for existing conditions.

Computer Time - Required CPU time for the existing conditions was approximately .97 second per run (a total of three runs were required). The optimization runs required from 6.22 seconds of CPU time for the 70 second cycle to 9.06 seconds for the 98 second cycle. A total of 284 K of core storage was required.

REFERENCES

9.1 Robertson, D.I., "TRANSYT: A Network Study Tool," TRRL Report LR 253, 1969.

9.2 Robertson, D.I. and P. Gower, "User Guide to TRANSYT Version 6," TRRL Supplementary Report 255, 1977.

9.3 Hunt, P.B. and J.V. Kennedy, "A Guide to TRANSYT/7," TRRL Note UN/78/11, January, 1978.

9.4* Wallace, C.E., K.G. Courage, D.P. Reaves, G.W. Schoene and G.W. Euler, "TRANSYT-7F User's Manual," Prepared for the Federal Highway Administration, Office of Traffic Operations, Contract No. DTFH61-80-C-00072, February, 1981.

9.5 Vincent, R.A., A.I. Mitchell and D.I. Robertson, "Users Guide to TRANSYT Version 8," TRRL Report LR 888, 1980.

CHAPTER 10 - SIGOP III (NETWORK OPTIMIZATION MODEL)

Chapter 9 described a street network signal analysis and optimization model developed in the United Kingdom called TRANSYT. This chapter describes a similar model developed in the United States -- SIGOP III. The similarities between SIGOP III and TRANSYT fall primarily in the functional area; that is, both models are macroscopic signal timing design and analysis models. Both contain two primary submodels: 1) a traffic flow submodel and 2) an optimization submodel which minimizes a user specified "disutility" function. The specific approaches employed differ somewhat between the models, however.

SIGOP III uses the underlying principles of the TRANSYT model, and was based upon the following objectives (10.2).

1. Develop a new, improved optimization procedure.
2. Improve effective utilization of the model.
3. Enable explicit representations of the traffic environment, including exclusive turning bays.
4. Consider the effect of extensive queueing to prevent "spillover" into upstream intersections.
5. Explicitly consider multi-phase control.
6. Include useful features of other models.

SIGOP III is an outgrowth of the SIGOP model, but most of the difficulties with the earlier model have been overcome. Several SIGOP features, notably the time-space plot capability, have been retained in SIGOP III.

One of the major differences between SIGOP III and TRANSYT concerns the optimization objective function. TRANSYT considers delay and stops. SIGOP III also considers delay and stops but, additionally, the objective function includes a term for queue "spillover."

Figure 99. Arterial Network

SIGOP III is a powerful analysis and design tool. Preset conditions, such as existing conditions, may be analyzed in terms of a number of useful traffic engineering measures. The signal timing may be optimized for cycle length, splits and effects to minimize the "disutility" function. Comparisons of results of several candidate configurations enables the engineer to evaluate the relative effectiveness of the alternative designs.

SIGOP III was developed by KLD Associates, Inc. for the Office of Research, Federal Highway Administration (FHWA). The model will be disseminated and maintained by the Implementation Division of FHWA, thus the utility and useful life of the model should be both current and reliable.

Program inputs include network geometrics, traffic flows and link capacities, link speeds, signal timing parameters and control options. The inputs are greatly improved over the original SIGOP. Data requirements for SIGOP III are relatively less than TRANSYT and NETSIM but more than PASSER II(80).

MODEL DESCRIPTION

SIGOP III is an acronym for Traffic SIGnal OPtimization Model, version III. The program is written in FORTRAN IV and has successfully run on both CDC 6600, IBM 360 and 370, and Amdahl 470 computer systems. The current version contains 34 subroutines and 23 common blocks. the FORTRAN program is approximately 7,900 lines in length of which approximately 76% are definition and executable statements. The program requires approximately 300k bytes of core storage on an IBM 360 computer, but an overlay structure reduces the space requirement to 200k bytes.

Execution time is variable and depends upon the number of intersections (nodes) and the number of cycle length iterations. The computing time varies approximately linearly with the number of nodes and cycle iterations (Reference 10.2). Thus, even large networks can be optimized in a relatively short time, and computer time is comparable to recent versions of TRANSYT (TRANSYT-7 and TRANSYT-7F of Chapter 9).

The study network can presently consist of a maximum of 50 nodes and 130 links, however, the developers have given instructions for expanding the capacity of the program (Reference 10.2).

SIGOP III is a macroscopic, deterministic, simulation and optimization model with a periodic time scan over the solution space (e.g., cycle lengths, offsets and splits). The optimization technique employs a gradient methodology to scan the feasible solution surface to be confident that the system-wide global optimum solution is found. The model uses an application of a technique referred to as the "Method of Successive Approximations" (Reference 10.5) that shortens the solution times. These techniques are discussed in greater detail later in this chapter.

The model deals exclusively with mixed-flow traffic on a signalized arterial network. Multiple approaches (e.g., diagonal streets) are permissible and signal timing is assumed to be fixed-time, but with multiple phasing.

The model contains four main program segments which are: 1) an executive module, 2) an initialization module, 3) a traffic submodel, and 4) the optimization submodel. The program structure is shown in Figure 100.

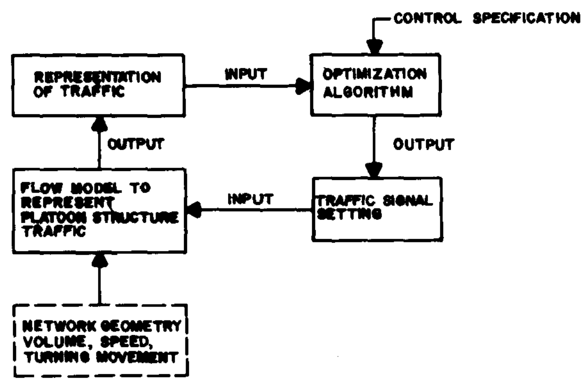


Figure 100. SIGOP III Program Structure

INPUT REQUIREMENTS

There are 13 types of input cards available for SIGOP III, a sample of the deck layout is shown in Figure 101. A largely standardized input format has been designed for the benefit of the users. Alphabetic information is input to name the network and streets. Most numeric data are input in standard 4-column integer fields. A summary of the inputs is provided in Table 24.

Table 24 - Input Requirements For SIGOP III

CARD TYPE	CARD DESCRIPTION	REQUIREMENTS
Identification Card (required)	Provide general information about the run.	Run number, time, date and name of run.
Network Card (required)	Network-wide parameters and objective function.	Min. and max. cycle, half cycle flag, lost time, headways, saturation limits, optimization flag and other control flags.
Minimum Phase Duration Cards (required)	Minimum green times for each node in network.	Node number and minimum greens for each phase.
Link Cards (required)	Link geometric and characteristics.	Link-end node numbers, length, no. of lanes, turn bays, % trucks, speed, headway, lost time, weight factor, input flows, source/sink flows, output flows and control codes.
Coupled Approach Cards (required)	Indicate links that "share" a common stopline and move in parallel.	Link-end node numbers.
Link Name Cards (required)	Link names.	Link-end node numbers and names.
Plot Header Card (optional)	Plot control card.	Number of plots.
Plot Name Card(s) (optional)	Title of plot.	Title.
Node Sequence Cards (optional)	Node sequence for plot.	Node numbers in order to be plotted.
Fixed Offset Cards (optional)	Signal offsets not to be changed.	Node numbers and offsets.
Fixed Phase Duration Cards (optional)	Phase splits not to vary.	Node numbers and splits.
Signal Timing Cards (optional)	Initial phase splits.	Node numbers and signal offsets and phase durations.
End-of-Run	Output control information.	Number of copies of outputs, flow scaling factors (for up to four additional runs) and plot scaling factors.

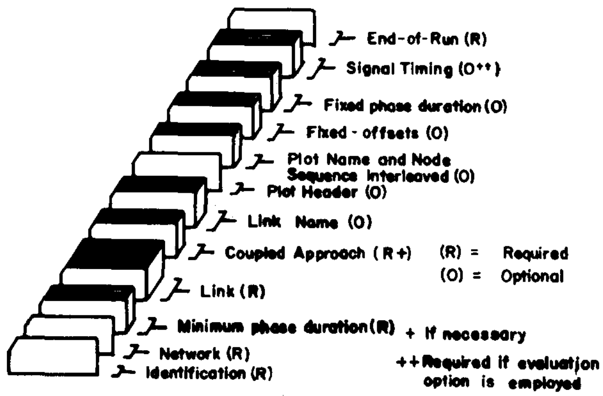


Figure 101. Typical SIGOP III Data Deck

The network structure is input by identifying each node. Links are identified by link-end node numbers, thus a link running from Node 1 to Node 2 would be "named" Link (1,2). Generally, one link will exist between each adjacent set of nodes in each direction, if two-way. Turning bays are handled explicitly, rather than via separate links (e.g. as in TRANSYT). The flow through the network is further identified by inputting the downstream node number receiving through traffic from each link. Only internal links carry traffic. External links (identified by having an external node number of 800 or greater) serve only as input sources, or exit sinks, and no travel occurs in these links. Neither are the 800 level nodes included in the network. Queueing and delay do, however, occur on external input links.

Mid-block sources or sinks may be included to reflect the affect of parking lots, shopping centers, etc.

Links that share common, or parallel, movements may be coupled together and, thus, move on simultaneous phases.

Volumes must be specified, both in terms of inputs and outputs. A "primary" volume is the through input from upstream. "Secondary" volume is that from other upstream movements, such as turns from cross streets (excluding sink/source flows). Output volumes are expressly input as to turning movement, where the through output volume is calculated, as the sum of all inputs, less the sum of output right and left turns. Since the input/output flows are specified per link, volumes need not "balance" from node to node. This is convenient since data collection techniques are rarely sufficiently accurate that volumes do balance.

Signal patterns are input in a fairly easy manner (although probably no more so than in TRANSYT). The steps are given below:

1. Diagram the phase patterns (for several examples see Figure 102) and identify the movement diagram for the link in question (say from the left, or eastbound, in the 4-phase example).

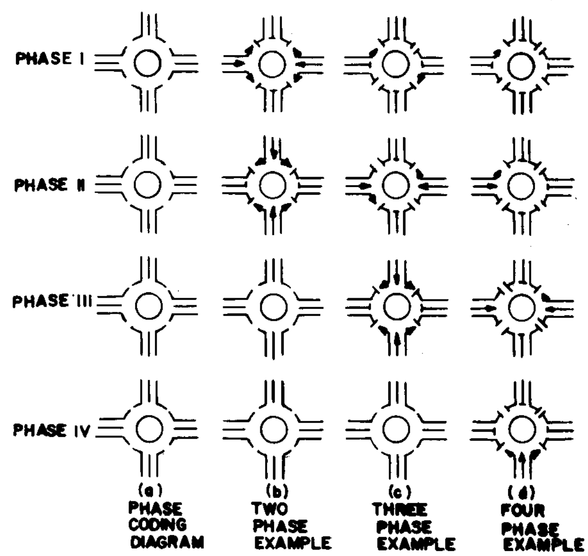


Figure 102. Phase Movement Coding Diagram

2. Determine which phases carry the through movement from this link (e.g. ø2 & ø3).

Table 25 - Input Phase Codes For Link Card

Code	Phase(s) Servicing Indicated Movement			
	I	II	III	IV
1	X			
2		X		
3			X	
4				X
12	X	X		
13	X		X	
14	X			X
23		X	X	
24		X		X
34			X	X
41	X	X	X	
42	X	X		X
43	X		X	X
44	X	X	X	X
45		X	X	X
50	Movement is not services			

3. Enter Table 25 to determine the code for this link that satisfies the phases determined in step 2 (e.g., code = 23). This value is entered in the first of three fields on the Link Card that are provided for patterns.

4. Repeat steps 2 and 3 for left-turns (e.g., code = 12) and right-turns (e.g., code = 50). These codes are entered in the remaining two fields of the pattern section on the Link Card.

5. Repeat steps 1-4 for all remaining approaches at this node, and subsequently for all nodes.

Note that for less than three phases per approach, the code is identical to the phase numbers continuing in order, thus, the user should quickly become familiar with the coding scheme.

The major disadvantage of this approach is the limitation to a 4-phase cycle. Many controllers operate on five or six phases even in fixed time operations. The advantage is that it provides and easy to understand encoding scheme.

Capacities of movements are input in terms of the numbers of lanes, start-up lost time and minimum discharge headways. The latter value, for a given link, is the reciprocal of the maximum vehicle service rate, thus users who normally work with capacities (vphg) can easily convert to minimum discharge headway. For example, 1700 vphg leads to a 2.1 sec headway (3600 sec hour ÷ 1700 vphg). The value is input in tenths of seconds, so 21 would be input.

Signal offsets and splits may be input to analyze preset (e.g., existing) conditions. Furthermore, if the user desires, selective offsets and splits may be input which cannot be changed by the optimization model. This feature may be used, for example, when optimizing a very large system, by segmenting the network into groups of 80 or fewer nodes. The "border" street(s) could be optimized in one segment, then fixed in the adjacent segment.

In summary, the inputs to SIGOP III are functionally similar to TRANSYT. Both programs have some advantages over the other in terms of ease of coding, although SIGOP III appears to have a slight advantage in this regard. One minor problem with the SIGOP III coding scheme is the necessity to indicate, on one card, the identification of the following card. The codes for "next card" vary among cards; thus, the user must always be attentive to the "current" card.

OPERATIONAL SUMMARY

As noted before, SIGOP III is a macroscopic, deterministic model with a traffic submodel and an optimization submodel.

The network is formulated as a system of nodes with unidirectional links between nodes, as required. External links have psuedo nodes, indicated by node numbers greater than 799. An example of a network is shown in Figure 103.

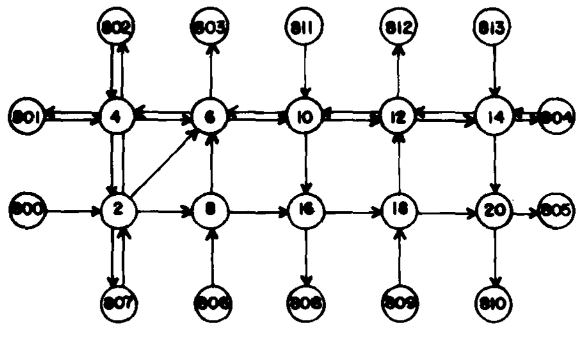


Figure 103. Typical SIGOP III Network

Traffic appears on the external input links and is assumed to arrive uniformly at the input stop line. Within the system traffic is assumed to travel in platoons which disperse over downstream links according to 1) the time of release upstream, 2) the distance traveled and 3) the free speed. The relationship between traffic and control is illustrated in the nine "standard" cases depicted in Figure 104. The primary and secondary platoons are according to the definitions given in the discussion of volumes in the previous section.

Upon the onset of green, and after the initial start-up and acceleration lost times expire, any existing queue is assumed to discharge at the saturation flow rate. The traffic moves in a coherent platoon along the link, but dispersing (i.e. lengthening) as it progresses. Robertsons' platoon dispersion technique (Reference 10.6) is used (although indirectly, as explained later). Delay, stops and queuing can thus be computed, given the predictable arrival and departure profiles of the traffic. The methodology for these computations is discussed in the next section. (Also see Chapter 9 on TRANSYT for further information on platoon dispersion.)

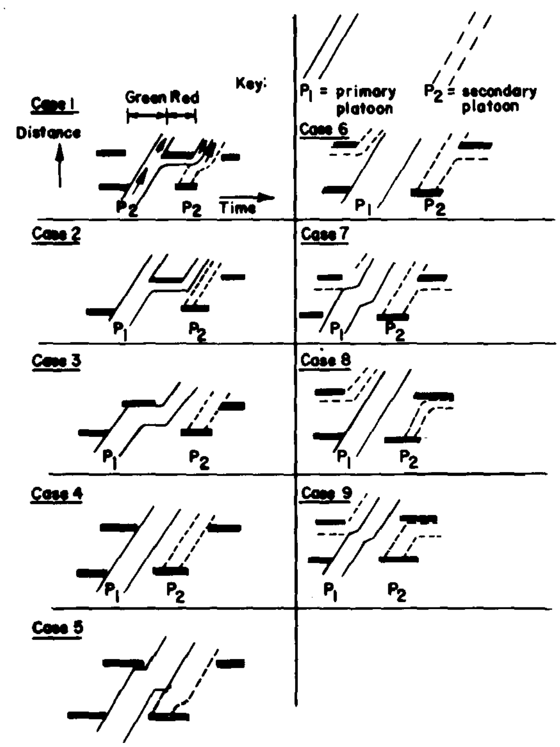


Figure 104. Sketches of Flow Control Configuration, in Time-Space Plane for SIGOP III

The above describes the traffic submodel briefly. The traffic model can be exercised for each link, given the signal timing of the upstream and downstream nodes. The optimization process thus searches for a set of signal timings (offsets and splits) that minimizes the "disutility function" (defined later). By switching the signal timing according to a rule, the effect on traffic flow is recalculated and the disutility is compared with the previous value. If improvement (reduction) results, the model (see Figure 10.2) continues to "search" until disimprovement is encountered. By repeatedly evaluating changes in the disutility, due to new signal settings, an optimal condition, or design, can be determined. The optimization technique is also discussed further in the next section.

COMPUTATIONAL ALGORITHMS

From the foregoing discussion, it might appear that the computations of the SIGOP III model, while numerous, are somewhat trivial. This is not the case. Several sophisticated techniques are employed in both the traffic submodel and the optimization submodel. Indeed, the calculation of splits is of interest as well. Once the signal timing has been completed for any given iteration, the traffic submodel is entered to obtain the measures of effectiveness (MOE) followed by the optimization process. The salient computational algorithms in each of these steps are described below, in turn.

Signal Timing

Signal timings input to the traffic submodel are cycle length, splits and offsets. The cycle length range is a user input as is the increment of cycle length. Thus cycle length is constant for each iteration analyzed. Offsets are affected in the optimization process and are discussed later.

Unlike TRANSYT, which allows all splits to vary (subject to the minimum green constraint) to achieve the lowest value of the objective function, SIGOP III calculates minimum green requirements using Webster's method:

$$g_K = \frac{Y_k}{Y} (C-L), \qquad (10.1)$$

where g_K = green time required to service traffic on approach k,
Y_k = critical volume/capacity ratio for approach k,
$Y = \Sigma Y_k$
C = cycle length, and
L = total lost time per cycle.

Then, if the sum of these green times is less than the cycle length (e.g., $\Sigma g_k < C$), the remaining "slack" time is allocated to the major movements only in the optimization.

Traffic Flow and Measures of Effectiveness (MOE)

The salient MOE noted previously are delay, stops and queue length. The developers of SIGOP III have conducted extensive investigations to relate the offset/split relationship of adjacent signals to traffic flow on the link. The entire process is too complex to relate here, and interested readers are referred to Reference 10.3. Critical to all the calculations is the assumption concerning platoon dispersion. Robertsons' method (Ref. 10.6) was found to be satisfactory (see the discussion on platoon dispersion in Chapter 9), but to eliminate the recursion relationship from the computations (and thus save computing time), a series of studies were performed to replace Robertson's recursion formula with a direct estimate of the additional time required to service a platoon of, say, length N beyond the time the platoon is discharging at the saturation flow rate. Thus, the total green time required to service the bulk of a platoon (e.g., allowing the relatively small number of vehicles, having long headways, at the tail of the platoon to be "clipped" off) was derived as (Ref. 10.3):

$$\nabla = T_P - T_Q = \qquad (10.2)$$

$$a_1 + a_2N + a_3N^2 + L(a_4 + a_5N + a_6N^2)$$

where ∇ = additional time to service the platoon relative to the saturation service rate,

T_P = time for a platoon of length $N-N_C$ to pass a point located L feet downstream of the signal,

T_Q = time required to service a platoon discharging at the saturation rate (e.g., T_Q = Nh, where h is the saturation headway in sec/veh)

a_i = constants of regression,

N = total number of vehicles in the platoon,

L = distance to the downstream point, or the next stopline.

According to the developers, close comparisons resulted from this technique when compared to Robertson's approach.

This approach eliminates the step-wise simulation used in TRANSYT, thus MOE must be calculated deterministically. The current version of SIGOP III calculates delay similar to Websters method (Ref. 10.7); namely for light flow:

$$D = \frac{C(1-\lambda)^2}{2(1-\lambda\chi)} + \frac{\chi^2}{2q(1-\chi)}, \qquad (10.3)$$

where D = average delay in sec/veh,

C = cycle length,

λ = proportion of the cycle that is effectively green,

q = flow rate,

χ = degree of saturation

For moderate to heavy flow the revised equation is (Ref. 10.3):

$$D = \frac{C(1-\lambda)^2}{2(1-\lambda\chi)} + \frac{IH(\mu)\chi}{2q(1-\chi)} \qquad (10.4)$$

where I = variance of the number of arrivals per each cycle divided by the average number of arrivals per cycle;

$H(\mu)$ = a complex function of μ, that shears Webster's curve through the region where the q/s ratio is close to or exceeds 1.0,
where $\mu = (sg-gC)/Isg$,
g = effective green time and,
s = saturation flow in veh/sec; and
all other variables are as previously defined.

Stops are computed for each of the conditions depicted in Figure 10.6, for example for case 1 (Ref. 10.3):

$$S = \alpha(\frac{L}{V} + {}_1 + P_i + t_o - t_{on} + P_2), \qquad (10.5)$$

where S = stops in veh/sec;

α = mean queue service rate, veh/sec;

L = link length, ft.;

V = link free flow speed, fps;

ρ_1 = sum of start-up and acceleration lost time for platoon P_1;

P_i = platoon size expressed in bandwidths, or sec, for primary (i = 1) and secondary (i = 2) platoons;

t_o = start of green at upstream node; and

t_{on} = end of green at downstream node.

Similar formulas were developed and tested for each of the other cases.

The SIGOP III documentation is not clear as to how queue length is explicitly determined. The necessary ingredients are, however, available from the queue profiles depicted on Figure 104 and the estimates of stops. The maximum length is controlled by the user in the parameters input to the disutility function.

Finally, SIGOP III has the facility (if the user so indicates) to automatically examine double cycling of signals if the degree of saturation does not exceed a threshold, also input by the user. This is a very convenient method of examining double cycling.

Optimization Submodel

Most traffic signal optimization models employ some sort of iterative methodology to arrive at the optimal design. SIGOP II employs a unique approach in its optimization process.

First, the objective function (disutility function) is defined as follows (Ref. 10.1):

$$\min \Sigma J_{ij} = \Sigma\left\{D_{ij} + KS_{ij} + \frac{\delta\left[D_Q(Q_{max} - Z_{ij})^2\right]}{R^2}\right\} \quad (10.6)$$

where J_{ij} = disutility on link ij during one cycle;

D_{ij} = delay on link ij per cycle, veh-sec;

S_{ij} = stops on link ij per cycle, veh-stops;

k = user specified equivalence factor for stops;

D_Q = user specified equivalence factor in veh-sec;

$(Q_{max})_{ij}$ = estimated maximum queue length on link ij, in feet;

R = user specified value of residual storage desired on all links beyond $(Q_{max})_{ij}$ to prevent spillback arising from short-term fluctuations in volume, in feet;

Z_{ij} = the distance from the downstream stopline back to the previous intersection, or L_{ij} - R, where, L_{ij} = link length; and

= a binary index which is zero (0) if $Q_{max} \leq Z_{ij}$ or one (1) if $Q_{max} > Z_{ij}$.

The third term, controlled by the index, is not involved unless the maximum queue threatens to spill back into the upstream intersection.

The user controls the objective function through his inputs of the values k, D_Q, and R.

The optimization process is algorithmic, rather than analytical, thus it is described below in steps.

Step 1 - Initial Settings - At the beginning of a run it is necessary to arrive at an initial set of signal timings that will subsequently be revised in the optimization process. The procedure used in SIGOP III produces a "good" set of timings for the network (i.e., including offsets).

a. Transform the network into a series of nodes separated by "links" whose "length" is proportional to the two-way volume on the "link" (the developers refer to these as arcs).

b. Using a technique developed by Kruskal (Ref. 10.8), determine the maximum "path" through the network. That is, construct a "tree" which includes all nodes and is the maximum "length" of all trees possible. Store the node sequence of this tree.

c. For the actual network, use Webster's equation (Eq. (10.1), to determine splits.

d. For each node in turn, construct a mini-network where the current node is the central node and it is connected to any adjacent nodes which have already been processed in this manner (e.g., "brought in" to the network).

e. Treating the current central node of the mini-network, exercise the optimization procedure on the current mini-network to adjust the signal timing of the current (central) node to produce the minimum disutility in the mini-network.

f. Repeat steps 3 through 5 along the spanning tree determined at step 2 until all nodes have been treated.

This process produces a "good" initial timing since the spanning process emphasizes the heaviest traveled links. It thus reduces the number of iterations in the network optimization.

Step 2 - Calculate Traffic Performance and Disutility - The initial settings enter the traffic model and the performance measures and the disutility function are computed as discussed earlier. This process is repeated after each change of signal timing from the optimization process.

Step 3 - Gradient Search - Making use of the known aspects of the relationship between traffic operations and control, namely that platoons arriving primarily during the green will result in the lowest delay and stops (see Figure 104), the developers of SIGOP III established predictable relationships between offsets and splits. The assumption is made first that the primary platoon always enters the link shortly after the beginning of green at the upstream intersection and the secondary platoon enters shortly after the onset of red. By projecting the platoons downstream, an ideal offset is easily determined for each link. A practical range of offsets is also readily calculated, since the length of the platoons (in seconds) is known. Within this relatively narrow range of alternative offsets (and splits on the major links), the optimization submodel does a gradient search over all possible values of offset and split to achieve the minimum network disutility.

The last process is functionally similar to the hillclimb process used in TRANSYT; however, the preparation for entering the search is so highly developed by that point, the computer time required to conduct the search is greatly reduced.

The developers do caution, however, that there is no guarantee that the true global optimum will always be achieved. (Note: This is true of all "optimization" models with the possible exception of MAXBAND, ref. 14.18)

OUTPUT REPORTS

There are three general types of outputs provided by SIGOP III, several of which are comprised of more than one table or plot. The major outputs are discussed separately below.

Input Data Report

The inputs to SIGOP III are reported back to the user in a series of formatted tables. A Link Data Input Report reflects the geometric and traffic data. An example of this report is shown in Figure 105. Data in this report come from the Identification, Network and Link Cards.

Shorter reports indicate the inputs on the Minimum Phase Duration, Coupled Approaches, the various Plot, Fixed Offset and Split and Signal Timing Cards. An example of the Minimum Phase Duration report is shown in Figure 106. The remaining network-wide parameters not specified in Figure 105 are shown in Figure 107.

Table 25 (shown earlier) is also output by SIGOP III for the convenience of the user.

Optimal Signal Settings

The signal settings determined by SIGOP III (or input by the user if no optimization was to be performed) are output in the format shown in Figure 108. Note that the order of phases is not that to be implemented, but rather, phases should be implemented in the order I, II, III and IV, as applicable. The affected links, offset and splits are output for each phase. This permits the relatively easy conversion to yield points after correcting for clearance and interval length.

Performance Analysis

This report shows the disutility value for each iteration of the model, and reports the optimal. For example, in Figure 109, "sweep" 3 was the optimal. Next are given the per-

SIGOP III JANUARY 31,1981

ALGORITHM TO PROVIDE OPTIMAL, CYCLE-BASED, TRAFFIC SIGNAL TIMING PATTERNS

FOR THE PERIOD EXTENDING FROM 1630 TO 1730 HOURS

RUN NUMBER 3 EXECUTED ON 4/ 8/1981

ASHLEY DR ARTERIAL ANALYSIS-OPTIMUM CYCLE RANGE PM PEAK

LINK FROM,TO	RECV NODE	LNGTH (FT)	NO LN	L-PK LANE	R-PK LANE	TRK PCT	SPD MPH	HDWY (SECONDS)	LST (SECONDS)	WT. (SECONDS)	PRI-VOL (VPH)	SEC-VOL (VPH)	S/S-VOL (VPH)	L-TRN (VPH)	R-TRN (VPH)	RED-CLR (SEC)	CODES T	CODES L	CODES R	L
(800, 1)	2	0	2	0	0	5	0	1.9*	3.5*	1.0*	572	0	0	0	76	0	1	50	1	1
(2, 1)	800	313	2	1	0	5	25	1.9*	3.5*	1.0*	644	276	0	436	0	0	12	2	50	2
(1, 2)	3	286	2	1	0	5	25	1.9*	3.5*	1.0*	496	0	0	20	0	0	1	1	50	3
(813, 2)	801	0	2	1	1	5	0	1.9*	3.5*	1.0*	751	154	0	45	276	0	2	2	2	4
(2, 3)	4	291	3	0	0	5	25	1.9*	3.5*	1.0*	476	792	160	0	174	0	1	50	1	5
(801, 2)	3	0	0	2	1	5	0	1.9*	3.5*	1.0*	747	0	0	516	231	0	50	3	23	6
(3, 2)	1	286	2	0	1	5	25	1.9*	3.5*	1.0*	905	102	0	0	423	0	1	50	13	7
(4, 3)	2	322	3	1	0	5	25	1.9*	3.5*	1.0*	915	143	0	93	0	0	13	3	50	8
(802, 3)	812	0	2	1	1	0	0	1.9*	3.5*	1.0*	376	0	0	211	102	0	2	2	2	9
(3, 4)	5	292	3	0	0	5	25	1.9*	3.5*	1.0*	1254	211	0	0	0	0	1	50	50	10
(811, 4)	0	0	0	2	1	0	0	1.9*	3.5*	1.0*	490	42	0	143	389	0	50	2	2	11
(5, 4)	3	272	3	0	0	5	25	1.9*	3.5*	1.0*	926	0	-11	0	0	0	1	50	50	12
(4, 5)	6	292	3	0	0	5	25	1.9*	3.5*	1.0*	1465	389	0	0	220	0	1	50	1	13
(6, 5)	4	338	3	1	0	5	25	1.9*	3.5*	1.0*	1001	40	0	115	0	0	12	2	50	14
(5, 6)	7	237	3	1	0	5	25	1.9*	3.5*	1.0*	1634	0	0	5	0	0	13	3	50	15
(809, 6)	803	0	2	0	0	0	0	1.9*	3.5*	1.0*	135	114	0	40	209	0	2	2	2	16
(7, 6)	5	243	3	0	0	5	25	1.9*	3.5*	1.0*	931	70	0	0	0	0	1	50	1	17
(6, 7)	8	348	3	0	1	5	25	1.9*	3.5*	1.0*	1629	209	0	0	226	0	1	50	1	18
(804, 7)	808	0	3	1	0	5	25	1.9*	3.5*	1.0*	636	0	0	229	70	0	2	2	2	19
(8, 7)	6	288	3	0	0	5	25	1.9*	3.5*	1.0*	895	36	0	0	0	0	1	50	50	20
(7, 8)	806	284	2	1	0	5	25	1.9*	3.5*	1.0*	1623	229	0	263	0	0	12	2	50	21
(807, 8)	805	0	2	0	1	5	25	1.9*	3.5*	1.0*	480	110	0	36	259	0	3	3	3	22
(806, 8)	7	0	3	0	1	5	25	1.9*	3.5*	1.0*	1029	0	0	0	134	0	1	50	1	23

Figure 105. SIGOP III Link Data Input Data Report

MINIMUM PHASE DURATIONS (SEC)

NODE	PHASES I	II	III	IV
1	14	23	0	0
2	23	23	23	0
3	14	23	10	0
4	14	23	0	0
5	14	23	0	0
6	14	23	10	0
7	14	23	0	0
8	14	10	23	0

Figure 106. SIGOP III Minimum Phase Duration Report

SPECIFIED NETWORK-WIDE PARAMETERS

CYCLE LENGTHS- MINIMUM= 70 SEC. MAXIMUM= 78 SEC. INCREMENTAL CHANGES= 2 SEC.

CODE FOR DOUBLE-CYCLING = 1

NETWORK-WIDE START-UP LOSS=3.5 SECONDS DISCHARGE HEADWAY=1.9 SECONDS

WEIGHT ASSIGNED TO VEHICLE STOPS IS 5

VALUE OF PERCENT SATURATION BELOW WHICH A NODE MAY BE DOUBLE-CYCLED IS 25 PERCENT

MIN. DURATION OF HALVED CYCLE LENGTH IS 0 SEC.

MIN. DURATION OF MINOR PHASES IS 10 SEC.

THE MAXIMUM DISUTILITY ARISING FROM A QUEUE EXTENDING THE FULL LENGTH OF A LINK IS 200 VEH-SECONDS (EQUIV.)

RESIDUAL STORAGE THRESHOLD IS 90 FEET

SATURATION CODE= 0 CONTINUITY CODE=25 CONVERGENCE CODE= 4 PROCESSING CODE=0

WARNING SECONDARY VOLUME ON LINK (2, 3) IS TOO HIGH. CONTINUITY VIOLATED BY 65 PERCENT

NUMBER OF OUTPUT COPIES- 1

ADDITIONAL RUNS (IF ANY) WILL APPLY THE FOLLOWING PERCENTAGES OF THE INITIAL VOLUMES- 0 0 0 0

* * * THERE WERE A TOTAL OF 0 INPUT ERRORS * * *

NOSC 7 20 20

Figure 107. SIGOP III Network wide Input Data Report

NETWORK-WIDE SIGNAL SETTINGS

SWEEP NUMBER 3

NODE	PHASE	APPROACH LINKS		OFFSET (SEC)	OFFSET (PCT)	DURATION (SEC.)	SPLIT (PCT.)	CYCLE (SEC.)	CONGEST (1,0)
1	I	(800, 1)	(2, 1)	12	(17)	36	51	70	0,MAJR
1	II	(2, 1)		48	(69)	34	49	70	0,MAJR
2	I	(1, 2)	(3, 2)	37	(53)	23	33	70	0,MAJR
2	II	(813, 2)		60	(86)	24	34	70	0,MAJR
2	III	(3, 2)	(801, 2)	14	(20)	23	33	70	0,MINR
3	I	(2, 3)	(4, 3)	10	(14)	32	46	70	0,MAJR
3	II	(802, 3)		42	(60)	28	40	70	0,MAJR
3	III	(4, 3)		0	(0)	10	14	70	0,MINR
4	I	(3, 4)	(5, 4)	6	(9)	33	47	70	0,MAJR
4	II	(811, 4)		39	(56)	37	53	70	0,MAJR
5	I	(4, 5)	(6, 5)	28	(40)	42	60	70	0,MAJR
5	II	(6, 5)		0	(0)	28	40	70	0,MAJR
6	I	(5, 6)	(7, 6)	10	(14)	27	39	70	0,MAJR
6	II	(809, 6)		37	(53)	33	47	70	0,MAJR
6	III	(5, 6)		0	(0)	10	14	70	0,MINR
7	I	(6, 7)	(8, 7)	36	(51)	46	66	70	0,MAJR
7	II	(804, 7)		12	(17)	24	34	70	0,MAJR
8	I	(7, 8)	(806, 8)	54	(77)	37	53	70	0,MAJR
8	III	(807, 8)		31	(44)	23	33	70	0,MAJR
8	II	(7, 8)		21	(30)	10	14	70	0,MINR

THE FIRST TWO PHASES ARE THE MAJOR PHASES SERVICING THE INDICATED APPROACHES

THE REMAINING PHASES (IF ANY) ARE THE MINOR PHASES

Figure 108. SIGOP III Optimal Signal Settings Report

SYSTEM DISUTILITY

SWEEP	DISUTILITY
1	93009
2	36746
3	20314
4	20469
5	42171
6	32091
7	38263

SWEEP NO. 3 PROVIDES MINIMUM DISUTILITY, 20314, AT A CYCLE OF 70 SECONDS

VEHICLE-MILES/HOUR= 963.9 VEHICLE-HOURS/HOUR= 55.4 MEAN SPEED=17.39 M. P. H. STOPS/MINUTE= 24

LINK FROM, TO	VOLUME (P.C.U./HR.)	EFF. SPEED (M.P.H.)	DELAY (SEC./P.C.U.)	STOPS (PER MIN.)	CAPACITY (P.C.U./HR.)	PERCENT SATURATION	MAXIMUM QUEUE	FUEL (GAL./HR.)
(2, 1)	976	16.2	4.7	3.4	4474	22	4	4
(1, 2)	526	17.7	3.2	0.0	1646	32	0	2
(2, 3)	1559	14.9	5.4	2.6	2366	66	3	7

Figure 109. SIGOP III Performance Report

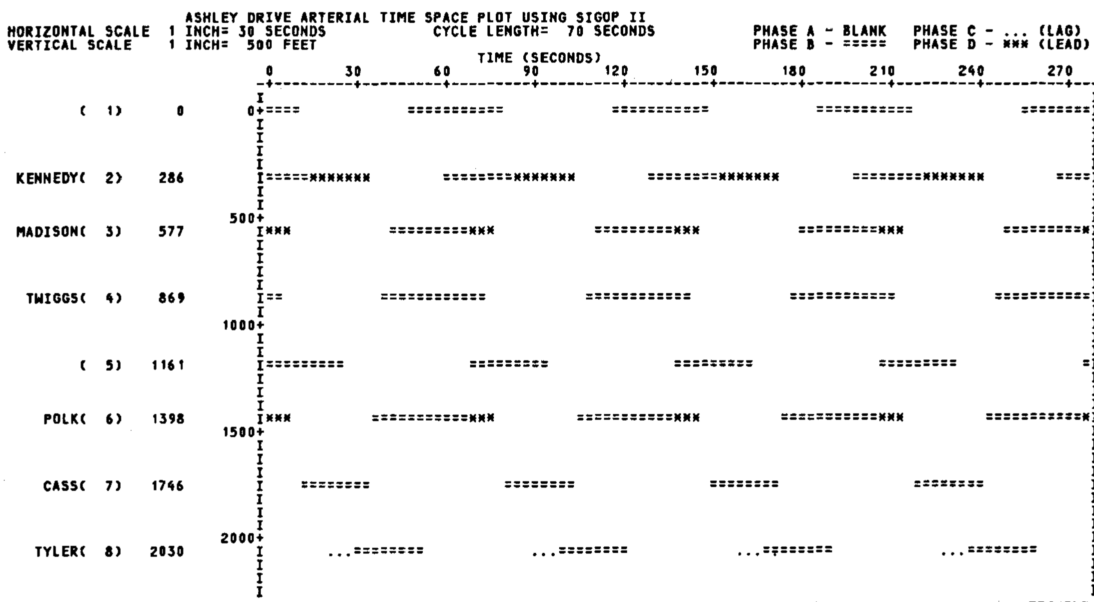


Figure 110. SIGOP III Time-Space Plots

formance values for each link and the network total. The MOE are:

- o Volume (vph)
- o Average Speed (mph)
- o Delay (sec/veh)
- o Stops (per minute)
- o Capacity (vphg)
- o Degree of Saturation (%)
- o Maximum Queue (veh)
- o Fuel Consumption (gal/hour)
- o Total Emissions (16/hu.)
  - Hydrocarbons
  - Carbon Monoxide
  - Nitric Oxide

Finally, the user specified time-space plots are issued, as illustrated in Figure 110.

Diagnostic Messages

SIGOP III performs extensive checks on the input data to identify obvious errors. During execution of the model other errors may be detected, such as excessive saturation. There are a total of 52 error messages in the library. Some of these also advise the user on a course of action, if applicable. In all cases, the messages, cause and corrective action required are well documented (Ref. 10.1).

ADDITIONAL FEATURES

As already noted, SIGOP III can handle multiphase signals (up to four phases) and can automatically investigate the advantage of double cycling signals that have a low degree of saturation (thus extensive delay, stops and queue length).

SIGOP III can be used purely as an analysis tool to evaluate alternative timing plans derived from sources other than the SIGOP III optimization or to examine alternative patterns. Naturally, the user must code and run each alternative and evaluate the results manually.

Up to five runs may be executed per cycle length with no limit on the number of cycles optimized. This enables the user to investigate the effect of changing trend in traffic demand. Although limited to 80 signals and 230 links, the documentation describes how to expand the capacity of the program.

APPLICATIONS AND LIMITATIONS

SIGOP III is a powerful design and analysis tool for the engineer concerned with coordinated signal systems. Functionally, both SIGOP III and TRANSYT are quite similar, both with unique properties not available in the other. For example, inclusion of maximum queue length in the objective function is an important advantage in SIGOP III.

There are several items that would be considered as limitations in SIGOP III. These are listed below.

1. The limitation to four phases in the cycle cannot adequately serve some users. Up to six phases are not uncommon in many systems.

2. There is no provision for bus links in a SIGOP III analysis.

3. Permissive and unprotected turns are not addressed explicitly by SIGOP III. While this is true of other models, the user is often able to "model" such conditions by restricting the capacities of such movements. This is not possible in SIGOP II. However, permissive and unprotected turns are accounted for within the model.

4. The model does not explicitly deal with minor intersections (e.g., stop sign control).

In summary, SIGOP III has, as do all traffic models, several limitations and disadvantages. Nonetheless, the complexity of the optimization technique makes this model somewhat faster in terms of running time. The multiple cycle length capability is clearly an asset, which can save the designer a considerable amount of time that would ordinarily be spent in generating numerous jobs.

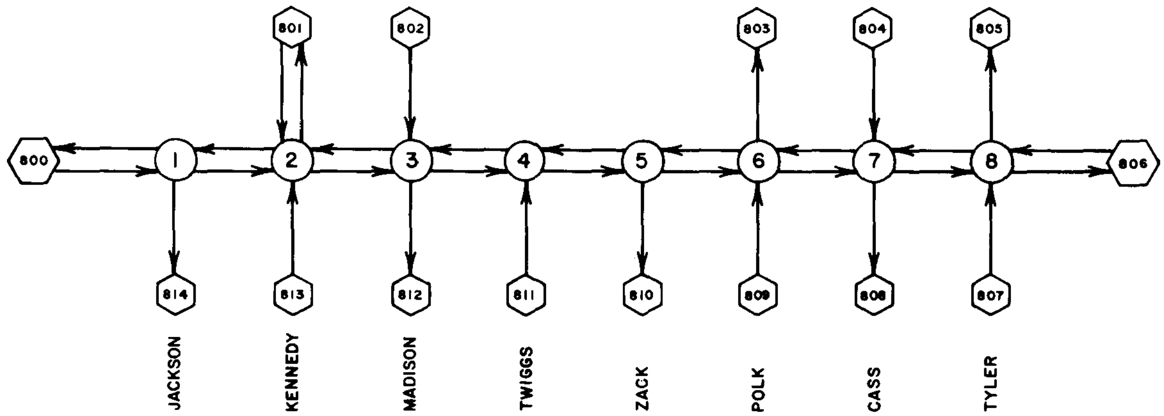


Figure 111. SIGOP III Link-Node Diagram Ashley Drive

EXAMPLE APPLICATION

The previous Ashley Drive arterial signal system was used to illustrate the application of SIGOP III. The following describes the use of SIGOP III for this existing signal system.

Problem Description

As with the previous example the basic problem is to determine if a change in signal timing can be implemented along Ashley Drive that will result in improved traffic operation. SIGOP III will be used to model existing signal timing and develop alternate signal timing plans for evaluation.

Analysis of Existing Conditions

The first step was the preparation of a link-node map to assist in coding the network. This diagram is shown in Figure 111. Unlike TRANSYT, which uses a link number, SIGOP defines a link by the two connecting nodes or intersections. A total of 15 external nodes (external traffic sources and/or traffic exits) were used with eight internal nodes, or intersections. A total of 32 one-way links were used to describe the street system. The existing conditions were coded on standard forms which are available from the Implementation Division (HDV-21) of FHWA. The forty (40) lines of coded input data required to reproduced existing conditions is shown on Figure 112.

The data were keypunched and the data deck submitted for model execution. Figure 113 illustrates the output obtained for existing conditions.

Define and Analyze Alternatives

Once the existing conditions have been coded, and results from the model have been accepted as representative of the existing operations, the data can be modified to define alternatives. In order to define and obtain alternative signal timing plans only two cards need to be changed: (1) the identification, or title card, and (2) the network control card. For the purposes of this example application signal optimization runs were requested for each even cycle length between 70 seconds and 98 seconds (as was done for TRANSYT-7F).

Figure 114 shows the performance table for the optimum 88 second cycle. Similar tables were obtained for each cycle length.

SIGOP III CODING SHEET

CITY	Tampa, Fla.	AREA OF CITY	Ashley Drive - CBD	PAGE	1	OF	10
PROGRAMMER	ASB	ROOM NUMBER		JOB NO.	77069-F	DATE	8/4/81

IDENTIFICATION CARD

RUN NUMBER	TIME AT BEGINNING OF OPTIMIZATION PERIOD	TIME AT END OF OPTIMIZATION PERIOD	MONTH	DAY	YEAR	ANY ALPHA-NUMERIC INFORMATION
1	1630	1730	08	04	81	ASHLEY DR ARTERIAL ANALYSIS- EXIST. CONDITIONS PM PEAK

NETWORK CARD

MINIMUM CYCLE LENGTH	MAXIMUM CYCLE LENGTH	CYCLE LENGTH INCREMENTS (DEFAULT: 10 SECONDS)	CODE FOR HALF-CYCLE OPTION (DEFAULT: 0)	NETWORK-WIDE START-UP LOSS (DEFAULT: 2.3 SECONDS)	NETWORK-WIDE DISCHARGE HEADWAY (DEFAULT: 2.1 SECONDS)	EQUIVALENCE FACTOR FOR VEHICLE STOPS (DEFAULT: 4 SECONDS)	SATURATION PERCENT FOR HALF-CYCLE (DEFAULT: 25%)	MINIMUM LENGTH OF HALF-CYCLE (DEFAULT: 0 SECONDS)	MINIMUM DURATION OF MINOR PHASES (DEFAULT: 15 SECONDS)	CODE FOR OPTIMIZING OR FOR EVALUATION (DEFAULT: 0)	EQUIVALENT DELAY AT INCIPIENT SPILLBACK (DEFAULT: 250 V-SEC)	STORAGE BUFFER FOR MAXIMUM QUEUE (DEFAULT: VARIES)	SATURATION CODE (DEFAULT: 0)	FLOW CONTINUITY CODE (DEFAULT: 10%)	ITERATIVE SWEEP CODE (DEFAULT: 4)	PROCESSING CODE (DEFAULT: 0)	CODE FOR NETWORK TOPOLOGY (DEFAULT: 0)
90	90	0	1	35	19	5			10	1	200	90		25		0	0

MINIMUM PHASE DURATION CARD

NODE NUMBER	MINIMUM DURATION FOR PHASE I	MINIMUM DURATION FOR PHASE II	MINIMUM DURATION FOR PHASE III	MINIMUM DURATION FOR PHASE IV	NODE NUMBER	MINIMUM DURATION FOR PHASE I	MINIMUM DURATION FOR PHASE II	MINIMUM DURATION FOR PHASE III	MINIMUM DURATION FOR PHASE IV	NODE NUMBER	MINIMUM DURATION FOR PHASE I	MINIMUM DURATION FOR PHASE II	MINIMUM DURATION FOR PHASE III	MINIMUM DURATION FOR PHASE IV	CODE FOR NEXT CARD
1	14	23			2	23	23	23							0
4	14	23			5	14	23			3	14	23	10		0
7	14	23			8	14	10	23		6	14	23	10		1

LINK CARDS

UPSTREAM NODE	DOWNSTREAM NODE	DOWNSTREAM NODE OF RECEIVING LINK	LINK LENGTH	DISCHARGE LANES EXCLUDING POCKETS	LEFT-TURN PKT LANES	RIGHT-TURN PKT LANES	PERCENT TRUCKS	DESIGN SPEED, MPH	DISCHARGE HEADWAY IN TENTHS (SEC/VEH) (DEFAULT: NETWORK VALUE)	START-UP LOST TIME IN TENTHS (SEC) (DEFAULT: NETWORK VALUE)	LINK WEIGHT IN TENTHS (DEFAULT: 10)	TOTAL PRIMARY VOLUME (VPH)	TOTAL SECONDARY VOLUME (VPH)	SOURCE/SINK (+/-) VOLUME (VPH)	TOTAL LEFT-TURN VOLUME (VPH)	TOTAL RIGHT-TURN VOLUME (VPH)	ALL-RED CLEARANCE TIME, EACH MAJOR PHASE	PHASE CODE-THRU	PHASE CODE-LEFT-TURN	PHASE CODE-RIGHT-TURN	CODE FOR NEXT CARD
800	1	2		2	0	0	5					572	0	0	0	76	0	1	50	1	0
2	1	800	313	2	1	0	5	25				694	276	0	436	0	1	2	2	50	0
1	1	3	286	2	1	0	5	25				496	0	0	20	0		1	1	50	0
813	2	801		2	1	1	5					751	157	0	45	276		2	2	2	0
3	2	1	286	2	0	1	5	25				905	102	0	0	423		1	50	13	0
801	2	803		0	2	1	5					747	0	0	516	231	50		3	23	0
2	3	4	291	3	0	0	5	25				476	792	+160	0	174		1	50	1	0
4	3	2	322	3	1	0	5	25				915	143	0	93	0	1	3	3	50	0
802	3	812		2	1	1	5					376	0	0	211	102		2	2	2	0
3	4	5	292	3	0	0	5	25				1254	211	0	0	0		1	50	50	0
811	4	0		0	2	1	0					490	92	0	193	389	50		2	2	0
5	4	3	272	3	0	0	5	25				926	0	-11	0	0		1	50	50	0
4	5	6	292	3	0	0	5	25				1465	389	0	0	220		1	50	1	0
6	5	4	338	3	1	0	5	25				1001	40	0	115	0	1	2	2	50	0
5	6	7	237	3	1	0	5	25				1634	0	0	5	0	1	3	3	50	0

Figure 112. Coded SIGOP III Input Data for Ashley Drive (Existing Conditions)

LINK CARDS

Upstream Node	Downstream Node	Downstream Node of Receiving Link	Link Length	Discharge Lanes Excluding Pockets	Left-Turn Pkt Lanes	Right-Turn Pkt Lanes	Percent Trucks	Design Speed, MPH	Discharge Headway in Tenths (Sec/Veh) (Default: Network Value)	Start-Up Lost Time in Tenths (Sec) (Default: Network Value)	Link Weight in Tenths (Default: 10)	Total Primary Volume (VPH)	Total Secondary Volume (VPH)	Source/Sink (+/-) Volume (VPH)	Total Left-Turn Volume (VPH)	Total Right-Turn Volume (VPH)		All-Red Clearance Time, Each Major Phase	Phase Code-Thru	Phase Code-Left-Turn	Phase Code-Right-Turn	Code for Next Card
809	6	803		2	0	0	0					135	114	0	40	209			2	2	2	0
7	6	5	243	3	0	0	5	25				831	70	0	0	0			1	50	1	0
6	7	8	398	3	0	1	5	25				1629	209	0	0	226			1	50	1	0
804	7	808		3	1	0	5	25				636	0	0	229	70			2	2	2	0
8	7	6	288	3	0	0	5	25				895	36	0	0	0			1	50	50	0
7	8	806	284	2	1	0	5	25				1623	229	0	263	0			12	2	50	0
807	8	805		2	0	1	5	25				460	110	0	36	259			3	3	3	0
805	8	7		2	0	1	5	25				1029	0	0	0	134			1	50	1	2

LINK NAME CARD

Upstream Node	Downstream Node	Link Name	Upstream Node	Downstream Node	Link Name	Upstream Node	Downstream Node	Link Name	Upstream Node	Downstream Node	Link Name	Upstream Node	Downstream Node	Link Name
800	1	ASHLEY	1	2	ASHLEY	2	3	ASHLEY	3	4	ASHLEY	4	5	ASHLEY
5	6	ASHLEY	6	7	ASHLEY	7	8	ASHLEY	806	8	ASHLEY	8	7	ASHLEY
7	6	ASHLEY	6	5	ASHLEY	5	4	ASHLEY	4	3	ASHLEY	3	2	ASHLEY
2	1	ASHLEY	1	814	JACKSON	801	2	KENNEDY	813	2	KENNEDY	802	3	MADISON
811	4	TWIGGS	5	810	ZACK	809	6	POLK	804	7	CASS	807	8	TYLER
814	1	JACKSON	810	5	ZACK									

PLOT HEADER CARD

Number of Time-Distance Plots	Code for Next Card
1	-3

PLOT NAME CARD

TITLE OF TIME-DISTANCE PLOT:
ANY ALPHA-NUMERIC INFORMATION

ASHLEY DRIVE ARTERIAL TIME SPACE PLOT USING SIGOP III

Figure 112. Coded SIGOP III Input Data for Ashley Drive (Existing Conditions). (Continued)

NODE SEQUENCE CARD

FIRST NODE ALONG PATH TO BE PLOTTED	SECOND NODE ALONG PATH TO BE PLOTTED	THIRD NODE ALONG PATH TO BE PLOTTED	FOURTH NODE ALONG PATH TO BE PLOTTED	FIFTH NODE ALONG PATH TO BE PLOTTED	SIXTH NODE ALONG PATH TO BE PLOTTED	SEVENTH NODE ALONG PATH TO BE PLOTTED	EIGHTH NODE ALONG PATH TO BE PLOTTED	NINTH NODE ALONG PATH TO BE PLOTTED	TENTH NODE ALONG PATH TO BE PLOTTED	ELEVENTH NODE ALONG PATH TO BE PLOTTED	TWELFTH NODE ALONG PATH TO BE PLOTTED	THIRTEENTH NODE ALONG PATH TO BE PLOTTED	FOURTEENTH NODE ALONG PATH TO BE PLOTTED	FIFTEENTH NODE ALONG PATH TO BE PLOTTED	SIXTEENTH NODE ALONG PATH TO BE PLOTTED	SEVENTEENTH NODE ALONG PATH TO BE PLOTTED	EIGTHTEENTH NODE ALONG PATH TO BE PLOTTED	NINETEENTH NODE ALONG PATH TO BE PLOTTED	
1	2	3	4	5	6	7	8												

SIGNAL TIMING CARD

NODE NUMBER AT WHICH SIGNAL IS LOCATED	OFFSET TO PHASE I	DURATION OF PHASE I	DURATION OF PHASE II	DURATION OF PHASE III	DURATION OF PHASE IV	NODE NUMBER AT WHICH SIGNAL IS LOCATED	OFFSET TO PHASE I	DURATION TO PHASE I	DURATION OF PHASE II	DURATION OF PHASE III	DURATION OF PHASE IV	NODE NUMBER AT WHICH SIGNAL IS LOCATED	OFFSET TO PHASE I	DURATION OF PHASE I	DURATION OF PHASE II	DURATION OF PHASE III	DURATION OF PHASE IV		CODE FOR NEXT CARD
1	97	26	64			2	52	27	40	23		3	40	47	29	17			0
4	91	52	38			5	39	63	27			6	59	48	28	14			0
7	53	54	26			8	52	38	29	23									1

END-OF-RUN CARD

NUMBER OF COPIES OF OUTPUT	PERCENT OF ORIGINAL VOLUME FOR NEXT RUN	PERCENT OF ORIGINAL VOLUME FOR NEXT RUN	PERCENT OF ORIGINAL VOLUME FOR NEXT RUN	PERCENT OF ORIGINAL VOLUME FOR NEXT RUN	HORIZONTAL SCALE TIME SPACE PLOT (SEC/INCH) (DEFAULT: 1 INCH = 20 SEC)	VERTICAL SCALE TIME SPACE PLOT (FEET/INCH) (DEFAULT: 1 INCH = 1000 FEET)	REVISED PRINTER SETTING VERTICAL LINES PER INCH (DEFAULT: 8 LINES/INCH)
					30	500	8

Figure 112. Coded SIGOP III Input Data for Ashley Drive (Existing Conditions) (Continued).

SIGOP III

JANUARY 31, 1981

ALGORITHM TO PROVIDE OPTIMAL, CYCLE-BASED, TRAFFIC SIGNAL TIMING PATTERNS

FOR THE PERIOD EXTENDING FROM 1630 TO 1730 HOURS

RUN NUMBER 1 EXECUTED ON 4/ 8/1981

ASHLEY DR ARTERIAL ANALYSIS- EXIST. CONDITIONS PM PEAK

LINK FROM,TO	RECV NODE	LNGTH (FT)	NO LN	L-PK LANE	R-PK LANE	TRK PCT	SPD MPH	HDWY (SECONDS)	LST	WT.	PRI-VOL (VPH)	SEC-VOL (VPH)	S/S-VOL (VPH)	L-TRN (VPH)	R-TRN (VPH)	RED-CLR (SEC)	CODES T	L	R	L
(800, 1)	2	0	2	0	0	5	0	1.9*	3.5*	1.0*	572	0	0	0	76	0	1	50	1	1
(2, 1)	800	313	2	1	0	5	25	1.9*	3.5*	1.0*	644	276	0	436	0	0	12	2	50	2
(1, 2)	3	286	2	1	0	5	25	1.9*	3.5*	1.0*	496	0	0	20	0	0	1	1	50	3
(813, 2)	801	0	2	1	1	5	0	1.9*	3.5*	1.0*	751	154	0	45	276	0	2	2	2	4
(3, 2)	1	286	2	0	1	5	25	1.9*	3.5*	1.0*	905	102	0	0	423	0	1	50	13	5
(801, 2)	3	0	0	2	1	5	0	1.9*	3.5*	1.0*	747	0	0	516	231	0	50	3	23	6
(2, 3)	4	291	3	0	0	5	25	1.9*	3.5*	1.0*	476	792	160	0	174	0	1	50	1	7
(4, 3)	2	322	3	1	0	5	25	1.9*	3.5*	1.0*	915	143	0	93	0	0	13	3	50	8
(802, 3)	812	0	2	1	1	0	0	1.9*	3.5*	1.0*	376	0	0	211	102	0	2	2	2	9
(3, 4)	5	292	3	0	0	5	25	1.9*	3.5*	1.0*	1254	211	0	0	0	0	1	50	50	10
(811, 4)	0	0	0	2	1	0	0	1.9*	3.5*	1.0*	490	42	0	143	389	0	50	2	2	11
(5, 4)	3	272	3	0	0	5	25	1.9*	3.5*	1.0*	926	0	-11	0	0	0	1	50	50	12
(4, 5)	6	292	3	0	0	5	25	1.9*	3.5*	1.0*	1465	389	0	0	220	0	1	50	1	13
(6, 5)	4	338	3	1	0	5	25	1.9*	3.5*	1.0*	1001	40	0	115	0	0	12	2	50	14
(5, 6)	7	237	3	1	0	5	25	1.9*	3.5*	1.0*	1634	0	0	5	0	0	13	3	50	15
(809, 6)	803	0	2	0	0	0	0	1.9*	3.5*	1.0*	135	114	0	40	209	0	2	2	2	16
(7, 6)	5	243	3	0	0	5	25	1.9*	3.5*	1.0*	931	70	0	0	0	0	1	50	1	17
(6, 7)	8	348	3	0	1	5	25	1.9*	3.5*	1.0*	1629	209	0	0	226	0	1	50	1	18
(804, 7)	808	0	3	1	0	5	25	1.9*	3.5*	1.0*	636	0	0	229	70	0	2	2	2	19
(8, 7)	6	288	3	0	0	5	25	1.9*	3.5*	1.0*	895	36	0	0	0	0	1	50	50	20
(7, 8)	806	284	2	1	0	5	25	1.9*	3.5*	1.0*	1623	229	0	263	0	0	12	2	50	21
(807, 8)	805	0	2	0	1	5	25	1.9*	3.5*	1.0*	480	110	0	36	259	0	3	3	3	22
(806, 8)	7	0	3	0	1	5	25	1.9*	3.5*	1.0*	1029	0	0	0	134	0	1	50	1	23

MINIMUM PHASE DURATIONS (SEC)

NODE	PHASES I	II	III	IV
1	14	23	0	0
2	23	23	23	0
3	14	23	10	0
4	14	23	0	0
5	14	23	0	0
6	14	23	10	0
7	14	23	0	0
8	14	10	23	0

Figure 113. SIGOP III Output Report for Existing Conditions on Ashley Drive.

SPECIFIED NETWORK-WIDE PARAMETERS

CYCLE LENGTHS- MINIMUM= 90 SEC. MAXIMUM= 90 SEC. INCREMENTAL CHANGES=10 SEC.

CODE FOR DOUBLE-CYCLING = 1

NETWORK-WIDE START-UP LOSS=3.5 SECONDS DISCHARGE HEADWAY=1.9 SECONDS

WEIGHT ASSIGNED TO VEHICLE STOPS IS 5

VALUE OF PERCENT SATURATION BELOW WHICH A NODE MAY BE DOUBLE-CYCLED IS 25 PERCENT

MIN. DURATION OF HALVED CYCLE LENGTH IS 0 SEC.

MIN. DURATION OF MINOR PHASES IS 10 SEC.

THE MAXIMUM DISUTILITY ARISING FROM A QUEUE EXTENDING THE FULL LENGTH OF A LINK IS 200 VEH-SECONDS (EQUIV.)

RESIDUAL STORAGE THRESHOLD IS 90 FEET

SATURATION CODE= 0 CONTINUITY CODE=25 CONVERGENCE CODE= 4 PROCESSING CODE=0

WARNING SECONDARY VOLUME ON LINK (2, 3) IS TOO HIGH. CONTINUITY VIOLATED BY 65 PERCENT

PROGRAM WILL DETERMINE NETWORK DISUTILITY FOR THE FOLLOWING SIGNAL TIMING

SPECIFIED SIGNAL TIMING PATTERN

NODE NUMBER	OFFSET REF. TO PHASE I	DURATION OF PHASE I (SEC)	DURATION OF PHASE II (SEC)	DURATION OF PHASE III (SEC)	DURATION OF PHASE IV (SEC)
1	47	26	64	0	0
2	52	27	40	23	0
3	40	47	29	14	0
4	41	52	38	0	0
5	39	63	27	0	0
6	59	48	28	14	0
7	63	64	26	0	0
8	52	38	29	23	0

NUMBER OF OUTPUT COPIES- 1

ADDITIONAL RUNS (IF ANY) WILL APPLY THE FOLLOWING PERCENTAGES OF THE INITIAL VOLUMES- 0 0 0 0

* * * THERE WERE A TOTAL OF 0 INPUT ERRORS * * *

NOSC 1 1 1

NETWORK-WIDE SIGNAL SETTINGS

SWEEP NUMBER 1

NODE	PHASE	APPROACH LINKS		OFFSET (SEC)	OFFSET (PCT)	DURATION (SEC.)	SPLIT (PCT.)	CYCLE (SEC.)	CONGEST (1,0)
1	I	(800, 1)	(2, 1)	47	(52)	26	29	90	0,MAJR
1	II	(2, 1)		73	(81)	64	71	90	0,MAJR
2	I	(1, 2)	(3, 2)	52	(58)	27	30	90	0,MAJR
2	II	(813, 2)		79	(88)	40	44	90	0,MAJR
2	III	(3, 2)	(801, 2)	29	(32)	23	26	90	0,MINR
3	I	(2, 3)	(4, 3)	40	(44)	47	52	90	0,MAJR
3	II	(802, 3)		87	(97)	29	32	90	0,MAJR
3	III	(4, 3)		26	(29)	14	16	90	0,MINR
4	I	(3, 4)	(5, 4)	41	(46)	52	58	90	0,MAJR
4	II	(811, 4)		3	(3)	38	42	90	0,MAJR
5	I	(4, 5)	(6, 5)	39	(43)	63	70	90	0,MAJR
5	II	(6, 5)		12	(13)	27	30	90	0,MAJR
6	I	(5, 6)	(7, 6)	59	(66)	48	53	90	0,MAJR
6	II	(809, 6)		17	(19)	28	31	90	0,MAJR
6	III	(5, 6)		45	(50)	14	16	90	0,MINR
7	I	(6, 7)	(8, 7)	63	(70)	64	71	90	0,MAJR
7	II	(804, 7)		37	(41)	26	29	90	0,MAJR
8	I	(7, 8)	(806, 8)	52	(58)	38	42	90	0,MAJR
8	III	(807, 8)		29	(32)	23	26	90	0,MAJR
8	II	(7, 8)		0	(0)	29	32	90	0,MINR

THE FIRST TWO PHASES ARE THE MAJOR PHASES SERVICING THE INDICATED APPROACHES

THE REMAINING PHASES (IF ANY) ARE THE MINOR PHASES

Figure 113. SIGOP III Output Report for Existing Conditions on Ashley Drive (Continued).

SYSTEM DISUTILITY

SWEEP	DISUTILITY
1	83120

SWEEP NO. 1 PROVIDES MINIMUM DISUTILITY, 83120, AT A CYCLE OF 90 SECONDS

VEHICLE-MILES/HOUR= 963.9   VEHICLE-HOURS/HOUR= 83.0   MEAN SPEED=11.61 M. P. H.   STOPS/MINUTE= 102

LINK FROM, TO	VOLUME (P.C.U./HR.)	EFF. SPEED (M.P.H.)	DELAY (SEC./P.C.U.)	STOPS (PER MIN.)	CAPACITY (P.C.U./HR.)	PERCENT SATURATION	MAXIMUM QUEUE	FUEL (GAL./HR.)
(2, 1)	976	17.0	4.0	2.7	4960	20	4	4
(1, 2)	526	18.1	3.0	0.0	1520	35	0	2
(3, 2)	1180	12.2	8.2	4.0	2000	59	6	6
(2, 3)	1559	11.9	8.7	2.7	2800	56	4	8
(4, 3)	1122	6.1	27.4	2.0	3920	29	2	10
(3, 4)	1553	20.0	2.0	13.3	3120	50	7	6
(5, 4)	971	5.0	29.8	11.3	3120	31	5	8
(4, 5)	2023	13.9	6.4	18.7	3800	53	9	9
(6, 5)	1103	18.1	3.5	2.0	6000	18	3	5
(5, 6)	1732	17.0	3.0	0.0	3960	44	0	5
(7, 6)	1061	21.2	1.2	0.7	2840	37	0	3
(6, 7)	2008	8.0	20.3	41.3	5160	39	11	16
(8, 7)	987	17.8	3.2	0.0	3880	25	0	4
(7, 8)	1963	12.6	7.6	3.3	3240	61	5	9

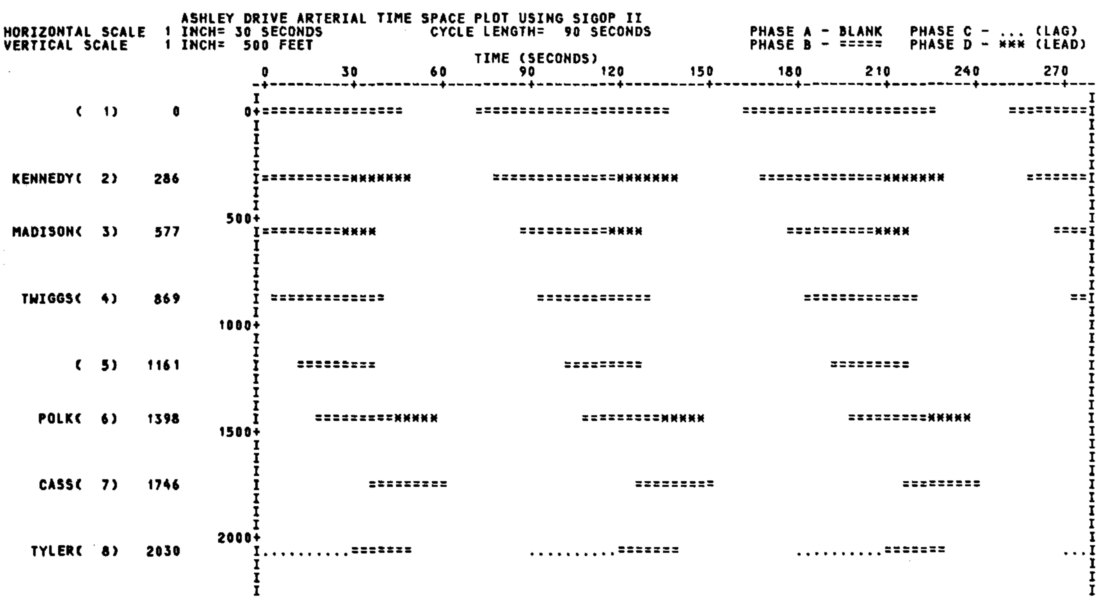
TOTAL FUEL CONSUMPTION FOR THIS TIMING PLAN IN GALLONS PER HOUR IS 95.

TOTAL EMISSIONS FOR THIS TIMING PLAN

HYDROCARBONS 19 POUNDS / HOUR
CARBON MONOXIDE 202 POUNDS / HOUR
NITRIC OXIDE 7 POUNDS / HOUR

EMISSIONS WILL INCREASE AS THE AMBIENT AIR TEMPERATURE DROPS BELOW 80 F AND AT ELEVATIONS ABOVE 4000 FT.

EMISSIONS WILL BE LOWER IN CALIFORNIA.



BEST CYCLE LENGTH SO FAR IS 90 SECONDS

Figure 113. SIGOP III Output Report for Existing Conditions on Ashley Drive (Continued).

11 24750

SWEEP NO. 7 PROVIDES MINIMUM DISUTILITY, 16466. AT A CYCLE OF 88 SECONDS

VEHICLE-MILES/HOUR= 963.9 VEHICLE-HOURS/HOUR= 53.7 MEAN SPEED=17.96 M. P. H. STOPS/MINUTE= 3C

LINK FROM, TO	VOLUME (P.C.U./HR.)	EFF. SPEED (M.P.H.)	DELAY (SEC./P.C.U.)	STOPS (PER MIN.)	CAPACITY (P.C.U./HR.)	PERCENT SATURATION	MAXIMUM QUEUE	FUEL (GAL./HR.)
(2, 1)	976	10.8	11.3	6.1	4500	22	6	6
(1, 2)	526	18.1	3.0	0.0	1841	29	0	2
(3, 2)	1180	18.8	2.6	2.7	2332	51	4	4
(2, 3)	1559	15.4	4.9	0.0	2986	52	0	7
(4, 3)	1122	20.7	1.8	0.7	3805	29	1	5
(3, 4)	1553	20.8	1.6	0.0	2332	67	0	6
(5, 4)	971	21.1	1.4	0.0	2332	42	0	3
(4, 5)	2023	19.5	2.2	13.6	3682	55	7	8
(6, 5)	1103	20.6	2.0	2.0	6055	18	3	5
(5, 6)	1732	18.1	2.4	0.0	3027	57	0	5
(7, 6)	1061	21.2	1.2	0.0	2209	48	0	3
(6, 7)	2008	20.9	1.9	0.0	4745	42	0	9
(8, 7)	987	17.8	3.2	0.0	3559	28	0	4
(7, 8)	1963	14.7	5.4	4.8	2618	75	7	8

TOTAL FUEL CONSUMPTION FOR THIS TIMING PLAN IN GALLONS PER HOUR IS 75.

TOTAL EMISSIONS FOR THIS TIMING PLAN

HYDROCARBONS 14 POUNDS / HOUR
CARBON MONOXIDE 439 POUNDS / HOUR
NITRIC OXIDE 7 POUNDS / HOUR

EMISSIONS WILL INCREASE AS THE AMBIENT AIR TEMPERATURE DROPS BELOW 80 F AND AT ELEVATIONS ABOVE 4000 FT.

EMISSIONS WILL BE LOWER IN CALIFORNIA.

ASHLEY DRIVE ARTERIAL TIME SPACE PLOT USING SIGOP II

HORIZONTAL SCALE 1 INCH= 30 SECONDS CYCLE LENGTH= 88 SECONDS PHASE A - BLANK PHASE C - ... (LAG)
VERTICAL SCALE 1 INCH= 500 FEET PHASE B - ===== PHASE D - *** (LEAD)

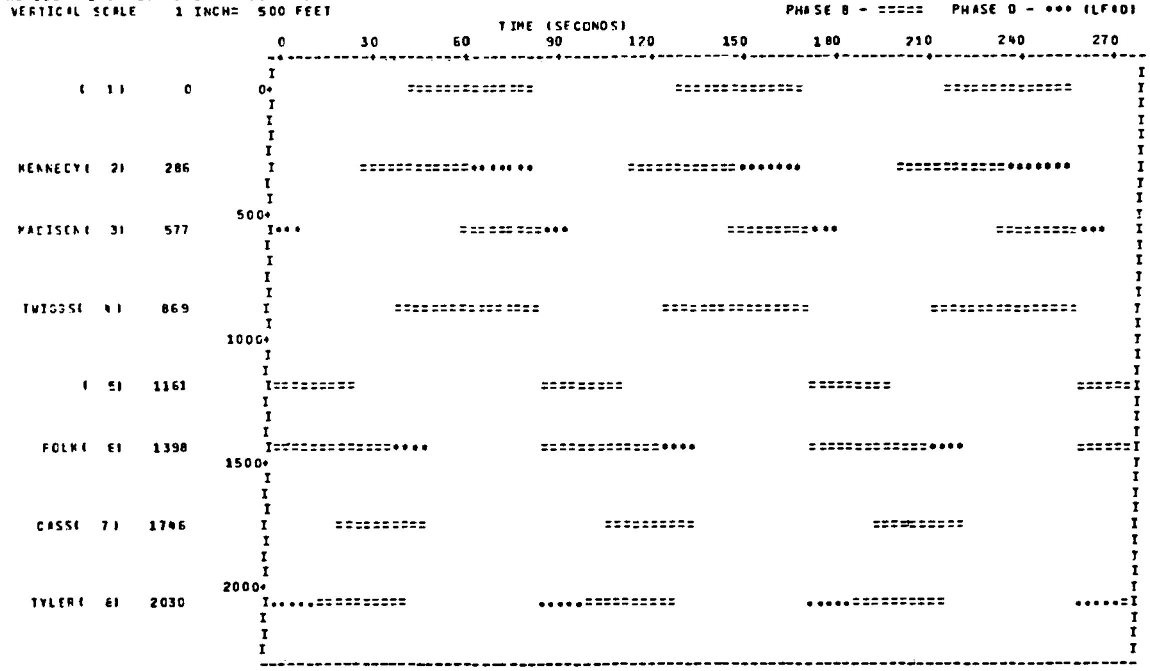


Figure 114. SIGOP III Performance Table for Optimal Cycle Length (88 Seconds) for Ashley Drive.

Table 26 - Comparison of SIGOP III Alternatives For Ashley Drive

Alternative	Cycle Length	Disutility	Veh-Hrs	Mean Speed (mph)	Stops per min.	Fuel Consumption (Gals.)
Existing	90	83,120	83.0	11.61	102	95
1	70	20,314	55.4	17.39	24	75
2	72	21,050	54.7	17.61	30	74
3	74	24,203	56.4	17.10	30	75
4	76	19,753	56.0	17.22	17	75
5	78	18,715	54.6	17.64	21	73
6	80	30,488	60.9	15.83	29	77
7	82	31,544	60.0	16.05	33	77
8	84	23,764	56.3	17.11	30	74
9	86	16,472	54.2	17.80	16	74
10	88	16,466	53.7	17.96	30	75
11	90	26,800	58.0	16.61	30	75
12	92	21,874	56.2	17.14	22	74
13	94	19,417	54.5	17.68	27	73
14	96	28,519	59.3	16.26	28	78
15	98	53,045	69.5	13.87	54	85

Evaluation of Results

Table 26 provides a comparison of the measure of effectiveness (MOE's) obtained for each two second cycle length which was evaluated between 70 and 98 seconds, as well as the existing 90 second cycle length.

Unlike TRANSYT-7F, which indicated that as cycle length increases the stops, delay and travel time generally increases, the MOE's for SIGOP III signal timing plans varied, but with minimum disutility occurring for the 88 second cycle. The next best cycle length was 86 seconds, followed by 78 seconds and 94 seconds.

The optimum plan developed by SIGOP III resulted in a reduction of 35% in arterial vehicle hours of travel and a 70% reduction in stops per minute (from 102 to 30). Most significant was a reduction in fuel consumption of from 85 gals/hr. to 75 gals/hr. or 21%.

Summary of Work Effort Required

The following summarizes the effort required to use SIGOP III for this problem.

Data Collection - The data required for SIGOP III was readily available from the city's files.

Data Coding - Data coding was rather straightforward. The exception was traffic volumes, which required some manual manipulation. However, the existing conditions data were coded within approximately two hours, with less than one hour required for identifying and correcting coding errors. Two runs were required to obtain final data.

Computer Time - Execution time on the IBM 360/370 varied from 0.72 seconds for existing conditions to between 5 and 6 seconds for each optimization run per cycle length evaluated. A total of 1.4 minutes of CPU time was required to evaluate the 16 alternatives. A minimum of 258k of core storage was used.

REFERENCES

1. Traffic Management Center, "An Introduction to Using SIGOP II," Federal Highway Administration Report, April, 1976.

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4. "SIGOP: Traffic Signal Optimization Program, Traffic Research Corporation, September, 1966.

5. Bellman, R.E. and S.E. Dreyfus, "Applied Dynamic Programming, Princeton University Press, 1962.

6. Robertson, D.I., "TRANSYT: A Network Study Tool," Road Research Laboratory Report LR 253, Crowthorne, 1969.

7. Webster, F.V. and B.M. Cobbe, "Traffic Signals," Road Research Technical Paper No. 56, Longon, 1966.

8. Kruskal, J.B., "On the Shortest Spanning Subtree of a Graph and the Traveling Salesman Problem, "Proceedings of the American Mathematics Society, Vol. 7, 1965.

9. Leiberman, E.B. and J.L. Woo, "SIGOP III - User's Manual," Federal Highway Administration Report No. FHWA-IP-82-A, July, 1982.

10. Leiberman, E.B. and J.L. Woo, "SIGOP III - Formulation and Software Documentation," Federal Highway Administration, July, 1982 (unpublished).

CHAPTER 11- NETSIM (NETWORK SIMULATION MODEL)

The majority of traffic operations models described in this Handbook are of the macroscopic type. Many models serve the dual purpose of analysis (i.e., simulation) and design (i.e., optimization). Those which perform macroscopic simulations or deterministic estimates (e.g., SOAP, TRANSYT-7F and SIGOP III) contain deterministic traffic flow models that are based on theoretically acceptable traffic behavioral concepts. These necessarily only predict what might be referred to as "average conditions" because they assume homogeneous, non-varying traffic operations. Such predictions are often acceptable for analyzing signal design and geometric configurations for the purposes of evaluation of various alternatives.

Figure 115. Arterial Signal System

Frequently, however, the engineer needs to analyze potential designs more rigorously than the macroscopic models are able to achieve, or they need to consider the stochastic variations of traffic flow. Additionally, a highway network may contain a mix of geometric, control and traffic management strategies which exceed the capabilities of the macroscopic models (such as real-time control systems or bus stop placement). In such cases, the only viable evaluation techniques are microscopic simulation and empirical studies. Empirical studies are often impractical (e.g., due to the cost, time and potentially undesirable permutations to traffic involved), but more significantly, the evaluation of alternatives process is usually part of the design phase where the engineer is searching for the appropriate design to implement. Thus the empirical method is automatically eliminated (except, perhaps, to perform a post-implementation vs. pre-implementation evaluation).

Microscopic simulation is the logical choice. This class of model is necessarily more complex than macroscopic models, both in terms of computations and data management, as well as input requirements. One such model, the TEXAS model, has already been discussed in Chapter 5. TEXAS is a single, isolated intersection model. Obviously, the vast majority of intersections in an urban area form networks in which the signalized (and unsignalized, for that matter) intersections are interrelated--that is, the operation of one intersection influences the operation of others adjacent to it, and vice versa.

One of the first successful large scale network microscopic simulation models was the Urban Traffic Control System model, referred to as UTCS-1 (Reference 11.1), developed by Peat, Marwick, Mitchell and Co., for FHWA based on two earlier models, DYNET and TRANS. The model was extended by KLD and Associates (and others) for FHWA and the name of the extended model was changed to NETSIM to reflect its new characteristics as part of the TRAF family (see Chapter 14 and Ref. 10.2-10.7).

NETSIM can evaluate any configuration of an urban network, including any normal form of traffic control at the individual intersections. The modular format enables analysis of extremely flexible design configurations and strategies. Inputs are extensive, but standardized to a large degree. Most input parameters have built-in default values to minimize local calibration.

NETSIM is designed primarily to provide the engineer with a powerful analysis tool to test complex network problems. It is particularly well suited for analysis of dynamically controlled (i.e., real-time) traffic control systems, which cannot be analyzed macroscopically because of the highly variable nature of their operation (analysis of real-time control systems requires special programming of the particular real time logic to be simulated, as discussed later).

The original development of NETSIM was initiated by the Office of Research, Federal Highway Administration (FHWA) and FHWA will both disseminate and maintain the model. Thus, the utility and useful life of the model can be expected to be both current and reliable.

MODEL DESCRIPTION

NETSIM, which is an abbreviation (see explanation of the naming of TRAF models in Chapter 14) for NETwork SIMulation model, composed of the prefix NET for surface street network and the suffix term SIM for microscopic simulation. It is written in FORTRAN IV for IBM OS/360/370 and CDC 6600 computer systems. The current version contains 74 separate routines with a total of approximately 11,000 executable FORTRAN statements and 84 data blocks. The total program length, including comments, continuations, etc., is 14,000 records. The core requirement varies slightly, but (IBM) computers with 280k bytes should be able to execute NETSIM with overlays. (Note: As of this writing, the preprocessor subroutine is very long and may not compile on many computer systems. A modified version is being developed which will overcome this problem.)

Table 27 -
Major Features of NETSIM Model

MICROSCOPIC, STOCHASTIC SIMULATION OF INDIVIDUAL VEHICLE MOVEMENTS

SIMULATION OF FULL RANGE OF CONTROL FEATURES, INCLUDING:

- "Stop" and "Yield" Signs
- Turn Controls
- Parking Controls
- Fixed-Time Signals
- Vehicle-Actuated Signals
- Real-Time Traffic Control and Surveillance Systems

MODULAR STRUCTURE INCORPORATING DETAILED TREATMENT OF:

- Car Following Behavior
- Network Geometry
- Grades
- Bus Traffic
- Queue Formation
- Intersection Discharge
- Intra-Link Friction and Mid-Block Blockages
- Pedestrian-Vehicular Conflicts

PROVISION FOR FLEXIBLE MIX OF STANDARD OUTPUT MEASURES

Execution time is highly variable. It depends upon the number of links, nodes and vehicles to be simulated. Depending on the complexity, the efficiency may range from about 1:13 (seconds of computer time to seconds of simulated time) to nearly 1:1, but averages about 1:2 on large applications. Clearly, large, complex systems will require extensive computer time (although run time is much better on CDC and Burroughs computers). Run time is most sensitive to the number of vehicles simulated.

The model is based on a microscopic simulation of individual vehicles which are moved through the system along the links, according to specified controls at nodes (intersections), stochastically determined turning movements and deterministic car following. No set paths are modeled as turning movements are purely random.

The model can investigate a wide mix of traffic control and traffic management strategies, including fixed or actuated signal control, and sign control; special-use (i.e., turn) and general-use lanes; and standard or channelized geometrics.

The capacity of the model may be expressed in the maximum number of nodes (99), links (160) and vehicles (1600 in the network at any instant).

The model contains two major modules which are:

- o Preprocessor - reads and checks input data
- o Simulator - the main simulation model

INPUT REQUIREMENTS

In light of the complexity of the model's capabilities, the developers have strived to make the user's task of providing the necessary inputs as simple as possible. They have for example, minimized the quantities and uniqueness of data required, minimized the amount of manual analyses necessary, maximized effective use of the input data, and simplified modification procedures for "embedded" inputs.

The basic model input is a coded street network which must be accompanied by information about the system traffic control(s) to be studied. Average flow rates must be specified for both the "entry links" on the periphery of the network and the "source/sink" nodes within the network. In addition, presumed performance characteristics which may include such things as gap distributions, discharge rates, etc., must be input for the traffic movements along each link and through each intersection approach.

The input data may be classified in two ways. First, a distinction is made between characteristics which are considered to be "location-specified", that is unique to a particular link (or node), or "network-wide" constants that apply to all points within a network.

A further distinction is made for those two types of data that they may be expressed in the model either as exogenous or embedded inputs. Exogenous inputs must be specified by the user for each application, and must be read into the model using input control cards. Embedded inputs are directly incorporated within one or more of the main simulation routines. The embedded data may be changed to suit the user's particular requirements.

The following is a list of the card input requirements grouped by function for the NETSIM model (some of these being optional):

- o Identification cards - title and network name cards
- o Link cards - link name, link geometry, link operation, link turning movements, and opposing link identification cards
- o Signal cards - fixed-time signal and traffic actuated signal cards
- o Flow rate cards
- o Control cards - execution control, network priming and simulation control cards
- o Surveillance cards;
- o Bus system cards - path, bus station, bus route, bus flow and dwell time cards;
- o "Rare" event cards

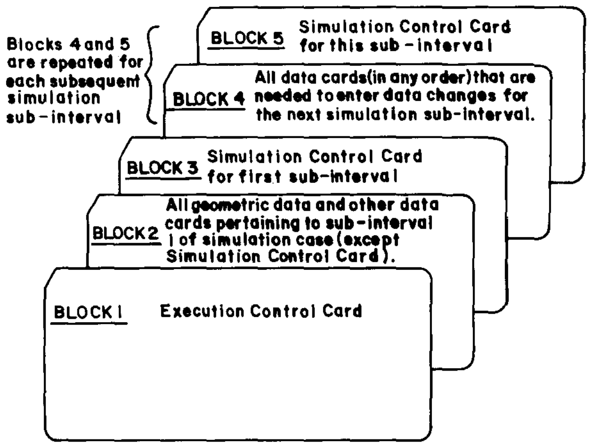

Figure 116. Simplified NETSIM Data Deck

o Embedded data change cards

o Updated data cards

As noted above, the user is provided with a wide range of options to allow flexibility of the simulated conditions.

Table 28 gives a summary description of each of the input cards and their use. Figure 116 shows a simplified data deck stack.

Each execution of NETSIM may be implemented for one of three purposes:

1. Peripheral data management activities and diagnostic checking of input data using the preprocessor module,

2. Diagnostic testing of the "clean" input data by the simulator module, and

3. Execution of a simulation analysis comprised of one or more "subintervals" of time for a specified network.

It should be noted that, although the model provides extensive diagnostic data evaluation, care should be exercised in the preparation of the input data to insure accuracy of the simulation. An example would be such items as the length of a turning pocket or the placement of a bus stop which cannot be detected as an error by the preprocessor.

OPERATIONAL SUMMARY

NETSIM is a microscopic, stochastic, simulation model with fixed time-scan updating.

The network is described as a series of unidirectional links and nodes. Each link represents a particular approach to a node and changes in link characteristics (e.g., added or dropped lanes) may be modeled by inserting mid-block nodes. Traffic generators, such as parking lots, minor streets and the like, may be included as "sink/source" nodes. A link may contain up to five lanes of traffic plus a left and a right turn pocket.

Traffic demand is initially input to the network via "entry" links on the periphery of the system or "source" nodes within the network. Upon reaching the periphery or internal sinks, vehicles are processed out via "exit" links and "sink" nodes, respectively.

Within the network, vehicles are propagated through the system along the various links every second, with their time-space trajectories being recorded at 0.1 second resolution. The internal simulation is extremely complex and vehicle motion is governed by a series of car-following, queue discharge and lane changing algorithms.

Within any sub-interval, all conditions (e.g., input flow rates, turning movements rates, signal timing, etc.) are constant. To allow for variation in such variables, several sub-intervals, which may be as short as one minute, or as long as desired, are input.

Table 28 - Input Requirements For NETSIM

CARD TYPE	CARD NAME	PURPOSE	DATA REQUIREMENTS
CONTROL CARD (1 per run)	Execution Control Card	Identifies mode of execution and other administrative functions.	Input mode specified (magnetic tape or data cards).
	Network Priming Cards	Specifies maximum initialization time.	Initialization time in seconds and clock time.
	Simulation Control Card	Controls duration, intermediate and cumulative output.	Duration, start time and length of time for intermediate output, elapsed time (sec) between successive cumulative outputs.
IDENTIFICATION CARDS (1 per run)	Title Card	Identifies case study.	Alphanumeric title and seed for random number.
	Network Name Card	Identifies descriptive information.	Network name, city, code number of file on data tape.
LINK CARD (1 set per run)	Link Name Cards	Identify each link by street name.	Upstream and downstream node nos., street names.
	Link Geometry Card (1 per 3 links)	Define geometry of all entry and internal network links.	Node numbers, length, grade, right- and left-turn capacity, downstream nodes receiving turning traffic.
	Link Operation Cards (1 per 3 links)	Define operational characteristics of traffic on each internal and entry link.	Node Nos., right-turn-on-red, no. of lanes, speed, queue discharge rates, lost time, pedestrian volume level, channelization of lanes.
	Link Turning Movement Cards (1 per 4 links)	Specifies turning movements (as percentages or volumes) for each link.	Counts or percentage of through, left-, right- and diagonally-turning vehs.
	Opposed Link Identification Card (if req'd)	Specifies all links which have opposed left turn movements.	All pertinent node numbers for links in question.
SIGNAL CARDS (1 set per run)	Fixed Time Signal Cards (1 per non-actuated node)	Specifies signal control at each non-actuated control node (including non-signalized intersections).	Node number, offset, interval duration, control code on each approach for each interval (max. 6).
	Fixed Time Signal Continuation Card (if required)	Extension of above Card Type for signals with over six intervals.	Node numbers, offset, control codes on each approach for each interval (7-9).
	Actuated Controller Card (1 per actuated node)	Defines all links serviced by actuated controller and other characteristics.	Node number, controller coordination, single/dual ring control, detector switching, cycle length.

Table 28 - Input Requirements For NETSIM (Continued)

CARD TYPE	CARD NAME	PURPOSE	DATA REQUIREMENTS
SIGNAL CARDS (1 set per run) (continued)	Phase Card (1 per phase for actuated signals)	Defines operating characteristics of each phase on each actuated controller.	Node, phase number, actuation type, yield point, offset, initial interval, passage time, min. gap, max. extension, max. green, amber, red, recall switch, etc.
	Phase Operation Card	Define signal indications associated with specified phase and location of all detectors affecting the phase.	Node, phase number, signal indication for each approach, and location of each detector.
FLOW RATE CARDS (1 set per run)	Volume Card (1 per 6 links)	Specifies traffic volumes on each link excluding buses.	Node numbers, flow rates, percent trucks.
SURVEILLANCE CARDS (1 set per run)	Surveillance Cards (if required)	Specifies detector type, location and placement on each link.	Node numbers, detector type, location, length of "presence" detector or distance of "counter" from node.
BUS SYSTEM CARDS (optional)	Path Cards	Define path of each specified bus route.	Route number, node numbers.
	Bus Station Cards	Identify, locate and describe each bus stop in network.	Stop number, lane, capacity and type of bus stop.
	Bus Route Cards	Relate bus routes and bus stations.	Route numbers, sequence of bus stations on route by station number.
	Bus Flow Card	Specifies volume of buses on each route.	Route numbers, mean headway for buses.
	Dwell Time Cards	Specifies mean dwell time of buses at each bus station.	Station numbers, mean dwell times to service passengers.
EVENT CARDS (optional)	Short-Term Event Cards	Locate and identify short-term events.	Node numbers, frequency and duration.
	Long-Term Event Cards	Locate and identify long-term events.	Node numbers, time of event, duration and lane blocked.
EMBEDDED DATA CHANGE CARDS (optional)	9 misc. cards	To input changes to the embedded calibration data.	Elements in calibration data and program variable names.
UPDATE CHANGE DECK	Update Control Card	Construct a new data set by modifying a previously generated data set which is on tape.	Card type numbers.

In order to predict the performance of individual vehicles within the network, each vehicle is randomly assigned various characteristics upon entry into the system. These characteristics, noted in the previous section, are vehicle type, average discharge headway, average acceptable gap, etc.

Nodes are operated according to the type of traffic control specified. Nodes may be yield or stop sign controlled or signalized with fixed-time, actuated (both isolated or coordinated) or volume-density controlled. The latter two may involve detectors in either pulse or presence modes.

Depending on the control status and queue length, vehicles are either queued, discharged or processed through the node. Turning movements occur randomly--that is, based on the input proportions of turns, individual vehicles are selected to execute left or right turns. Turns may be protected or unprotected, as specified by the user. In the case of signalized control, up to nine phases may be programmed for any given signal controller.

As the time scan proceeds, data are recorded in vehicle and link arrays. For example, for each vehicle, cumulative time, distance, delay and number of stops are maintained. Additionally, the vehicle's present position (link, lane, position in queue) and projected action at the next node are noted, as applicable.

Link statistics are similar, but additionally include the cumulative number of vehicles and turning movements processed, as well as the current link occupancy, queue lengths and signal status.

In addition to the above statistics, many of which are used for the statistical summaries output by NETSIM, several other aspects of traffic flow are treated to allow a detailed evaluation of the quality of system operation and traffic behavior. These include intersection discharge and queuing behavior, responses to temporary blockages, vehicle-pedestrian conflicts, impact of buses in the traffic stream and impact of various signal control strategies.

The overall operation of the model is summarized in the following seven steps (Reference 11.5) which are performed at each one- second interval within a "sub-interval".

1. All vehicles that were located in queues at the commencement of the time step are processed;

2. All remaining vehicles already on the network, but not "in-queue", are processed;

3. Any new vehicles are emitted onto the network via entry links in accordance with the specified flow rates for each entry link;

4. Any new vehicles to be emitted onto the network from any internal source nodes are processed;

5. The status of all traffic signals in the network is updated;

6. The set of standard vehicle and link statistics contained within the vehicle-array and link-array are accumulated and a series of diagnostic checks performed;

7. Finally, if a point has been reached in the simulation run where a statistical output is called for, the necessary results are printed.

These steps are repeated (as appropriate) for each time step and updates of the input conditions are made at the beginning of each subintervals.

COMPUTATIONAL ALGORITHMS

The myriad of computational requirements in NETSIM are simply too extensive to cover in detail in this Handbook. The more important algorithms are discussed functionally below, and equations or processes are given for the most significant of these. The discussions are necessarily simplified in the interest of brevity. For ease of continuity, they are discussed in the same order as the first six steps listed in the previous section.

Queue Processing

All links, and lanes on each link, are scanned for the presence of queues. When a queue is found, the queue leader is identified and it is determined whether it discharges at this interval or not (for example, red signal, lack of gap or headway not exhausted will result in no discharge). If the lead vehicle can be discharged, it is so processed (according to a deterministic acceleration rule). In this case, the status of all vehicles in the queue is updated to begin moving, and/or record storage time. If the leader is "blocked", vehicle and link statistics are simply updated.

Moving Vehicle Processing

This is the most complex step in the simulation, as the status of all moving vehicles must be updated. Vehicles are processed from downstream to upstream to allow for car-following, lane changing and the like. For example, the first vehicle on a particular link and lane to be processed will be the next vehicle which would encounter the queue (which has already been processed). Vehicle and link status updates are performed as each vehicle is processed. A variety of actions can occur depending on a vehicle's location, speed (actual and desired), lag, turning assignment, etc. Simplified, a vehicle may follow one of the following actions:

- o Speed may be adjusted by a car following rule,
- o It may join the queue,
- o It may discharge to another link,
- o It may change lanes,
- o It may be designated to exit at a "sink" node (if beyond mid-block), or
- o If a bus, it may stop at or leave a bus stop.

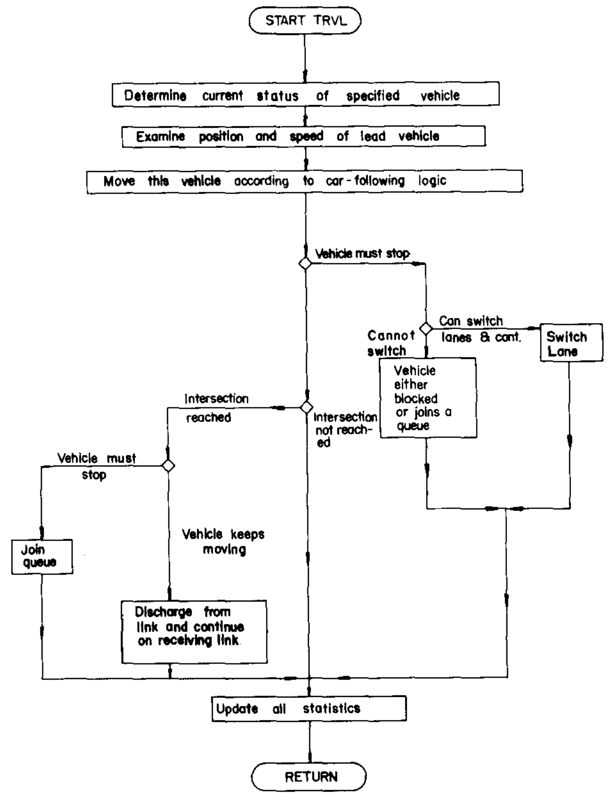

Figure 117. Flow Diagram of Car Following Model

The algorithm is best illustrated in the flow diagram shown in Figure 117.

The car following logic is the most complex (that is, all other actions are based on deterministic acceleration, deceleration or lane change rules). The natural variation of desired speeds requires that the car following rule consider the relative position, velocity and desired speeds of vehicles which are interacting with one another (otherwise a simple acceleration/steady-state/deceleration rule can be used). But when a trailing vehicle is influenced by a leading vehicle, a stimulus-response model must be invoked. A new model was developed for this purpose based on principles used in many existing car following models, but with changes to improve stability and avoid "collisions". The model, which applies only to a vehicle following another vehicle within 200 feet (61m) is stated as follows:

$$a_f = \frac{7(s_\ell - s_f - V_{f_i} - L_\ell) + (1/3)(V_\ell^2 - 2V^2{}_{f_i})}{V_{f_i} + 3} \qquad (11.1)$$

Where a_f = acceleration of follower at the end of the time slice

s = distance along link

V = speed

L = vehicle length, including 3 feet (1m) clearance

ℓ = subscript indicating lead vehicle

f = subscript indicating following vehicle at the end of the time step, or at the beginning if further subscripted by i

If the trailing vehicle's desired speed is reached, further processing is limited to a constant speed model until that vehicle "catches up" with the leader which is being stopped.

If a vehicle reaches the periphery of the network (or is assigned to a sink node) it is processed out at this point.

Input New Vehicles, Exterior

This routine scans all links to determine whether a new vehicle should be emitted into the system, effective at the end of the time step. If a vehicle is emitted, an identifying number is assigned and the following characteristics are randomly assigned:

- o Driver Characteristics
- o Vehicle classification (car, truck or bus-buses are processed differently in the simulation)
- o Lane assignment
- o Action at next node (e.g., turn or through)

Checks are made to determine whether space exists for the desired lane/turn assignments and the vehicle is flagged for lane change(s) if appropriate.

"Arrivals" at input links are based on a uniform distribution.

Input New Vehicle, Interior

These vehicles are generated at "source" nodes within the network. The logic is very similar to that described above. The documentation is not clear as to whether there must be a gap available to accept the vehicle.

Signal Status Update

All traffic signals are updated at this step. All nodes are scanned and at the signalized nodes, the current phase timer is decremented. When this timer reaches zero, the next phase is activated and the timer is reset. For fixed-time, this process is trivial. For actuated control, a routine is called which, for the appropriate type of controller, determines whether current conditions warrant updating the signals. If updating is not required, the controller acts (momentarily) similarly to a fixed-time unit. If updating is required (say a call is received on a semi-actuated approach), signals on all approaches are updated, and appropriate timers (e.g., extensions, minimums, etc.) are adjusted.

Statistics

In addition to simply updating all statistics in the simulation, several other important tasks are performed at this point. These are summarized as follows:

- o Insure that all status parameters are consistent, correct if not
- o Reset vehicle process codes
- o Update all "event" actions
- o Detect "spillback" of queues

- o Block or unblock lanes
- o Update pedestrian blockages
- o Update dwelling buses

The "events" referred to above may be short or long-term. These are user specified and may be input to simulate blockages such as accidents, standing or parked cars or other extraordinary perturbations in the network. The exact nature is not specified, but the difference is that short-term events occur randomly for a variable amount of time, and long-term events are preprogrammed (i.e., input directly) and occur on schedule for a specified amount of time.

OUTPUT REPORTS

There are five basic printed outputs generated by NETSIM. Some of these are automatic and others must be requested by the user. Results may also be stored on tape for future use, such as evaluation by the postprocessor. The outputs are discussed below.

Input Data Report

General input data are summarized in a formatted report which can be checked for accurancy. The report is shown in Figure 118. A detailed report (echo) of all data is also available.

Standard Statistical Report

A summary of important statistics or measures of effectiveness (MOE), is given at the end of each sub-interval. The cummulative performance on each link and the entire network are printed. The user may also request this report at any time in the simulation (e.g., every "n" minutes).

The contents of the report are summarized in the example output shown in Figure 119.

Note that total delay includes both delay due to stops and "delay" due to speeds reduced below some specified target level.

Intermediate Outputs

To obtain additional results to augment the above report, the user may request intermediate results at any point in the simulation. These reports are useful in detailed analyses of varying traffic conditions and/or selective (perhaps problem) locations. The contents of the report are shown in Figure 120.

Fuel Comsumption and Vehicle Emission Report

A summary of fuel comsumption and vehicle emissions for each link and the network as a whole is obtained for each run. The fuel consumption data is reported for three types of vehicles; (1) composite auto, (2) truck, and (3) bus, based upon vehicle characteristics coded on the Volume Card (autos and trucks) and Bus Flow Card. Fuel consumption is reported in both gallons and miles per gallon for each vehicle type. Vehicle emission is reported in grams per mile for autos only and includes hydrocarbons, nitrous oxide and carbon monoxides. Figure 121 shows the format and contents of this report.

Supplementary Outputs

A variety of optional outputs may be obtained for detailed analysis or input data. The following may be tabulated at the user's request:

- o The origin-destination pattern of all vehicles
- o Types and locations of all detectors
- o All "rare events"
- o Bus performance

Additionally, comprehensive error messages are ouput to assist the user in "debugging" the data or locating inconsistencies in the

ARTERIAL SIMULATION-ASHLEY DR.CORRIDOR-RUN NO.4 SIGOP OPT 90

ASHLEY DR. CBD CITY OF TAMPA FLORIDA 3 10/31/81

SEED FOR RANDOM NUMBER GENERATOR IS 3591

LINK	LANE	SPAN	POCK L	POCK R	MEAN U-F	H	TURNING MOVEMENTS LEFT	THRU	RT	DIAG	DESTINATION NODES LEFT	THRU	RT	DIAG	LOST	PED DEN	LANE CHAN 1	2	3	4	5	TYPE	G	L	IDENTIFICATION
(800, 1)	2	290	0	0	ENTRY	20	0	100	0	0	0	2	0	0	35		0	0	0	0	0	1	3	1	ASHLEY DR
(1, 2)	2	290	0	0	25	20	0	87	13	0	0	3	815	0	35	0	0	0	0	0	0	1	3	2	ASHLEY DR.
(2, 3)	2	286	4	0	25	20	4	96	0	0	13	4	0	0	35	0	0	0	0	0	0	1	3	3	ASHLEY DR.
(814, 14)	4	290	0	0	ENTRY	20	0	100	0	0	0	3	0	0	35		0	0	0	0	0	1	3	4	KENNEDY BLVD
(2, 1)	2	348	0	0	25	20	0	100	0	0	0	800	0	0	35	0	0	0	0	0	0	1	3	5	ASHLEY DR.
(3, 2)	2	313	5	0	25	20	47	53	0	0	815	1	0	0	30	0	0	0	0	0	0	1	3	6	ASHLEY DR.
(816, 14)	1	290	0	0	ENTRY	20	0	0	100	0	0	0	3	0	35		4	0	0	0	0	1	3	7	TAMPA STREET

SPECIFICATIONS OF SURVEILLANCE DETECTORS

LINK(13, 3)

NUMBER	LANE	TYPE	DISTANCE FROM NODE 3	LENGTH OF TRAP
7	1	PRESENCE		30
8	2	COUNTER	16	
9	3	COUNTER	20	

TRAFFIC SIGNAL DATA

* INDICATES RTOR IN EFFECT FOR THIS APPROACH

NODE 1 IS UNDER SIGN CONTROL

NODE	INTVL	DURATION	OFFSET	SIGNAL CODES FACING INDICATED APPROACHES (800, 1)*	(2, 1)*	(
1	1	80 (100P)	0 (0P)	1	1	

NODE	INTVL	DURATION	OFFSET	SIGNAL CODES FACING INDICATED APPROACHES (3, 2)*	(1, 2)*	(
2	1	44 (49P)	0 (0P)	7	1	
2	2	5 (6P)	44 (49P)	7	0	
2	3	36 (40P)	49 (54P)	1	2	
2	4	5 (6P)	85 (94P)	0	2	

NODE 10 IS UNDER SIGN CONTROL

SPECIFICATIONS FOR ACTUATED CONTROLLERS

NODE	COORDINATED	REST-IN-RED	CYCLE	ENTRY	DET. SW.
3	YES	NO	90	0	NO

LINK (2, 3)

PHASE	DETECTORS PROVIDING CALLS LOCATED IN LANE 1	2	3	4	5	DETECTORS PROVIDING GAPS LOCATED IN LANE 1	2	3	4	5
3	X	X			X	X	X			X

LINK (13, 3)

PHASE	DETECTORS PROVIDING CALLS LOCATED IN LANE 1	2	3	4	5	DETECTORS PROVIDING GAPS LOCATED IN LANE 1	2	3	4	5
2	X	X	X			X	X	X		

LINK (4, 3)

PHASE	DETECTORS PROVIDING CALLS LOCATED IN LANE 1	2	3	4	5	DETECTORS PROVIDING GAPS LOCATED IN LANE 1	2	3	4	5
2						X				
3	X	X	X			X	X	X		

LINK (14, 3)

THERE ARE NO DETECTORS ON THIS LINK

PHASE	NON-ACTUATED YIELD BEG	END	OFFSET	ACTUATED FORCE OFF	MIN INIT	IIC	INIT INT DATA	INIT ACT DATA	PASS TIME	MIN GAP	TIME TO RED.	RED. RATE	MAX EXT	MAX GRN	AMBR	RED CLR	RED RVRT	RECL SW.	MEM SW.	INH TRM	OVR CD
1	33	38	65												4	1					
2				57	10	0	0	0	3.0	0.0	0	0.0	0	18	5	0	0	NO	NO	NO	0
3				86	10	0	0	0	3.0	0.0	0	0.0	0	25	5	0	0	NO	NO	NO	0

PHASE	SIGNAL CODES FACING INDICATED APPROACHES (2, 3)*	(14, 3)	(13, 3)	(4, 3)	(
1	2	1	2	2	
2	2	2	1	3	
3	1	2	2	1	

NODE	COORDINATED	REST-IN-RED	CYCLE	ENTRY	DET. SW.
4	YES	NO	90	0	NO

Figure 118. NETSIM Input Data Report

CUMULATIVE STATISTICS SINCE BEGINNING OF SIMULATION

PRESENT TIME IS 16 40 0, ELAPSED SIMULATED TIME IS 10 MINUTES, 0 SECONDS

LINK STATISTICS

LINK	VEH-MILES	VEH TRP	MOV. TIME V-MIN	DELAY TIME V-MIN	M/T	TOTAL TIME V-MIN	T-TIME / VEH. SEC	T-TIME/ VEH-MILE SEC/MILE	D-TIME / VEH SEC	D-TIME/ VEH-MILE SEC/MILE	PCT STOP DELAY	AVG. SPEED MPH	AVG. OCC.	STOPS /VEH	AVG SAT PCT	CYCL FAIL
(1, 2)	5.5	100	12.3	25.5	0.33	37.8	22.7	413.2	15.3	278.7	77	8.7	3.7	0.53	13	0
(2, 3)	4.6	85	10.4	34.1	0.23	44.5	31.4	579.6	24.1	444.6	78	6.2	4.4	0.88	14	0
(2, 1)	6.7	102	16.2	0.7	0.96	16.9	10.0	151.0	0.4	6.5	0	23.8	1.7	0.0	5	0
(3, 2)	11.7	201	27.5	32.8	0.46	60.3	18.0	309.3	9.8	168.3	52	11.6	5.9	0.37	22	0
(3, 13)	48.0	176	113.1	30.3	0.79	143.4	48.9	179.2	10.3	37.8	36	20.1	14.4	0.40	11	0
(9, 8)	8.0	147	19.1	16.3	0.54	35.4	14.4	264.6	6.7	122.0	68	13.6	3.5	0.33	7	0
(10, 9)	6.3	165	15.5	18.1	0.46	33.6	12.2	322.6	6.6	173.7	55	11.2	3.2	0.31	9	0
(17, 9)	5.1	94	11.5	60.9	0.16	72.4	46.2	854.6	38.9	718.8	86	4.2	7.2	0.98	18	0

NETWORK STATISTICS

VEHICLE-MILES= 270.94 VEHICLE-MINUTES= 1811.1 VEHICLE-TRIPS (EST.)= 929 STOPS/VEHICLE= 1.86

MOVING/TOTAL TRIP TIME=0.359 AVG. SPEED (MPH)= 8.98 MEAN OCCUPANCY= 180.7 VEH. AVG DELAY/VEHICLE= 74.93 SEC

TOTAL DELAY= 1160.2 MIN. DELAY/VEH-MILE= 4.28 MIN/V-MILE TRAVEL TIME/VEH-MILE= 6.68 MIN/V-MILE

STOPPED DELAY AS A PERCENTAGE OF TOTAL DELAY=80.7

SPILLBACK HAS PREVAILED ON LINK (4, 3) FOR 32 SECONDS FROM TIME= 585 TO TIME= 617

SPILLBACK HAS PREVAILED ON LINK (4, 3) FOR 4 SECONDS FROM TIME= 677 TO TIME= 681

Figure 119. NETSIM Standard Statistical Report

LINK STATISTICS AT TIME 16 45 0

LINK	OCC.	VEH DIS	TURN MOVEMENT LEFT	THRU	RT.	QUEUE LENGTH BY LANE 1	2	3	4	5	DELAY/ VEH.	STOP DLY(P)	CYC FLR	EVNT	CURRENT CHANNELIZATION					AVG. SPEED	NO. STOP	SIG CODE
(800, 1)	0	143	0	143	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0.0	0	1
(1, 2)	7	144	0	132	19	2	4	0	0	0	16.3	77	0	0	0	0	0	0	0	8.3	83	1
(2, 3)	0	125	5	120	0	0	0	0	0	0	24.2	78	0	0	0	0	0	0	0	6.2	114	2
(6, 5)	4	230	0	234	0	0	0	0	0	0	8.2	77	0	0	0	0	0	0	0	11.9	99	1
(7, 6)	5	262	29	239	0	0	0	0	0	0	2.3	36	0	0	0	0	0	0	0	20.2	40	1
(15, 5)	5	138	38	0	108	0	0	0	0	0	21.1	71	0	0	4	0	1	0	0	6.8	135	2
(810, 16)	2	35	0	37	0	0	2	0	0	0	0.0	0	0	0	0	0	0	0	0	0.0	0	1
(7, 8)	1	359	0	244	116	0	0	0	0	0	4.0	14	0	0	4	0	0	0	0	17.6	48	1
(804, 11)	0	158	0	158	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0.0	0	1

Figure 120. NETSIM Intermediate Statistical Report

CUMULATIVE VALUES OF FUEL CONSUMPTION AND OF EMISSIONS

LINK	FUEL CONSUMPTION						VEHICLE EMISSIONS (GRAMS/MILE)								
	GALLONS			M.P.G.			HC			CO			NO X		
VEHICLE TYPE-	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
(1, 2)	1.2	0.3	0.0	5.9	3.0	0.0	6.9	0.0	0.0	121.0	0.0	0.0	9.3	0.0	0.0
(2, 3)	1.1	0.2	0.0	5.2	3.5	0.0	8.2	0.0	0.0	157.6	0.0	0.0	7.3	0.0	0.0
(2, 1)	0.7	0.0	0.0	16.0	6.2	0.0	2.1	0.0	0.0	29.3	0.0	0.0	3.2	0.0	0.0
(3, 2)	2.3	0.3	0.0	6.9	2.9	0.0	5.4	0.0	0.0	98.1	0.0	0.0	8.7	0.0	0.0
(3, 13)	4.7	0.5	0.0	14.2	6.6	0.0	2.4	0.0	0.0	36.3	0.0	0.0	3.3	0.0	0.0
NETWORK-WIDE STATISTICS	56.45	6.20	0.0	6.86	3.65	0.0	5.75	0.0	0.0	105.46	0.0	0.0	6.43	0.0	0.0

VEHICLE TYPE 1 = COMPOSITE AUTO, TYPE 2 = TRUCK, TYPE 3 = BUS

Figure 121. NETSIM Fuel Consumption and Vehicle Emissions Report

network description. Special problems are also identified through these messages.

Output Tape

The data may be ouput to tape, for evaluating several simulations. A list of these data is given in Table 29.

Table 29 - Summary of Data Output to Tape

LINK-SPECIFIC DATA	NETWORK-WIDE DATA
Vehicles discharged	Total vehicle trips
Travel time per vehicle	Total vehicle-miles
Delay per vehicle	Total vehicle-minutes
Average speed	Stops per vehicle
Stops per vehicle	Ratio of moving/ stopped time
Percent stop delay	Average Speed
Average saturation	Mean occupancy
Number of cycle failures	Average delay
Ratio of moving/stopped time	Total delay % stop delay

Diagnostic Messages

As note earlier, there are extremely extensive diagnostic checks and feedback messages available in NETSIM. Indeed there are too many to itemize here. Errors may occur in several ways. If errors are detected in reading the input data, NETSIM will point out the error and disallow execution of the simulation, but error checking will continue to determine whether further errors exist in the data. The approximate breakdown of the documented errors (i.e., execution aborted) and warnings (i.e., fixup taken, but careful review should be made for possible error) is as follows:

PROGRAM STEP	ERROR	WARNING
Preprocessor	112	1
Simulation	2	5

ADDITIONAL FEATURES

As with most large-scale microscopic simulation models, NETSIM has a multiplicity of features, and user options. Virtually any feasible geometric configuration, traffic control system, traffic management strategy and demand configuration can be modeled. The type of network may vary from a single intersection, up to a complex grid network.

A major enhancement underway and being developed by the University of Washington, is an interactive graphic capability. This enhancement (referred to as NETGRAF) will enable the user to make more effective use of the postprocessor function of NETSIM. Presently, two-way comparisons must be run off-line, a process which can be time consuming. With NETGRAF, the comparisons can be run, and displayed, on-line, thus greatly reducing the time required to compare a number of NETSIM simulations. NETGRAF will be disseminated by the U.S. Department of Transportation.

APPLICATIONS AND LIMITATIONS

NETSIM is particularly applicable to the analysis of large-scale complex traffic networks, optionally with coordinated systems (whether master controlled or dynamically controlled).

NETSIM is an operational, analysis and evaluation model. Its sole function is to approximate real-world conditions that are input by the user. It performs no design itself. Thus, in single runs, any of the infinitely variable input conditions may be considered by the user. Several of these may be evaluated by the user to determine which is "best", thus the evaluation function is, to a certain extent, a design tool, but it must be emphasized that the "best" solution is only among those alternatives tested. There is no assurance that the "best" solution is an optimal solution.

Analysis is the role of microscopic simulation models. The results are generally more reliable than those obtained from macroscopic models, since the natural stochastic variation of traffic demand and behavior are considered. Although any simulation model is a simplification of the real-world, NETSIM is sufficiently flexible to handle a highly sophisticated system of intersections, including on-line signal control system (with additional user programming).

Also inherent to microscopic simulation models are the disadvantages of costly calibration, extensive input requirements and the requirements for a high level of expertise in using them. These are all true of NETSIM; although the developers have written the model with the user in mind to the degree possible. For example, most parameters are furnished in the model, but these may be changed if the user has local data which would better calibrate the model.

Several specific limitations of the model are discussed below.

1. Physical constraints are 99 nodes, 160 links and 1600 vehicles in the system at any time. These can be increased easily, but a substantial increase in computer time will result to run larger networks.

2. Freeway facilities cannot be modeled in NETSIM. A rough estimate of the effect of freeways on the street system is possible, by making the ramps "sink/source" nodes. The freeway effects must be estimated separately.

3. Similarly, rotary intersections and semi major uncontrolled intersections cannot be modeled only with difficulty.

4. For agencies with limited access to large computers, NETSIM can be quite expensive to use, either in terms of dollars or computer time, depending on local operating policies.

5. It has been noted that real-time control systems can be simulated; however, the algorithms must be inserted by the user. NETSIM does not contain any package dynamic control systems. Surveillance capabilities do exist, however.

6. Preset vehicle trajectories through the network are not possible though they can be estimated by adding additional statements to the code. Vehicles are simply input to the network and turns are assigned randomly. This limits evaluation of one-way street systems and does not allow for induced diversion from congested streets. The latter would have to be approximated by the user manually "directing" traffic via increased turns to effect the diversion or via utilization of the NETFLO model.

7. Inputs to the system are based on a uniform distribution. This is often not realistic. A patch deck is available from FHWA which corrects this difficulty.

In summary, NETSIM has several limitations inherent to any microscopic simulation model, as well as several limitations peculiar to this model. But on the whole, it is a powerful analysis tool for the traffic engineering agency that has the level of staff expertise and computer facilities to use the model. To overcome this latter requirement (i.e., resources), some state departments of transportation are assisting localities in using NETSIM on their facilities. Thus, mid-to-large-sized urban areas should not be discouraged from using this excellent traffic engineering tool.

EXAMPLE APPLICATION

To illustrate the use of NETSIM the Ashley Drive arterial signal problem previously used to illustrate signal optimization models was selected. The following describes the use of NETSIM to evaluate alternative signal timing plans.

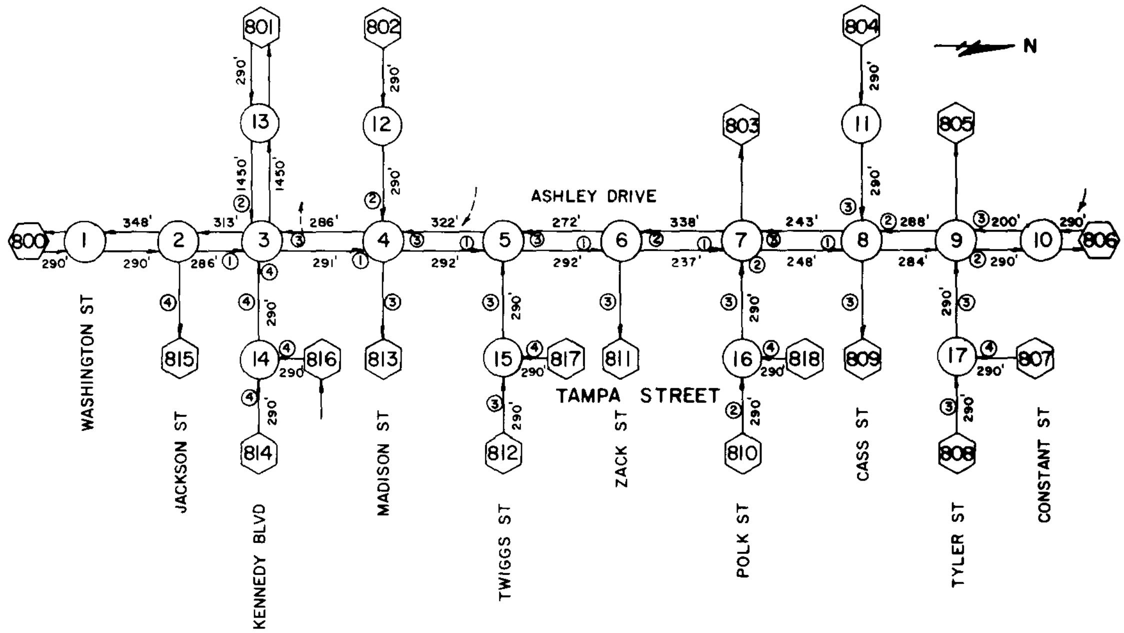

Figure 122. NETSIM Link-Node Network for Ashley Drive

Problem Description

The previous models described in this Handbook (PASSER 80, TRANSYT-7F and SIGOP III) were used to evaluate existing operations and to develop improved signal timing plans. In case of each of these models it was necessary to assume the signals were operating as fixed time signals, when in fact seven of the eight signals were semi-actuated signals with a background cycle. There were no provisions for evaluating the affect varying traffic volume during each cycle had on the splits or even the possible affect of skipping a phase.

In this example NETSIM will be used to evaluate the optimal signal timing plan developed by each of the previous models for a 90 second background cycle. As previously indicated these signals are part of a downtown signal system of fifty-six signals what are operating during the PM peak hour under the same cycle length. Each of the previous models were used to develop optimal signal timing for Ashley Drive as an arterial system, rather than a network. Therefore, the reader should not infer from this example use of NETSIM that one of the optimization modules gives better results than another. Both the TRANSYT-7F and SIGOP III models are network models, and to develop an optimal signal timing plan for Ashley Drive, should have been coded as part of the total system. However, for the purpose of brevity this was not done, therefore, the results of this application will not result in a fair comparison of each of the optimization model's ability to develop optimal signals plans.

Analysis of Existing Conditions

The first step in the evaluation process is the use of NETSIM to represent the existing system. This provides the user with an opportunity to check the model's ability to to represent traffic conditions in the field as the basis for evaluating alternative plans.

Figure 122 illustrates the link-node network for the example applications. Notice that in this example the traffic signals at the intersections affecting traffic flow on the cross stretch have been included. On Kennedy Blvd. (the major cross street), west of Ashley Drive there is a signal (node 13) located approximately 1450 feet west of Ashley Drive. This is not part of a system and presently operates as a 60 second fixed time signal. The other signals affecting traffic flow on the cross streets (nodes 14, 15, 16, and 17) are located on a parallel one-way street (Tampa Street). This street is one-way southbound and is controlled by two phase, fixed time signals within the 90 second cycle length. Since we are only interested in simulating traffic arrivals from the cross streets, only the signals and traffic movements affecting westbound traffic were modeled. A total of 17 nodes were required to represent signals (13) or intersections (4) to insure data will be obtained on traffic affected by the Ashley Drive signals.

Once the remaining data on geometrics, traffic volume and signal operation were obtained it was possible to code the network. Figure 122 illustrates the data coded to represent existing conditions. A total of 125 lines of coded data was required. With the exception of two items, all data (geometric, traffic counts, operating speed, and signal operations) were easily obtained.

The only judgment required for coding the network were the queue discharge rate (mean headways from standing queue) and lost time (queue start-up delay) by lead vehicle. Since headway studies had been conducted the average mean headway of 2.0 seconds was utilized. Although the model has a default distribution for lost-time, a 3.5 second value for lost time was used in the example.

The input data were keypunched and submitted to the computer for execution. Several submissions were required in order to obtain a run with no errors. Basically, these errors were related to improper coding of signal codes for actuated signals and the detector operations. Figure 124 shows a copy of the standard statistical reports obtained from the accepted existing conditons run. The input data report (17 pages are not shown, however, excerpts from its report were showm previously in Figure 118.

One of the initial problems with the final run was the use of an initialization period of 300 second (5 minutes). This was insufficient and it was necessary to go to 600 seconds. However, the final run for existing conditions (after getting rid of other errors) only required 360 seconds to reach equilibrium.

One of the first facts obtained from the existing conditions report is that on Link (4,3) spillback occurs frequently during the simulation (for 404 seconds or 45% of the 900 seconds simulation interval. In other words, for 40 of the 90 cycles, the vehicle queue exceeded the length of this lane and vehicles could be blocking intersection 3.

The link statistics report provides valuable data in specific problems. For Link (4,3) we see that traffic demand is 71% of saturation flow, yet the green time available is only .45% of the cycle (41 out of 90 seconds) thus spillback would obviously occur.

On a link by link basis deficiences can be readily identified. From a level of service point of view one could look at average delay time in seconds per vehicle per each link. Using delay in excess of 30 seconds as a criterion four links would be of concern. These are Links (2,3), (13,3), (4,3), and (11,8). In addition Link (5,4) in close with 28.4 seconds of delay. Three of the four critical links are approaches to intersection 3 (Ashley Drive and Kennedy Blvd.).

A second measure of effectiveness (stops per vehicle) further indicates the magnitude of problems on these links. Data obtained from the output for existing conditions can be utilized to determine the credibility of the model. Intermediate statistical reports are available upon request (see Figure 120) which

TITLE: ASHLEY DRIVE CORRIDOR | CODER: ASB PHONE: 896-4730 | DATE: 5/12/81 | SHEET 1 OF 14

NETSIM CARD 99 - EXECUTION CONTROL

Field	Columns	Entry
Is data set followed by another data set? 0 = YES, 1 = NO	1	1
File no. identifying data set on the old tape	4–5	
Disposition code 0 = data set not stored	7	2
Execution of simulation desired? 0 = NO, 1 = YES	9	1
Peripheral activity desired 0 = no activity	11–12	12
Sequence numbers of files to be processed by peripheral activities	14–75	
Card type 99	79–80	99

NETSIM CARD 00 – TITLE

Title identifying this run (cols 1–65)	Seed for random number generator	Card type 00
ARTERIAL SIMULATION-ASHLEY DR. CORRIDOR-RUN NO. 1 EXIST. CONDITIONS	3591	00

NETSIM CARD 1 – NETWORK NAME

Network name	Name of city	Name of state	Code number of file on data tape	Month	Day	Year	Card type 01
ASHLEY DR. -CBD	CITY OF TAMPA	FLORIDA	101	10	31	81	01

NETSIM CARD 2 – LINK NAMES

Row	Upstream node (i)	Downstream node (j)	Street name for network link (i, j)	Upstream node (i)	Downstream node (j)	Street name for network link (i, j)	Upstream node (i)	Downstream node (j)	Street name for network link (i, j)	Card type 02	
1	801	1	ASHLEY DR	28	15	JACKSON ST	812	15	TWIGGS ST	02	1
2	1	800	ASHLEY DR	801	13	KENNEDY BLVD	15	5	TWIGGS ST	02	2
3	1	2		13	801		817	15	TAMPA STREET	02	3
4	2	1		13	3		6	811	ZACK STREET	02	4
5	2	3		3	13		810	16	POLK STREET	02	5
6	3	2		814	14		16	7	POLK STREET	02	6
7	3	4		14	3	KENNEDY BLVD	7	803	POLK STREET	02	7
8	4	3		816	14	TAMPA STREET	818	16	TAMPA STREET	02	8
9	4	5		813	4	MADISON STREET	804	11	CASS STREET	02	9
10	5	4		802	12	DOYLE-CARLTON DR	11	5	CASS STREET	02	10
11	5	6		12	4	DOYLE-CARLTON DR	8	809	CASS STREET	02	11
12	6	5		806	10	ASHLEY DR	808	17	TYLER STREET	02	12
13	6	7		10	806		17	9	TYLER STREET	02	13
14	7	6		9	10		9	805	TYLER STREET	02	14
15	7	8		10	9		807	17	TAMPA STREET	02	15
16	8	7	ASHLEY DR	8	9	ASHLEY DR	9	8	ASHLEY DR.	02	16
17										02	17
18										02	18
19										02	19
20										02	20

Figure 123. NETSIM Coded Input Data Form for Ashley Drive Existing Conditions.

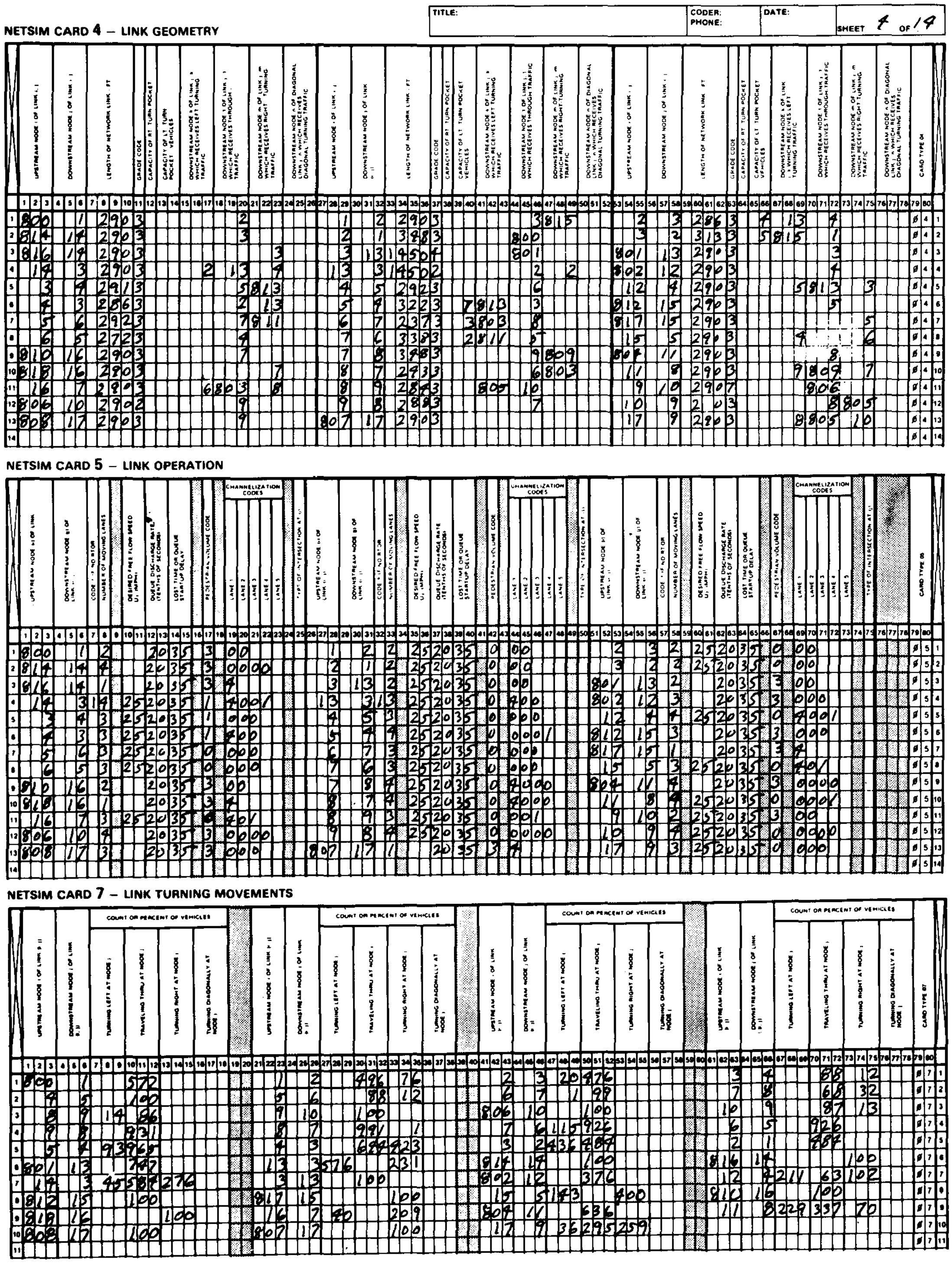

Figure 123. NETSIM Coded Input Data Form for Ashley Drive Existing Conditions (Continued).

TITLE:	CODER: PHONE:	DATE:	SHEET 7 OF 14

NETSIM CARD 10 – FIXED TIME CONTROL SIGNALS

Row	Node Number	Offset (leave blank if No. 11 card follows)	Upstream Node Number: Link No 1	Link No 2	Link No 3	Link No 4	Link No 5	Duration of Interval Number 1	Control Code (approach link no 1–5), Interval #1	Duration of Interval Number 2	Control Code, Interval #2	Duration of Interval Number 3	Control Code, Interval #3	Duration of Interval Number 4	Control Code, Interval #4	Duration of Interval Number 5	Control Code, Interval #5	Duration of Interval Number 6	Control Code, Interval #6	Card Type 10
1	1		800	2					11											10
2	2	68	3	1				22	71	5	70	58	12	5	02					10
3	10		806	9					11											10
4	11		804						1											10
5	12		802						1											10
6	13		801	3				40	11	4	00	16	22							10
7	14	22	816	819				41	12	5	02	40	21	4	20					10
8	15	24	817	812				49	12	5	02	32	21	4	20					10
9	16	21	818	810				62	12	5	02	19	21	4	20					10
10	17	7	807	808				43	12	5	02	38	21	4	20					10
11																				10

NETSIM CARD 15 – ACTUATED CONTROLLER

Row	Node Number of Intersection Controlled by an Actuated Signal Controller	Approach No 1 Upstream Node No	Approach No 1 Downstream Node No	Approach No 2 Upstream	Approach No 2 Downstream	Approach No 3 Upstream	Approach No 3 Downstream	Approach No 4 Upstream	Approach No 4 Downstream	Approach No 5 Upstream	Approach No 5 Downstream	Approach No 6 Upstream	Approach No 6 Downstream	Approach No 7 Upstream	Approach No 7 Downstream	Controller Coordination Code (CCC) (0 = not coord, 1 = coordinated)	Rest in Red Option (0 = not applied, 1 = applied)	Background Cycle Length (applicable when CCC = 1)	Entry Codes (0 = single ring, 1 = single & dual entry, 2 = dual R & dual entry)	Detector Switching Code (0 = switching inactive, 1 = switching active)	Card Type 15
1	3	2	3	13	3	4	3	14	3							1	0	90	0	0	15
2	4	3	4	12	4	5	4									1	0	90	0	0	15
3	5	4	5	15	5	6	5									1	0	90	0	0	15
4	6	5	6	7	6											1	0	90	0	0	15
5	7	6	7	16	7	8	7									1	0	90	0	0	15
6	8	7	8	9	8	11	8									1	0	90	0	0	15
7	9	8	9	17	9	10	9									1	0	90	0	0	15
8																					15

NETSIM CARD 16 - NA – NON-ACTUATED PHASE OF ACTUATED SIGNAL

Row	Node Number of Intersection Controlled by an Actuated Signal Controller	Phase Number (1, 2)	Phase Actuation Code	Yield Point - Beginning of Yield Interval, Sec.	End of Yield Interval Sec (if phase is coordinated)	Offset, Sec (if phase is coordinated)	Amber Duration Sec	Red Clearance Duration Sec	Card Type 16
1	3	1	1	34	39	79	4	1	16
2	4	1	1	43	47	39	4		16
3	5	1	1	48	52	40	4		16
4	6	1	1	59	63	38	4		16
5	7	1	1	34	38	58	4		16
6	8	1	1	60	64	48	4		16
7	9	1	1	34	38	52	4		16
8			1						16

Figure 123. NETSIM Coded Input Data Form for Ashley Drive Existing Conditions (Continued).

TITLE:	CODER: PHONE:	DATE:	SHEET 10 OF 14

NETSIM CARD 16-A – ACTUATED PHASE

	Node number of intersection controlled by an actuated signal controller	Phase number (2, ... 9)	Phase actuation code	Force-off point, sec. (if signal is semiactuated)	Minimum initial interval, sec.	Initial interval code (0, 1, 2, 3)	Initial interval data	Initial actuation data	Passage time, tenths of sec.	Minimum gap, tenths of sec. (unit extension)	Time to reduce, sec.	Amount of gap reduction, tenths of sec.	Time between gap reductions, tenths of sec.	Gap reduction per sec., tenths of sec.	Maximum extension, sec.	Maximum green, sec.	Amber duration, sec.	Red clearance duration, sec.	Red revert time, sec.	Recall switch code (0, 1)	Memory switch code (0, 1)	Max. termination code (0, 1)	Overlap code (0, 1, 2, 3)	Card type 16
1	3	2	ø	56	10	0			30							19	5			0	0	0	0	16 1
2	3	3	ø	86	10	0			30							22	5			0	0	0	0	16 2
3	4	2	ø	70	10	0			30							23	5			0	0	0	0	16 3
4	4	3	ø	86	10	0			10							10	4			0	0	0	0	16 4
5	5	2	ø	86	10	0			30							32	4	1		0	0	0	0	16 5
6	6	2	ø	86	10	0			30							25	4			0	0	0	0	16 6
7	7	2	ø	70	10	0			30							23	4	1		0	0	0	0	16 7
8	7	3	ø	86	5	0			30							10	4			0	0	0	0	16 8
9	8	2	ø	86	10	0			30							21	4	1		0	0	0	0	16 9
10	9	2	ø	63	5	0			50							25	4			0	0	0	0	16 10
11	9	3	ø	86	10	0			30							17	4	1		0	0	0	0	16 11
12			ø																					16 12

NETSIM CARD 17 – ACTUATED PHASE OPERATIONS

Detector locations are given as approach no. and lane no.

	Node number of intersection controlled by an actuated signal controller	Phase number	Signal code for approach no. 1	Signal code for approach no. 2	Signal code for approach no. 3	Signal code for approach no. 4	Signal code for approach no. 5	Detectors used when phase is inactive: Detector location 1	Detector location 2	Detector location 3	Detector location 4	Detector location 5	Detector location 6	Detector location 7	Detector location 8	Detectors used when phase is active: Detector location 1	Detector location 2	Detector location 3	Detector location 4	Detector location 5	Detector location 6	Detector location 7	Detector location 8	Card type 17
1	3	1	2	2	2	1																		17 1
2	3	2	2	1	3	2		21	22	23						21	22	23	31					17 2
3	3	3	1	2	1	2		11	12	15	31	32	33			11	12	15	31	32	33			17 3
4	4	1	1	2	1																			17 4
5	4	2	2	1	2			21	22	23	24					21	22	23	24					17 5
6	4	3	2	2	1			34	35							34	35							17 6
7	5	1	1	2	1																			17 7
8	5	2	2	1	2			21	22	23						21	22	23						17 8
9	6	1	1	1																				17 9
10	6	2	2	4				25								25								17 10
11	7	1	1	2	1																			17 11
12	7	2	2	1	2			21	22	23						21	22	23						17 12
13	7	3	1	2	2			15								15								17 13
14	8	1	1	1	2																			17 14
15	8	2	2	2	1			31	32	33	34					31	32	33	34					17 15
16	9	1	1	2	1																			17 16
17	9	2	1	2	2			13								13								17 17
18	9	3	2	1	2			21	22	23						21	22	23						17 18
19																								17 19

NETSIM CARD 20 – VOLUMES

	Upstream node (i) of link (i, j)	Downstream node (j) of link (i, j)	Change in flow rate (VPH) between (i) and (j)	Percent trucks	Upstream node (i) of link (i, j)	Downstream node (j) of link (i, j)	Change in flow rate (VPH) between (i) and (j)	Percent trucks	Upstream node (i) of link (i, j)	Downstream node (j) of link (i, j)	Change in flow rate (VPH) between (i) and (j)	Percent trucks	Upstream node (i) of link (i, j)	Downstream node (j) of link (i, j)	Change in flow rate (VPH) between (i) and (j)	Percent trucks	Upstream node (i) of link (i, j)	Downstream node (j) of link (i, j)	Change in flow rate (VPH) between (i) and (j)	Percent trucks	Upstream node (i) of link (i, j)	Downstream node (j) of link (i, j)	Change in flow rate (VPH) between (i) and (j)	Percent trucks	Card type 20
1	800	1	572	5	801	13	747	5	802	12	376	0	804	11	636	3	806	10	1029	5	807	17	110	5	2ø 1
2	808	17	480	5	818	16	114	5	810	10	135	5	817	15	56	5	812	15	490	5	816	14	157	5	2ø 2
3	814	14	751	5	3	4	160	0																	2ø 3
4																									2ø 4

Figure 123. NETSIM Coded Input Data Form for Ashley Drive Existing Conditions (Continued).

TITLE:	CODER: PHONE:	DATE:	SHEET 13 OF 14

NETSIM CARD 25 – SURVEILLANCE

Card	Upstream node (I) (1–3)	Downstream node (J) (4–6)	Detector type (7)	Lane number (8)	Length or location (distance upstream) (9–12)	Detector type (13)	Lane number (14)	Length or location (distance upstream) (15–18)	Detector type (19)	Lane number (20)	Length or location (distance upstream) (21–24)	Detector type (25)	Lane number (26)	Length or location (distance upstream) (27–30)	Detector type (31)	Lane number (32)	Length or location (distance upstream) (33–36)	Detector type (37)	Lane number (38)	Length or location (distance upstream) (39–42)	Detector type (43)	Lane number (44)	Length or location (distance upstream) (45–48)	Detector type (49)	Lane number (50)	Length or location (distance upstream) (51–54)	Detector type (55)	Lane number (56)	Length or location (distance upstream) (57–60)	Detector type (61)	Lane number (62)	Length or location (distance upstream) (63–66)	Detector type (67)	Lane number (68)	Length or location (distance upstream) (69–72)	Detector type (73)	Lane number (74)	Length or location (distance upstream) (75–78)	Card type 25 (79–80)	
1	2	30	1		15	0	2	15	0	5	15																												25	1
2	4	31	1		30	0	2	15	0	3	15																												25	2
3	13	31	1		30	0	2	16	0	3	20																												25	3
4	5	4	1	4	75	1	5	75																															25	4
5	12	40	1		20	0	2	20	0	3	20	0	4	20																									25	5
6	15	50	1		20	0	2	20	0	3	20																												25	6
7	7	6	1	5	45																																		25	7
8	6	7	1	5	35																																		25	8
9	16	70	1		20	0	2	20	0	3	20																												25	9
10	11	80	1		20	0	2	20	0	3	20	0	4	20																									25	10
11	17	90	1		20	0	2	20	0	3	20																												25	11
12	8	9	1	3	70																																		25	12
13																																							25	13

NETSIM CARD 3 – NETWORK PRIMING

Maximum initialization time (seconds) (1–4)	Clock time at start of run hours - minutes (6–9)	Card type 03 (79–80)
-600	1630	3

NETSIM CARD 60 – SIMULATION CONTROL (LAST CARD IN DATA FOR EACH SIMULATION SUB-INTERVAL)

Duration of simulation sub-interval (seconds) (1–4)	Elapsed time in seconds between successive intermediate printouts	No. of sec. after start of simulation sub-interval that interm output should start	Span of time (seconds) that intermediate output will be produced	Elapsed time (minutes) between cumulative outputs	Are O-D volumes desired? 0 = No, 1 = Yes (28)	Do input cards pertaining to next sub-interval follow? 0 = No, 1 = Yes (40)	Card type 60 (79–80)
900					1	0	60

Figure 123. NETSIM Coded Input Data Form for Ashley Drive Existing Conditions (Continued).

SIMULATION TIME INTERVAL = 900 SECONDS.
SCANNING INTERVAL=1 SECOND
INTERMEDIATE OUTPUT COMMENCES 300 SECONDS AFTER BEGINNING OF SUB-INTERVAL
FOR A PERIOD OF 900 SECONDS, PRINT-OUT WILL APPEAR AT INTERVALS OF 300 SECONDS
CUMULATIVE OUTPUT WILL APPEAR EVERY 5 MINUTES DURING SUB-INTERVAL
CLOCK TIME NOW
4 30 P.M.
FUEL CONSUMPTION AND EMISSIONS WILL BE PROCESSED
VEHICLE TRAJECTORY DATA WILL NOT BE WRITTEN TO UNIT 23

EQUILIBRIUM ATTAINED

PERIOD	OCCUPANCY	CHANGE
1	165	5
2	160	9
3	151	37

DURING PAST CYCLE, 160 VEHICLES OCCUPIED THE NETWORK. NET CHANGE IN OCCUPANCY WAS 9 AT TIME=360
DURING PAST CYCLE, 151 VEHICLES OCCUPIED THE NETWORK. NET CHANGE IN OCCUPANCY WAS 37 AT TIME=270

INITIALIZATION PERIOD COMPLETED AFTER 360 SECONDS

COMMENCE SIMULATION AND GATHER STATISTICAL DATA
SPILLBACK HAS PREVAILED ON LINK (4, 3) FOR 52 SECONDS FROM TIME= 137 TO TIME= 189
SPILLBACK HAS PREVAILED ON LINK (4, 3) FOR 64 SECONDS FROM TIME= 217 TO TIME= 281

CUMULATIVE STATISTICS SINCE BEGINNING OF SIMULATION
PRESENT TIME IS 16 45 0, ELAPSED SIMULATED TIME IS 15 MINUTES, 0 SECONDS
LINK STATISTICS

LINK	VEH-MILES	VEH TRP	MOV. TIME V-MIN	DELAY TIME V-MIN	M/T	TOTAL TIME V-MIN	T-TIME / VEH. SEC	T-TIME/ VEH-MILE SEC/MILE	D-TIME / VEH SEC	D-TIME/ VEH-MILE SEC/MILE	PCT STOP DELAY	AVG. SPEED MPH	AVG. OCC.	STOPS /VEH	AVG SAT PCT	CYCL FAIL
(1, 2)	7.9	143	17.7	82.0	0.18	99.7	41.8	761.4	34.4	626.1	87	4.7	6.6	0.83	23	0
(2, 3)	6.6	121	14.7	128.7	0.10	143.4	71.1	1312.4	63.8	1178.0	91	2.7	9.6	1.02	30	0
(2, 1)	10.0	151	23.6	0.9	0.96	24.5	9.7	147.7	0.3	5.3	0	24.4	1.7	0.0	5	0
(3, 2)	16.1	277	38.5	40.2	0.49	78.7	17.0	292.5	8.7	149.4	52	12.3	5.1	0.24	19	0
(3, 13)	69.8	256	167.5	42.2	0.80	209.7	49.1	180.1	9.9	36.3	32	20.0	14.0	0.32	10	0
(14, 3)	12.2	225	29.5	40.0	0.42	69.5	18.5	342.1	10.7	196.9	63	10.5	4.5	0.44	9	0
(13, 3)	36.5	133	114.0	755.0	0.13	869.0	392.0	1427.5	340.6	1240.3	98	2.5	57.8	1.44	27	0
(3, 4)	10.9	203	25.2	30.9	0.45	56.1	16.6	309.6	9.1	170.4	57	11.6	3.8	0.43	11	0
(4, 5)	13.9	252	32.7	24.4	0.57	57.1	13.6	245.8	5.8	105.1	50	14.6	3.8	0.38	11	0
(12, 4)	5.2	95	11.9	52.3	0.19	64.2	40.5	738.3	33.0	601.5	86	4.9	4.2	0.87	8	0
(4, 3)	12.6	235	28.9	351.2	0.08	380.1	97.0	1808.4	89.7	1671.1	96	2.0	25.3	0.92	71	0
(5, 4)	15.3	251	38.2	118.8	0.24	157.0	37.5	615.3	28.4	465.7	87	5.9	10.4	0.63	17	0
(5, 6)	19.1	354	45.9	17.4	0.73	63.3	10.7	198.9	2.9	54.6	19	18.1	4.2	0.12	11	0
(6, 7)	14.0	311	33.4	17.6	0.65	51.0	9.8	219.2	3.4	75.6	61	16.4	3.5	0.29	9	0
(6, 5)	12.3	238	28.3	45.7	0.38	74.1	18.7	362.4	11.5	223.8	85	9.9	5.0	0.49	13	0
(7, 6)	17.0	265	40.5	10.8	0.79	51.3	11.6	181.3	2.4	38.2	51	19.9	3.4	0.12	8	0
(15, 5)	7.4	136	18.6	16.7	0.53	35.2	15.5	285.5	7.4	135.1	33	12.6	2.3	0.26	6	0
(7, 8)	23.4	358	56.4	36.0	0.61	92.4	15.5	237.5	6.0	92.6	48	15.2	6.1	0.29	10	0
(8, 7)	11.4	249	27.3	8.1	0.77	35.4	8.5	186.8	1.9	42.6	16	19.3	2.3	0.09	6	0
(11, 8)	8.6	157	19.7	88.3	0.18	108.0	41.3	751.4	33.8	614.7	86	4.8	7.1	0.85	13	0
(16, 7)	3.3	62	8.5	9.4	0.48	17.9	17.3	328.3	9.1	172.0	43	11.0	1.2	0.55	3	0
(8, 9)	16.4	305	38.9	41.0	0.49	79.8	15.7	292.0	8.1	149.8	61	12.3	5.3	0.44	15	0
(9, 10)	17.5	325	44.0	10.6	0.81	54.6	10.1	186.8	2.0	36.4	0	19.3	3.6	0.00	15	0

Figure 124. NETSIM Standard Statistic Report for Existing Conditions - Ashley Drive.

(9, 8)	12.7	232	30.4	17.5	0.63	47.9	12.4	227.2	4.5	83.0	43	15.8	3.2	0.30	7	0
(10, 9)	9.7	257	22.9	49.5	0.32	72.5	16.9	446.6	11.6	305.3	73	8.1	4.7	0.42	12	0
(17, 9)	8.0	148	18.8	59.5	0.24	78.3	31.7	587.1	24.1	446.3	78	6.1	5.2	0.88	13	0

NETWORK STATISTICS

VEHICLE-MILES= 397.64 VEHICLE-MINUTES= 3070.5 VEHICLE-TRIPS (EST.)= 1391 STOPS/VEHICLE= 1.71

MOVING/TOTAL TRIP TIME=0.318 AVG. SPEED (MPH)= 7.77 MEAN OCCUPANCY= 204.0 VEH. AVG DELAY/VEHICLE= 90.35 SEC

TOTAL DELAY= 2094.7 MIN. DELAY/VEH-MILE= 5.27 MIN/V-MILE TRAVEL TIME/VEH-MILE= 7.72 MIN/V-MILE

STOPPED DELAY AS A PERCENTAGE OF TOTAL DELAY=84.8

SEED FOR RANDOM NUMBER GENERATOR IS 9008613

SPILLBACK HAS PREVAILED ON LINK (4, 3) FOR 243 SECONDS FROM TIME= 657 TO TIME= 900

CUMULATIVE VALUES OF FUEL CONSUMPTION AND OF EMISSIONS

LINK	FUEL CONSUMPTION						VEHICLE EMISSIONS (GRAMS/MILE)								
	GALLONS			M.P.G.			HC			CO			NO X		
VEHICLE TYPE-	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
(1, 2)	1.9	0.1	0.0	3.8	2.9	0.0	10.9	0.0	0.0	210.2	0.0	0.0	10.9	0.0	0.0
(2, 3)	2.5	0.0	0.0	2.5	2.5	0.0	16.1	0.0	0.0	338.9	0.0	0.0	11.7	0.0	0.0
(2, 1)	0.6	0.1	0.0	16.2	6.3	0.0	2.1	0.0	0.0	29.4	0.0	0.0	3.2	0.0	0.0
(3, 2)	2.0	0.4	0.0	7.0	3.0	0.0	5.3	0.0	0.0	95.1	0.0	0.0	8.7	0.0	0.0
(3, 13)	4.7	0.4	0.0	13.9	6.1	0.0	2.4	0.0	0.0	37.3	0.0	0.0	3.4	0.0	0.0
(14, 3)	1.7	0.2	0.0	6.9	3.4	0.0	5.7	0.0	0.0	94.9	0.0	0.0	8.7	0.0	0.0
(13, 3)	13.4	1.3	0.0	3.4	2.8	0.0	11.7	0.0	0.0	241.7	0.0	0.0	7.6	0.0	0.0
(3, 4)	1.5	0.1	0.0	6.7	2.7	0.0	5.7	0.0	0.0	100.0	0.0	0.0	8.7	0.0	0.0
(4, 5)	1.5	0.1	0.0	9.0	3.6	0.0	4.2	0.0	0.0	72.0	0.0	0.0	6.3	0.0	0.0
(12, 4)	1.2	0.0	0.0	4.0	0.0	0.0	10.2	0.0	0.0	195.1	0.0	0.0	10.1	0.0	0.0
(4, 3)	6.0	0.4	0.0	2.3	2.3	0.0	17.9	0.0	0.0	377.7	0.0	0.0	10.3	0.0	0.0
(5, 4)	2.9	0.2	0.0	5.2	3.7	0.0	7.7	0.0	0.0	149.1	0.0	0.0	7.2	0.0	0.0
(5, 6)	1.8	0.1	0.0	9.8	4.3	0.0	3.8	0.0	0.0	61.3	0.0	0.0	6.6	0.0	0.0
(6, 7)	1.2	0.1	0.0	11.9	6.3	0.0	3.5	0.0	0.0	55.0	0.0	0.0	4.7	0.0	0.0
(6, 5)	1.3	0.1	0.0	8.7	6.2	0.0	4.8	0.0	0.0	87.6	0.0	0.0	4.5	0.0	0.0
(7, 6)	1.2	0.2	0.0	12.9	6.0	0.0	2.9	0.0	0.0	44.6	0.0	0.0	4.4	0.0	0.0
(15, 5)	0.8	0.1	0.0	8.5	5.0	0.0	4.8	0.0	0.0	76.0	0.0	0.0	6.6	0.0	0.0
(7, 8)	2.2	0.1	0.0	10.3	6.3	0.0	3.8	0.0	0.0	62.3	0.0	0.0	5.2	0.0	0.0
(8, 7)	1.0	0.2	0.0	10.5	4.0	0.0	3.6	0.0	0.0	57.0	0.0	0.0	6.3	0.0	0.0
(11, 8)	2.0	0.1	0.0	3.9	3.5	0.0	10.4	0.0	0.0	199.8	0.0	0.0	10.7	0.0	0.0
(16, 7)	0.4	0.0	0.0	7.9	4.3	0.0	5.2	0.0	0.0	83.2	0.0	0.0	6.8	0.0	0.0
(8, 9)	2.0	0.1	0.0	7.9	4.3	0.0	4.9	0.0	0.0	87.7	0.0	0.0	6.8	0.0	0.0
(9, 10)	1.6	0.2	0.0	10.3	4.2	0.0	3.6	0.0	0.0	58.9	0.0	0.0	6.5	0.0	0.0
(9, 8)	1.2	0.2	0.0	9.9	4.3	0.0	3.7	0.0	0.0	61.9	0.0	0.0	5.5	0.0	0.0
(10, 9)	1.6	0.2	0.0	5.3	3.0	0.0	7.5	0.0	0.0	131.7	0.0	0.0	10.6	0.0	0.0
(17, 9)	1.5	0.1	0.0	4.9	3.1	0.0	8.4	0.0	0.0	155.5	0.0	0.0	9.0	0.0	0.0
NETWORK-WIDE STATISTICS	59.71	4.92	0.0	6.50	3.81	0.0	6.07	0.0	0.0	112.75	0.0	0.0	6.52	0.0	0.0

VEHICLE TYPE 1 = COMPOSITE AUTO, TYPE 2 = TRUCK, TYPE 3 = BUS

Figure 124. NETSIM Standard Statistic Report for Existing Conditions - Ashley Drive (Continued).

Table 30 - Comparison of NETSIM MOE's For Alternative Signal Timing Plans - Ashley Drive

MOE	ALTERNATIVES Existing	PASSER 80	TRANSYT-7F	SIGOP III
Vehicle Miles	397.64	377.50	401.77	403.60
Vehicle Minutes	3070.5	2985.9	2958.00	2856.2
Vehicle Trips	1391	1341	1395	1405
Stops per Vehicle	1.71	1.97	1.70	1.87
Moving Time per Total Time (%)	.318	.305	.330	.342
Avg. Speed (mph)	7.77	7.59	8.15	8.48
Mean Occupancy (vehicles)	204.0	198.5	196.5	189.9
Avg. Delay per Vehicle (sec.)	90.35	92.79	85.19	80.31
Total Delay (min.)	2094.7	2073.8	1980.7	1880.7
Delay per Veh.-mile (min. per mile)	5.27	5.49	4.93	4.66
Travel Time per Veh.-mile (min. per mile)	7.72	7.91	7.36	7.08
Stopped Delay per Total Delay (%)	84.8	83.8	84.7	82.0
Fuel Consumption (gals. per mile)	.0465	.0471	.0450	.0446
Vehicle Emissions (gross/mile)				
Hydro carbon (HC)	6.07	6.26	5.83	5.75
Carbon Dioxide (CO)	112.75	117.30	107.98	105.43
Nitrogen Oxide (NOX)	6.52	6.07	6.29	6.43

show queue length by lane at any specific instance of time. This is useful in calibrating the model. For instance, Link (4.3) that for the highest average saturation flow includes the exclusive right turn lane. In Figure 124 we only obtain information on the entire approach-e.g. average queue of 25.3 vehicle. However, the intermediate statistical report should 23 vehicles on the approach at the requested turn interval with 4 vehicles in lane 1 (thru lane) 9 in lane 2 (the thru lane) and 10 vehicles in lane 3 (the curb lane or exclusive right turn lane). Observation in the field indicates this is typical and indicates the model is reproducing arterial conditions.

This evaluation of existing conditions would include a similar comparison of other links within the network. In some cases a more detailed mathematical comparison would be required. However, in most instances this would not be economical.

Define and Analyze Alternatives

In order to define the alternate signal plans the existing signal timing card must be changed. For each alternative signal plan this required that card 16-NA (non-actuated phase of actuated signal) and card 16-A (actuated phase) be changed to include the new signal timing data (offsets, yield points, force offs and maximum green times) for the actuated signals. In addition card 10 (fixed time signal) must also be changed for node 2 (Ashley Drive and Jackson Street). In all a total of 19 of the 125 cards were changed for each alternative.

In order to evaluate each of the alternatives the summary of link statistics provides the most meanful information. For each of the alternatives the user could look at traffic characteristics on each of the links to identify problems which occur for each alternative.

Evaluation of Results

The reports obtained from each of the runs provide a useful tool for evaluation of the results. Table 30 provides a comparison of the summary statistics for the network as a whole.

Based on the developed signal timing plans some improvement in operations can be expected with several alternatives.

The PASSER 80 signal timing resulted in an overall deterioration of most measures of effectiveness. The most noticeable was an increase in the stops per vehicle (for 1.71 to 1.97) and seconds of delay per vehicle (from 90.35 to 92.79). The PASSER 80 optimization model was designed to increase bandwidth in both directions along Ashley Drive, which should result in fewer stops per vehicle. However, PASSER 80 assumed uniform arrivals on the cross-streets which does not occur when signals are controlled. Therefore, there was a net increase in length of delay and number of stops.

Both TRANSYT-7F and SIGOP III signal plan resulted in reduced vehicle delay time and stops per vehicle. TRANSYT-7F minimized stops per vehicle while SIGOP III minimized delay time per vehicle and both minimized fuel consumption. There was little significant difference between the reductions in gas consumption and vehicle emissions.

Since both TRANSYT-7F and SIGOP III results in similar improvements in traffic flow the user can feel confident that either of these plans would be noticeable to the driver using the system. Whether the driver would perceive the TRANSYT-7F timing (that minimized stops) or the SIGOP III timing (that minimized delay) as better would be left to the judgement of the user.

Summary of Work Effort Required

The following summarizes the work effor required for the example problem.

Data Collection - All data required were readily available from the traffic engineer's office.

Data Coding - The coding of the NETSIM input data required considerable time. Approximately 20 hours were required to develop the link-node diagram and to code the data. How ever, it is believed that persons experienced in coding of NETSIM could accomplish the work in less than 12 hours, since considerable time was spent referring to the User's Guide. An additional 6 hours of review time was required to identify errors and to resubmit 4 runs prior to obtaining acceptable output.

Computer Time - The required CPU time varied from 67.1 to 71.9 seconds for the 900 second simulation period. A total of 294k of core storage was utilized.

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CHAPTER 12 - PRIFRE (FREEWAY SIMULATION MODEL)

In recent years, emphasis has been placed on encouraging higher vehicle occupancy as a means of increasing capacities of transportation facilities and for conserving energy. One of the primary techniques of encouraging higher vehicle occupancy has been the designation of a priority lane reserved exclusively for high occupancy vehicles (HOV).

The more common application for the use of reserved lanes for HOV's has been along freeways, particularly those leading to the central city. Initially these applications considered giving priority to buses, however, in more recent years HOV's have included passenger vehicles with 2 and 3 or more persons per vehicle.

Computer models for evaluating these potential applications were first developed in 1968 at the University of California at Berkeley. Since that time numerous models have been developed and/or expanded upon to permit a more sophisticated analysis.

PRIFRE is an extension of two earlier models, EXBUS and FREEQ. The EXBUS model was written to evaluate mixed flow (i.e. buses and carpools) priority lanes on freeways but was restricted in its flexibility in terms of capacity and demand changes over time. FREEQ (renamed FREQ3 later) was a similar model designed to evaluate normal operations on a freeway and demand fluctuation over time and distance as well as being responsive to actual origin-destination patterns and congestion.

PRIFRE represents a combination of the philosophy of EXBUS and the realism of FREQ3 as well as several further improvements. Recently, many of the features of PRIFRE and FREQ5CP (which evaluate priority entry control) have been incorporated into a new model (FREQ6PL) which provides a more sophisticated evaluation. This model is available as part of the new FHWA PLANPAC 2 software package. Technical support is available through the Institute of Transportation Studies, University of California at Berkeley. However, the

Figure 125. HOV Lanes Along Freeway

PRIFRE model described in this chapter can provide a useful tool to the practicing traffic engineer in evaluating the potential benefits of priority lanes on freeways.

MODEL DESCRIPTION

PRIFRE is a reversed acronym for the FREeway PRIority Lane Model. The model is a unique, general purpose computer program written in FORTRAN IV which has been installed previously on both the CDC 6400 and IBM 360 computers. It requires approximately 80k bytes of core memory on IBM computers. The model is included as part of the FHWA Urban Transportation Program (PLANPAC) and has been widely used. The program consists of approximately 2500 lines of code with 86 percent action fortran statements.

The physical system considered by PRIFRE is a directional freeway with a priority lane reserved for high occupancy vehicles (HOV's) and the on and off ramps to the freeway. The freeway section is described as a series of contiguous sections which are internally operationally homogenous. The model allows the engineer to evaluate priority lane strategies on freeways.

PRIFRE can evaluate the existing condition without priority treatment for HOV's and various types of priority treatments. In its present form the assumption is made that the priority lane is a one-way "normal" flow lane which is accessible only at the beginning and egress only occurs at the end. But, with manual interfacing, it can analyze separate priority lanes, control flow lanes and ramp control schemes with priority entry for HOV's.

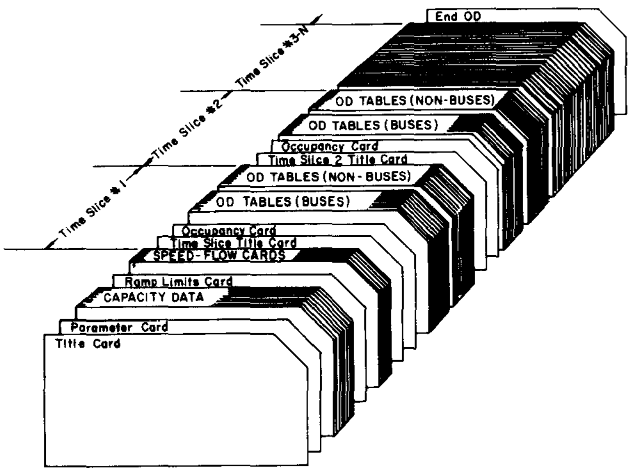

Figure 126. Typical PRIFRE Data Deck

INPUT REQUIREMENTS

The input data required for using the PRIFRE model does require data that is not normally maintained by traffic engineers. Indeed this data, the origin and destination patterns (on-ramp/off-ramp) and vehicle occupancy, are the most difficult to obtain.

Input data consist of seven (7) card types. These are stacked for input as shown in Figure 126 and include the following types:

Title Card - This single card describes the project under study.

Parameter Card - One card is used to establish the parameters controlling the evaluation. This includes the number of sections, time periods, output format, vehicle occupancy for HOV's, growth factors and other parameters.

Capacity Card - One card for each section is required to describe the information necessary to develop its capacity.

Ramp Limit Card - One card can be coded to define special ramp capacities, due to special restraints, to evaluate the effect of queuing at the designated locations.

Speed-Flow Capacity Cards - These cards define a set of curves the model uses to interpret reduced speeds due to the volume of traffic. However, this card is optional.

Time Slice Title Card - This card describes the periods under study.

Occupancy Card - This card defines the percent of cars with various occupancy levels and additional on-ramp capacity limits when developing ramp control strategies.

Origin-Destination Card - One card is required for each on-ramp and defines the number of cars exiting at each off-ramp from that on-ramp. Separate cards are required for cars and buses.

End O-D Card - One card is required at the end of the last O-D card to show this is the end of the data.

A summary description of the input data for each card type is shown on Table 31. A more detailed description is included in the reference material.

OPERATIONAL SUMMARY

PRIFRE reads and checks the input data, warning of detected errors and terminating execu-

Table 31 - Input Requirements For PRIFRE

CARD TYPE	CARD DESCRIPTION	REQUIREMENTS
TITLE (1 per run)	Provide title of simulation.	Arbitrary Information.
PARAMETER (1 per run)	Define parameters for entire simulation run.	No. of sections & time periods, output reports, min. veh. occ. for HOV's, lane operation, bus equiv. factors, etc.
CAPACITY (1 per section)	Define capacity of each freeway section (max. 50).	No. of lanes, capacity of normal & HOV lanes, length, design speeds, truck & bus factors & presence of ramps by type.
RAMP CAPACITY (1 per run)	Define ramp capacity.	General ramp capacity and special capacities for up to 6 on-ramps and 3 off ramps.
SPEED-FLOW/CAPACITY CURVES (Optional)	Define user supplied speed-v/c curves, if desired.	X(v/c) and Y(speed) coordinates of curve (max. 20 points).
TIME SLICE TITLE (1 per time period)	Provide title for each time period to be analyzed.	Time period, etc. of the period following.
OCCUPANCY (1 per time period)	Define vehicle occupancy for specific time period and modifiers to special on-ramps (max. 5).	Avg. passengers per bus, proportion of vehicles with 1, 2, ... 5 or more passengers, and revised capacities for specific on-ramps.
O-D DATA (2 per time period per on-ramp)	Define vehicle and bus destinations (off-ramps) for traffic entering on each on-ramp (origin).	One card for buses-vehicles per hour to each following off-ramp, and one card for vehicles-passengers per hour to each following off-ramp.
END (1 per run)	To terminate run.	Code END OD.

tion when a fatal error is found. Once the data check has been successfully completed and the data stored in work files, program execution begins.

The program progresses serially, by time slice, from subsection to subsection, performing the following analyses (for a single run, as runs may be stacked):

1. Ramp analysis is performed to determine if a ramp queue exists, develops or dissipates and compiles the appropriate delays.

2. Volume calculations are performed using the input demands, O-D's and any existing queues. If capacity is exceeded, the freeway and not the ramps, is queued. If the current subsection has the beginning of the priority lane, any ramp input lane, downstream or upstream with destination within the priority section, is denied entry to the priority lane. All other HOV's enter the priority lane and return to the general lanes at the end.

3. Ramp merging analysis is based on the ramp inputs and estimated right lane volumes. Again, if the right lane exceeds capacity (due to ramp inputs), the freeway is queued.

4. Weaving analysis is confined to on-off ramp maneuvers and capacity reductions are computed using techniques from the Highway Capacity Manual (Ref. 12.4). Weaving effects in the area of the HOV lane entrance and exit must be accounted for by adjusting the mainline capacities in these subsections.

5. Queuing analysis on the mainline takes into account the propagation of shockwaves, whether moving upstream or downstream, and adjusts volume vs. demand accordingly. This process is somewhat complex and interested readers should refer to the original documentation (Ref. 12.1) or documentation on the sub-model FREQ3 model (Ref. 12.5).

6. Speed-flow analysis uses the Highway Capacity Manual curves to determine travel time related impacts, based on the flow characteristics computed earlier. Additionally, the user can input up to nine of his own curves, which may be specified for use in any subsection(s).

COMPUTATIONAL ALGORITHMS

The most significant computational algorithm in PRIFRE is the simulation function of FREQ3, which is documented in Reference 12.2. The simulation, while detailed, is not overly complex.

Of primary interest is the speed-flow relationship. FREQ3 has design speed-flow curves based on the Highway Capacity Manual (Figure 9.1). Thus there are three curves available, having design (or free) speeds equal to 50, 60 or 70 mph. Additionally, as stated above, the user may input his own curves. If the default option is used, speeds in the upper region of the speed-V/C curve (i.,e. V/C < 1.0 and no congestion) are simply taken from the speed-flow table. If demand exceeds capacity, a more complex calculation is required to take into account the facts that queuing can extend upstream into the adjacent subsection and that shockwaves effect the speed. The equation for travel time is stated as follows:

$$TT_{i-1} = t \times d_{i-1} \times L_{i-1} + (d'_{i-1} - d_{i-1}) \times \frac{1}{2} \times t^2 r + (T_o - t) \times d'_{i-1} \times L_{i-1}, \qquad (12.1)$$

where TT_{i-1} = travel time in subsection i-1,

$$t = \min \left| \frac{L_{i-1}}{r}, T_o \right|$$

r = speed of shockwave =

$$\frac{RA_{i-1}}{d'_{i-1} - d_{i-1}} \qquad (12.2)$$

and RA_{i-1} $D_i - C_i$ = net rate of change in the number of vehicles in subsection i-1,

L'_{i-1} = length of subsection i-1,

d_{i-1} = queuing density in subsection i-1 (vpm),

d_{i-1} = non-queuing density in subsection i-1 (vpm),

T_o = time interval (e.g. 0.25 for 15 min.),

D_i = demand for subsection i, and,

U_i = Volume of traffic leaving subsection i.

These speed-v/c curves, and the above algorithm for congested flow, have not been widely accepted by recent researchers, and the user should strongly consider using his own curves. These may be based on observed data or derived. A single formula for obtaining speed (or rather travel time) as a function of demand (whether less than or greater than capacity) has been found both useful and accurate. This model is expressed as (Reference 12.6):

$$t = 0.87\ t_o\ [1-0.15(q/q_m)^4]; \qquad (12.3)$$

where t = average travel time over the subsection,

t_o = average travel time over the subsection at capacity,

q = average demand in the subsection, and

q_m = capacity of the subsection

The user can easily calculate values of t for various values of q/q_m and input this table as a user supplied speed - v/c "curve".

A second significant algorithm deals with the weaving effect. Again, Highway Capacity Manual techniques are used. The service volume is calculated by:

$$sv = [v + (k-1)w_2]/N; \qquad (12.4)$$

where sv = service volume,

v = total volume (demand),

k = weaving influence factor,

w_2 = smaller weaving volume and,

N = number of lanes.

All other computations are similarly based on Highway Capacity Manual techniques or other commonly accepted techniques.

OUTPUT REPORTS

The outputs from PRIFRE consist of four groups - (1) a listing of input data, (2) messages concerning the queues, (3) summary table of numerical results, and (4) travel times. These are covered below.

Input Data Listing

The general and subsection inputs are echoed in a readable format as shown in Figure 127. The column headings are as follows:

1. SSEC NO. - subsection number.

2. P - whether normal (blank) or priority subsection (P).

```
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HOV EXAMPLE I-95 MIAMI(AIRPORT XWAY TO GOLDEN GLADES)-EXIST. LANES 3 PERS HOV LN

INPUT DATA
 21 SUBSECTIONS   FAC(1)= 2.   FAC(2)= 1.   PRIORITY CUT-OFF= 3.   OPTION= 3    0 GROWTH PERIODS AT RATE 1.00    1 OCCUPANCY SHIFTS
PASSENGER CAR EQUIVALENCY OF BUSES(NORMAL) =  2.00     PASSENGER CAR EQUIVALENCY OF BUSES(PRIORITY) =  1.60

SSEC  NO. CAP. CAP 1  LENG NOR UNR RES  TRK. ORG. LFT      SUB SECTION LOCATION
NO. P LN        P. LN.      SPD SFD SPD  FAC. DES. RMP

  1   3  4350.   0.0 1000.  60  60  600.970   0     0      BEGIN SECTION (LOCS. BEGIN SECTS.) 01
  2 P 3  4350. 1500. 1390.  60  60  600.970         0      BEGIN PRIORITY LANE
  3 P 5  9300. 1500. 1341.  60  60  600.970   0     2      AIRPORT X-WAY ON          02
  4 P 5  7650. 1500. 3294.  60  60  600.970         0      LANE DROP
  5 P 4  6000. 1500.  900.  60  60  600.970   0     0      62 ST OFF                 01
  6 P 4  6000. 1500. 1863.  60  60  600.970   0     0      62 ST ON                  03
  7 P 4  6000. 1500. 2577.  60  60  600.970   0     0      69 ST ON                  04
  8 P 4  6000. 1500. 2075.  60  60  600.970   0     0      79 ST OFF                 02
  9 P 4  6000. 1500. 3091.  60  60  600.970   0     0      81 ST ON                  05
 10 P 4  6000. 1500. 1644.  60  60  600.970   0     0      95 ST OFF                 03
 11 P 5  7650. 1500. 1054.  60  60  600.970   0     0      95 ST ON                  06
 12 P 4  6000. 1500. 1506.  60  60  600.970   0     0      103 ST OFF                04
 13 P 4  6000. 1500. 3795.  60  60  600.970   0     0      103 ST ON                 07
 14 P 4  6000. 1500. 1982.  60  60  600.970   0     0      119 ST OFF                05
 15 P 4  6000. 1500. 1478.  60  60  600.970   0     0      125 ST OFF                06
 16 P 4  6000. 1500. 1880.  60  60  600.970   0     0      125 ST ON                 08
 17 P 3  4350. 1500. 1890.  60  60  600.970   0     0      135 ST OFF                07
 18 P 3  4350. 1500. 3434.  60  60  600.970   0     0      135 ST ON                 09
 19 P 3  4350. 1500. 2474.  60  60  600.970   0     0      151 ST OFF                08
 20   3  4350. 1500.  500.  60  60  600.970         0      END PRIORITY LANE
 21   3  4350.   0.0 1000.  60  60  600.970   0     0      END SECTION               09

   RAMP LIMITS =1500.
                   ON-RAMP   1 LIMIT=4350.
                   ON-RAMP   2 LIMIT=4350.
```

Figure 127. Example PRIFRE Input Data Listing

3. NO.LN - number of lanes (excluding priority lane).

4. CAP. - capacity of normal or unreserved roadway. Note that a very large capacity is given for the first subsection. This is to prevent queuing out of (up-stream of) the study area. Indeed this example begins at a toll station where queuing normally exists, but it is not to be included in the PRIFRE simulation.

5. CAP 1 P.LN. - capacity of priority lane.

6. LENG - length.

7. NOR SPD - speed curve for normal lanes.

8. UNR SPD - speed curve for unreserved lanes.

9. RES SPD - speed curve for priority lanes.

10. TRK.FAC. - the truck factor (0.970).

11. ORG.DES. - an O indicates an origin at the beginning of the subsection and a D indicates a destination at the end.

12. LFT RMP - would be 1 if any ramp was on the left.

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NO. OF PRIORITY LANES = 1 — RESERVED PRIORITY OPERATIONS | GROWTH PERIOD 0 | OCCUPANCY SHIFT 1 — UNRESERVED OR NORMAL OPERATIONS

SUB SEC	FINAL ORG	DEMD. DES	ORIG. TOTAL	FS	VOL	CAP	V/C	DEN V/M/L	MPH	TRAV TIME	UN NORM	NL	VOL	CAP	WEAVE EFF	V/C	DEN V/M/L	MPH	TRAV TIME	Q *	LENG	QUEUE FEET	RA
1	1335.	0.0	1335								N	3	1436.	4350.	0.0	0.33	99.	5.	2.36	*	1000.	1000	-101.
2	0.0	0.0	1335	1	61.	1500.	0.04	1.	53.	0.30	U	2	1373.	2900.	0.0	0.47	83.	8.	1.91	*	1390.	1390	-101.
3	1331.	0.0	2666	1	61.	1500.	0.04	1.	53.	0.29	U	5	2704.	7750.	0.0	0.35	103.	5.	2.92	*	1341.	1341	-101.
4	0.0	0.0	2666	1	61.	1500.	0.04	1.	53.	0.70	U	4	2704.	6120.	0.0	0.44	91.	7.	5.03	*	3294.	3294	-101.
5	0.0	57.	2666	1	61.	1500.	0.04	1.	53.	0.19	U	3	2704.	4500.	0.0	0.60	75.	12.	0.85	*	900.	900	-101.
6	230.	0.0	2829	1	61.	1500.	0.04	1.	53.	0.40	U	3	2867.	4500.	0.0	0.64	72.	13.	1.60	*	1863.	1863	-101.
7	130.	0.0	2959	1	61.	1500.	0.04	1.	53.	0.55	U	3	2997.	4500.	0.0	0.67	70.	14.	2.06	*	2577.	2577	-101.
8	0.0	128.	2959	1	61.	1500.	0.04	1.	53.	0.44	U	3	2997.	4500.	0.0	0.67	70.	14.	1.66	*	2075.	2075	-101.
9	357.	0.0	3188	1	61.	1500.	0.04	1.	53.	0.66	U	3	3226.	4500.	0.0	0.72	67.	16.	2.19	*	3091.	3091	-101.
10	0.0	124.	3188	1	61.	1500.	0.04	1.	53.	0.35	U	3	3226.	4500.	0.0	0.72	67.	16.	1.17	*	1644.	1644	-101.
11	145.	0.0	3209	1	61.	1500.	0.04	1.	53.	0.22	U	4	3247.	6120.	0.0	0.53	82.	10.	1.21	*	1054.	1054	-101.
12	0.0	160.	3209	1	61.	1500.	0.04	1.	53.	0.37	U	3	3247.	4500.	0.0	0.72	67.	16.	1.06	*	1506.	1506	-101.
13	124.	0.0	3153	1	61.	1500.	0.04	1.	53.	0.81	U	3	3191.	4500.	0.0	0.71	68.	16.	2.74	*	3795.	3795	-101.
14	0.0	219.	3153	1	61.	1500.	0.04	1.	53.	0.42	U	3	3191.	4500.	0.0	0.71	68.	16.	1.43	*	1982.	1982	-101.
15	0.0	221.	2934	1	61.	1500.	0.04	1.	53.	0.32	U	3	2972.	4500.	0.0	0.66	71.	14.	1.20	*	1478.	1478	-101.
16	143.	0.0	2862	1	61.	1500.	0.04	1.	53.	0.40	U	3	2900.	4500.	0.0	0.64	72.	13.	1.59	*	1880.	1880	-101.
17	0.0	405.	2862	1	61.	1500.	0.04	1.	53.	0.40	U	2	2900.	2900.	0.0	1.00	49.	29.	0.73		1890.	0	0.0
18	162.	0.0	2633	1	61.	1500.	0.04	1.	53.	0.73	U	2	2657.	2900.	0.0	0.92	36.	36.	1.07		3434.	0	0.0
19	0.0	102.	2633	1	61.	1500.	0.04	1.	53.	0.53	U	2	2657.	2900.	0.0	0.92	36.	36.	0.77		2474.	0	0.0
20	0.0	0.0	2534								N	3	2617.	4350.	0.0	0.60	20.	43.	0.13		500.	0	0.0
21	0.0	2617.	2534								N	3	2617.	4350.	0.0	0.60	20.	43.	0.26		1000.	0	0.0

			QUEUE LENGTH VEHICLES	DELAY VEH-HRS
ON-RAMP	1	INPUT POINT	999.19	1036.90
		MERGING POINT	0.0	0.0
		TOTAL	999.19	1036.90

Figure 128. Example PRIFRE Simulation Results - Priority Operation

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TIME SLICE 5 6:00 PM

NO. OF PRIORITY LANES = 0 GROWTH PERIOD 0 OCCUPANCY SHIFT 1

SUB SEC	FINAL ORG	DEMAND DES	ORIG. TOTAL	VOL	FWRY CAP	WEAVE EFF	V/C	DENS V/M/L	MPH	TRAV TIME	LENG	QUEUE FEET	RA
1	1335.	0.0	1335	1335.	4350.	0.0	0.31	9.	49.	0.23	1000.	0	0.0
2	0.0	0.0	1335	1335.	4350.	0.0	0.31	9.	49.	0.32	1390.	0	0.0
3	1331.	0.0	2666	2666.	9300.	0.0	0.29	9.	50.	0.31	1341.	0	0.0
4	0.0	0.0	2666	2666.	7650.	0.0	0.35	11.	49.	0.77	3294.	0	0.0
5	0.0	67.	2666	2666.	6000.	0.0	0.44	14.	47.	0.22	900.	0	0.0
6	230.	0.0	2829	2829.	6000.	0.0	0.47	15.	47.	0.45	1863.	0	0.0
7	130.	0.0	2959	2959.	6000.	0.0	0.49	16.	46.	0.63	2577.	0	0.0
8	0.0	128.	2959	2959.	6000.	0.0	0.49	16.	46.	0.51	2075.	0	0.0
9	357.	0.0	3188	3188.	6000.	0.0	0.53	18.	45.	0.77	3091.	0	0.0
10	0.0	124.	3188	3188.	6000.	0.0	0.53	18.	45.	0.41	1644.	0	0.0
11	145.	0.0	3209	3209.	7650.	0.0	0.42	14.	48.	0.25	1054.	0	0.0
12	0.0	180.	3209	3209.	6000.	0.0	0.53	18.	45.	0.38	1506.	0	0.0
13	124.	0.0	3153	3153.	6000.	0.0	0.53	17.	46.	0.95	3795.	0	0.0
14	0.0	219.	3153	3153.	6000.	0.0	0.53	17.	46.	0.49	1982.	0	0.0
15	0.0	221.	2934	2934.	6000.	0.0	0.49	16.	46.	0.36	1478.	0	0.0
16	149.	0.0	2862	2862.	6000.	0.0	0.48	15.	46.	0.46	1880.	0	0.0
17	0.0	391.	2862	2862.	4350.	0.0	0.66	23.	42.	0.51	1890.	0	0.0
18	162.	0.0	2633	2633.	4350.	0.0	0.61	20.	43.	0.90	3434.	0	0.0
19	0.0	99.	2633	2633.	4350.	0.0	0.61	20.	43.	0.65	2474.	0	0.0
20	0.0	0.0	2534	2534.	4350.	0.0	0.58	19.	44.	0.13	500.	0	0.0
21	0.0	2534.	2534	2534.	4350.	0.0	0.58	19.	44.	0.26	1000.	0	0.0

Figure 129. Example PRIFRE Simulation Results - Non Priority Operation

13. SUBSECTION LOCATION - landmark(s) of subsection.

Additionally, at each time slice the origin-destination tables for priority vehicles and non-priority vehicles are echoed.

Queuing and Numerical Results

These occur on the same report, an example of which is shown in Figure 128. The column headings are defined in the Figure for the numerical results. The queuing messages appear above the table. There are four of these messages which may occur. The first is of the type "QUEUE COLLISION 6 T2 = .106," which means that a queue in subsection 6 is growing (i.e. backing upstream) and left the subsection (i.e., entered subsection 5) at 0.106 hour after the current time slice. When T2 = .000, the queue began the time slice with a queue already backed upstream.

The next message is "QUEUE SPLIT 7" indicates that (in this case) subsection 7 could not handle the sum of demand and discharging vehicles and an existing queue split into two. The subsection becomes a bottleneck.

The last two messages occur in the last time-slice of a decreasing queue situation. PRIFRE tries to clear a queue at the end of a time-slice but this is not always possible. Thus, if a time slice is 0.25 hour long and the queue length reaches zero at 0.231 hour, the message "SEC 7 TL = 0.231" occurs.

If the queue still exists after 0.25 hours, it is cleared and the message "SECT 7 CLEAR 153" occurs, and 153 vehicles were instantaneously discharged from the queue.

If no priority operations exist, that is, the user is simulating existing conditions to compare with the priority condition to be "implemented," the output report is of the form shown in Figure 129.

Travel Time and Summary Data

The next output is the travel times. Tables of single trip travel times in hundredths of a minute from each origin to each destina-

TRAVEL TIME FOR ONE NON-PRIORITY TRIP .01 MINUTES

0	1	2	3	4	5	6	7	8	9
1	1307.	1639.	2175.	2402.	2820.	2939.	3171.	3355.	3395.
2	890.	1412.	1748.	1975.	2393.	2513.	2744.	2928.	2968.
3	0.	533.	869.	1096.	1513.	1633.	1864.	2048.	2088.
4	0.0	372.	708.	935.	1353.	1473.	1704.	1888.	1928.
5	0.0	0.	336.	563.	980.	1100.	1337.	1516.	1555.
6	0.0	0.0	0.	227.	644.	764.	996.	1180.	1219.
7	0.0	0.0	0.0	0.0	417.	537.	769.	953.	997.
8	0.0	0.0	0.0	0.0	0.0	0.	232.	416.	455.
9	0.0	0.0	0.0	0.0	0.0	0.0	0.	184.	224.

TRAVEL TIME FOR ONE PRIORITY TRIP .01 MINUTES

0	1	2	3	4	5	6	7	8	9
1	384.	523.	624.	678.	802.	833.	914.	1040.	1079.
2	118.	257.	358.	413.	536.	568.	648.	774.	814.
3	0.	139.	240.	295.	418.	450.	530.	656.	696.
4	0.0	99.	200.	255.	378.	410.	490.	617.	656.
5	0.0	0.	101.	156.	279.	311.	391.	517.	557.
6	0.0	0.0	0.	55.	178.	210.	290.	416.	456.
7	0.0	0.0	0.0	0.	123.	155.	235.	361.	401.
8	0.0	0.0	0.0	0.0	0.0	0.	80.	207.	246.
9	0.0	0.0	0.0	0.0	0.0	0.0	0.	126.	166.

	CURRENT TIME INTERVAL		CUMULATIVE VALUES	
FREEWAY TRAVEL TIME (NOR)	37. VEH-HRS	56. PASS-HRS	183. VEH-HRS	290. PASS-HRS
FREEWAY TRAVEL TIME (UNR)	740. VEH-HRS	925. PASS-HRS	3868. VEH-HRS	4847. PASS-HRS
FREEWAY TRAVEL TIME (RES)	4. VEH-HRS	25. PASS-HRS	38. VEH-HRS	218. PASS-HRS
INPUT DELAY (NOR)	1037. VEH-HRS	1439.PASS-HRS	1994. VEH-HRS	2815.PASS-HRS
INPUT DELAY (UNR)	0.0 VEH-HRS	0.0PASS-HRS	0.0 VEH-HRS	0.0PASS-HRS
TOTAL TRAVEL DISTANCE	11050. VEH/MI.	15028. PASS-MI.	68884. VEH/MI.	96253. PASS-MI.
TOTAL TRAVEL TIME UNDER PRIORITY OPERATIONS	1818. VEH-HRS	2446. PASS-HRS	6083. VEH-HRS	8170. PASS-HRS
TOTAL TRAVEL TIME UNDER NON-PRIORITY OPERATIONS			1893. VEH-HRS	2901. PASS-HRS
TRAVEL TIME SAVINGS OVER NON-PRIORITY OPERATION =			-4189.4 VEH-HRS	-5269.1 PASS-HRS

Figure 130. Example PRIFRE Summary Report

tion, both for non-priority trips and priority trips (see Figure 127). Below these tables are the summaries of normal, unreserved and reserved total travel time (veh-hr and passenger-hr) and the input delays. All data are given for the current time slice and cumulatively. Then total vehicle-miles and passenger-miles are given and finally the comparison of total travel time (all vehicles) under normal vs. priority conditions and the savings realized by priority operations.

ADDITIONAL FEATURES

PRIFRE is a special purpose simulation model and does not have any overt additional features. However, by proper manipulations of input parameters an expanded range of control strategies can be analyzed. For example, if a fixed-time metering system exists, this can be simulated by altering the affected ramp capacities from the normal (e.g. 1500) to the metering rate (eg. 900 vph).

A later extension of this model called FREQ-6PL combines the priority lane analysis with the freeway simulation and entry control optimization model FREQ - series (see Chapter 14).

APPLICATIONS AND LIMITATIONS

PRIFRE is a simulation tool which can be used to analyze and evaluate existing (normal) operations and priority operations where one or more lanes is reserved for buses and/or carpools. Comparative data allow the user to assess the benefits of such priority control strategies and estimate the cost effectiveness of a traffic improvement of this type.

The primary limitations are listed as follows:

1. The HOV lane can have only one entry point and one exit; thus concurrent flow lanes cannot be adequately studied. The PRIFRE documentation (Reference 12.1) recognizes this and some preliminary work has been reported on techniques to overcome the deficiency. A program LCHANGE has been written to calculate the required distances for lane changes between any two lanes on the freeway (including the freeway (including priority lanes) and weaves from an on-ramp to the HOV lane, and conversely, from the HOV to an off-ramp. LCHANGE has not been incorporated into PRIFRE per se; however, a later combined version of this and another program, called FREQ6PL goes a long way to overcome this deficiency (Reference 12.7).

2. Since PRIFRE is only a mathematical representation of a highly stochastic physical operation, some properties are not totally realistic. The major problem detected by the developers has to do with the handling of queues on the freeway. For example, when trying to evaluate improvement plans which called for adding auxiliary lanes with the algorithm predicted earlier, longer and slower queues developed when two queues collided. This was probably due to an erroneous assumption of a linear relationship between shockwave speed and queue growth/discharge rate.

3. The instantanenous propagation of vehicles from upstream to downstream results in spiraling errors which limit a study section to about 10 miles, otherwise gross errors can occur. Under 10 miles, the approximations are more reliable.

4. Such assumptions as constant demand and homogeneity of flow within subsections and time slices lead to obvious oversights. Thus the results must be considered to be the "average operation of an incident-free freeway where all driver behavior is exactly predictable."

5. No consideration is given to violators in the HOV lane, or qualified HOV's that do not use the priority lane.

Despite these shortcomings, PRIFRE can afford the engineer with an important tool for analyzing proposed transportation improvements. Several projects which were studied with this model have proven to be highly successful in carrying more people in the same number or fewer vehicles, and at higher speeds.

EXAMPLE APPLICATION

To illustrate the use and capabilities of the PRIFRE model an existing freeway section in Miami, Florida was selected as an example application. The following describes the freeway characteristics and the use of PRIFRE to evaluate the use of a high occupancy vehicle (HOV) lane.

Problem Description

The example freeway is I-95 in north Miami, Florida. The section under study extends from the interchange with the Airport Expressway north to the interchange of I-95 with Palmetto Expressway and the Florida Turnpike. I-95 is the primary highway facility in this northern corridor of Dade County connecting major residential areas in north Dade and southern Broward County (Ft. Lauderdale) with major employment centers in the greater Miami area.

I-95 was a six to ten lane, divided, full access controlled interstate highway. In 1975 it was determined that an effort would be made to use this facility as a demonstration to determine the potential benefits, of preferential treatment for high occupancy vehicles (HOV's).

For this example application several alternatives were to be evaluated. One set of alternatives was to look at the designation of one of the existing lanes for HOV's at 3 person per vehicle and 2 persons per vehicle. The other set of alternatives included the construction of an additional lane and evaluating operation without HOV lanes and with with HOV lanes, each with 3 and 2 persons per vehicle.

Figure 131 provides a graphic sketch of the existing freeway, its interchanges and the more important characteristics. The existing and future traffic lanes were all 12 foot in width. The PM peak hour for northbound traffic is to be evaluated. The peak hour factor is .85 with 3% trucks. For the purpose of this problem no adjustment was made for grades or obstructions. The developed capacity for the existing lanes and the additional (priority) lane are shown on Figure 131.

Analysis of Existing Conditions

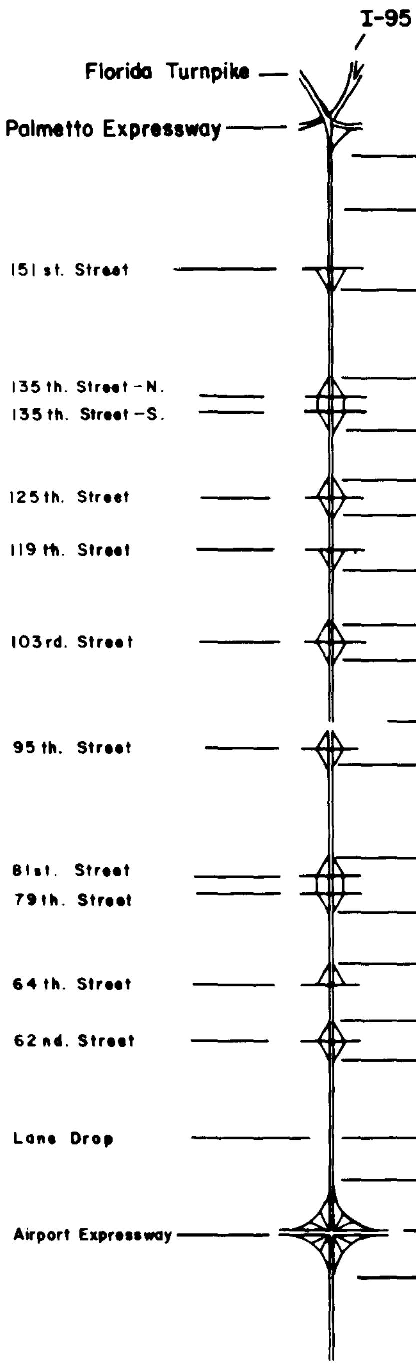
As part of each set of input data the existing conditions (without priority lane operations) is coded as well as an alternative priority lane operation. PRIFRE does not have a standard input coding form, therefore, a copy of the 80 x 80 listing of input data is shown on Figure 132. It should be noted that the blank spaces are Bus Origin & Destination cards which must be included even if there are no trips made, as shown here.

The results of the simulation run for existing conditions are shown on Figure 129. At the top of the report is a description of the input data for the established parameters and the section characteristics.

The measures of effectiveness for the existing operation are shown as part of the cumulative statistics at the end of the existing operation simulation. Under existing operation 1,893 vehicles hours and 2,901 passenger hours are required of the traffic using the portion of the freeway. During this two hour period the freeway served 80,483 vehicles-miles of travel and 123,215 passenger-miles. There were no input delays for vehicles entering the system.

Define and Analyses of Alternatives

The first alternative included a parameter to define one existing lane reserved for vehicles with 2 or more persons. Figure 133 shows the results of the simulation run under this condition.



SECTION DESCRIPTION								
NO.		LENGTH	LANES			CAPACITY (vph)		
		(FT.)	EXIST.	PRIOR.	TOTAL	EXIST.	PRIOR.	TOTAL
21	End Section	1000	3	0	3	4350	0	4350
20	End Prior Lane	500	3	0	3	4350	0	4350
19	off-ramp	2474	3	1	4	4500	1500	6000
18	on-ramp	3434	3	1	4	4500	1500	6000
17	off-ramp	1890	3	1	4	4500	1500	6000
16	on-ramp	1880	4	1	5	5150	1500	7650
15	off-ramp	1478	4	1	5	5150	1500	7650
14	off-ramp	1982	4	1	5	5150	1500	7650
13	on-ramp	3795	4	1	5	5150	1500	7650
12	off-ramp	1506	4	1	5	5150	1500	7650
11	on-ramp	1054	5	1	6	7800	1500	9300
10	off-ramp	1644	4	1	5	5150	1500	7650
9	on-ramp	3091	4	1	5	5150	1500	7650
8	off-ramp	2075	4	1	5	5150	1500	7650
7	on-ramp	2577	4	1	5	5150	1500	7650
6	on-ramp	1863	4	1	5	5150	1500	7650
5	off-ramp	900	4	1	5	5150	1500	7650
4	lane drop	3294	5	1	6	7,800	1500	9300
3	on-ramp	1341	6	1	7	8,450	1500	10,950
2	Begin Prior Lane	1390	3	1	4	4500	1500	6000
1	Begin Section	1000	3	0	3	4350	—	4350

Note:

Figure 131. PRIFRE Section Data for I-95 Example Problem

```
HOV EXAMPLE I-95 MIAMI(AIRPORT XWAY TO GOLDN GLADES)-EXIST. LANES 2 PERS HOV LN
  21     2     1     2 3     0   1.  1    2.  1.6
   1  3 4350        1000 60 60 60   .97  0   BEGIN SECTION (LOCS. BEGIN SECTS.) 01
  2P  3 4350 1500 1390 60 60 60   .97      BEGIN PRIORITY LANE
  3P  6 9300 1500 1341 60 60 60   .97  0 2AIRPORT X-WAY ON          02
  4P  5 7550 1500 3294 60 60 60   .97      LANE DROP
  5P  4 6000 1500  900 60 60 60   .97   0 62 ST OFF                 01
  6P  4 6000 1500 1863 60 60 60   .97  0   62 ST ON                 03
  7P  4 6000 1500 2577 60 60 60   .97  0   69 ST ON                 04
  8P  4 6000 1500 2075 60 60 60   .97   0 79 ST OFF                 02
  9P  4 6000 1500 3091 60 60 60   .97  0   81 ST ON                 05
 10P  4 6000 1500 1644 60 60 60   .97   0 95 ST OFF                 03
 11P  5 7550 1500 1054 60 60 60   .97  0   95 ST ON                 06
 12P  4 6000 1500 1506 60 60 60   .97   0 103 ST OFF                04
 13P  4 6000 1500 3795 60 60 60   .97  0   103 ST ON                07
 14P  4 6000 1500 1987 60 60 60   .97   0 119 ST OFF                05
 15P  4 6000 1500 1478 60 60 60   .97   0 125 ST OFF                06
 16P  4 6000 1500 1880 60 60 60   .97  0   125 ST ON                08
 17P  3 4350 1500 1890 60 60 60   .97   0 135 ST OFF                07
 18P  3 4350 1500 3434 60 60 60   .97  0   135 ST ON                09
 19P  3 4350 1500 2474 60 60 60   .97   0 151 ST OFF                08
 20   3 4350 1500  500 60 60 60   .97      END PRIORITY LANE
 21   3 4350        1000 60 60 60   .97   0 END SECTION             09
  1500                             1 4350  2 4350
TIME SLICE 1    3:30 PM
   40 58.5 22.1  5.3  3.2    .8
                                        2
                                        0

  53 100 105 129 129 136 237   551234
  58  38  79 109 159 130 205   501295
   0  11   5  20  16  26  59   10 237
   0   2   7  17  15  15  15    4 142
   0   0   5  17  21  24  63   15 440
   0   0   0   1   4  18  29   11 177
   0   0   0   0  10  15  23   10 146
   0   0   0   0   0   0  13    5 275
   0   0   0   0   0   0   0    7 260
TIME SLICE 2    4:00 PM
   40 53.0 24.2  7.2  5.6   0.0
                                        3
                                        1

TIME SLICE 5    6:00 PM
   40 71.0 22.0  4.7  1.8    .5
                                        5
                                        1

  45  34  83 109 109 115 201   451042
  48  33  53  97 136 109 172   431093
   0   9   5  16  15  22  49    8 195
   0   7   5  15  13  13  13    2 120
   0   0   5  15  18  20  54   13 371
   0   0   0   1   4  15  23    9 149
   0   0   0   0   8  13  19    8 123
   0   0   0   0   0   0  11    5 190
   0   0   0   0   0   0   0    5 219
END OD
```

NOTE: Coded bus and vehicle O&D cards for other time periods were not included in this figure.

Figure 132. PRIFRE Input Data Listing for I-95 Example Problem

```
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BERKELEY, CALIFORNIA

HOV EXAMPLE I-95 MIAMI(AIRPORT XWAY TO GOLDN GLADES)-EXIST. LANES 2 PERS HOV LN

INPUT DATA
 21 SUBSECTIONS   FAC(1)= 2.   FAC(2)= 1.   PRIORITY CUT-OFF= 2.   OPTION= 3    0 GROWTH PERIODS AT RATE 1.00
PASSENGER CAR EQUIVALENCY OF BUSES(NORMAL) =  2.00     PASSENGER CAR EQUIVALENCY OF BUSES(PRIORITY) =  1.60

SSEC  NO. CAP. CAP 1  LENG ACC UNR RES  TRK. OPC. LFT      SUB SECTION LOCATION
 NO. F LN        F. LN.      SPD SPD SPD  FAC. OFS. PMP

  1    3  4350.   0.0 1000.  60  60  600.970   0     0     BEGIN SECTION (LOCS. BEGIN SECTS.) 01
  2 F  3  4350. 1500. 1390.  60  60  600.970         0     BEGIN PRIORITY LANE
  3 F  5  9400. 1500. 1341.  60  60  600.970   0     2     AIRPORT X-WAY ON         02
  4 F  5  7650. 1500. 3294.  60  60  600.970         0     LANE DROP
  5 F  4  6000. 1500.  900.  60  60  600.970   0     0     62 ST OFF                01
  6 F  4  6000. 1500. 1863.  60  60  600.970   0     0     62 ST ON                 03
  7 F  4  6000. 1500. 2577.  60  60  600.970   0     0     69 ST ON                 04
  8 F  4  6000. 1500. 2075.  60  60  600.970   0     0     79 ST OFF                02
  9 F  4  6000. 1500. 3091.  60  60  600.970   0     0     81 ST ON                 05
 10 F  4  6000. 1500. 1644.  60  60  600.970   0     0     95 ST OFF                03
 11 F  5  7650. 1500. 1054.  60  60  600.970   0     0     95 ST ON                 06
 12 F  4  6000. 1500. 1506.  60  60  600.970   0     0     103 ST OFF               04
 13 F  4  6000. 1500. 3795.  60  60  600.970   0     0     103 ST ON                07
 14 F  4  6000. 1500. 1987.  60  60  600.970   0     0     119 ST OFF               05
 15 F  4  6000. 1500. 1478.  60  60  600.970   0     0     125 ST OFF               06
 16 F  4  6000. 1500. 1880.  60  60  600.970   0     0     125 ST ON                08
 17 F  3  4350. 1500. 1690.  60  60  600.970   0     0     135 ST OFF               07
 18 F  3  4350. 1500. 3434.  60  60  600.970   0     0     135 ST ON                09
 19 F  3  4350. 1500. 2474.  60  60  600.970   0     0     151 ST OFF               08
 20    3  4350. 1500.  500.  60  60  600.970         0     END PRIORITY LANE
 21    3  4350.   0.0 1000.  60  60  600.970   0     0     END SECTION              09

   RAMP LIMITS =1500.
                  ON-RAMP   1 LIMIT=4350.
                  ON-RAMP   2 LIMIT=4350.

TIME SLICE 0    8:00 PM
                          NO. OF PRIORITY LANES = 0            GROWTH PERIOD  0            OCCUPANCY SHIFT  1
SUB FIN. DEMAND ORIG.  VOL   FWY WEAVE  V/C DENS  MPH      TRAV  LENG QUEUE    FA
SEC  OFC   OFS TOTAL         CAP   FFF       V/M/L         TIME        FEET
  1 1335.   0.0  1335 1335. 4350.   0.0 0.31   9.   49.     0.23 1000.    0    0.0
  2   0.0   0.0  1335 1335. 4350.   0.0 0.31   9.   49.     0.32 1390.    0    0.0
  3 1331.   0.0  2666 2666. 9400.   0.0 0.28   9.   50.     0.31 1341.    0    0.0
  4   0.0   0.0  2666 2666. 7650.   0.0 0.35  11.   49.     0.77 3294.    0    0.0
  5   0.0   67.  2666 2666. 6000.   0.0 0.44  14.   47.     0.22  900.    0    0.0
  6  230.   0.0  2829 2829. 6000.   0.0 0.47  15.   47.     0.45 1863.    0    0.0
  7  130.   0.0  2959 2959. 6000.   0.0 0.49  16.   46.     0.63 2577.    0    0.0
  8   0.0  128.  2959 2959. 6000.   0.0 0.49  16.   46.     0.51 2075.    0    0.0
  9  357.   0.0  3188 3188. 6000.   0.0 0.53  16.   45.     0.77 3091.    0    0.0
 10   0.0  124.  3189 3188. 6000.   0.0 0.53  18.   45.     0.41 1644.    0    0.0
 11  145.   0.0  3209 3205. 7650.   0.0 0.42  14.   48.     0.25 1054.    0    0.0
 12   0.0  180.  3209 3209. 6000.   0.0 0.53  18.   45.     0.38 1506.    0    0.0
 13  174.   0.0  3153 3153. 6000.   0.0 0.53  17.   46.     0.55 3795.    0    0.0
 14   0.0  219.  3153 3153. 6000.   0.0 0.53  17.   46.     0.49 1987.    0    0.0
 15   0.0  221.  2934 2934. 6000.   0.0 0.49  16.   46.     0.36 1478.    0    0.0
 16  145.   0.0  2862 2862. 6000.   0.0 0.48  15.   46.     0.46 1880.    0    0.0
 17   0.0  491.  2862 2862. 4350.   0.0 0.66  23.   42.     0.51 1690.    0    0.0
 18  162.   0.0  2843 2843. 4350.   0.0 0.61  20.   43.     0.90 3434.    0    0.0
 19   0.0   99.  2844 2844. 4350.   0.0 0.61  20.   43.     0.65 2474.    0    0.0
 20   0.0   0.0  2534 2534. 4350.   0.0 0.58  19.   44.     0.13  500.    0    0.0
 21   0.0 2534.  2534 2534. 4350.   0.0 0.58  15.   44.     0.20 1000.    0    0.0

TRAVEL TIME FOR ONE NON-PRIORITY TRIP  .01 MINUTES

 0      1      2      3      4      5      6      7      8      9
 1    135.   245.   364.   525.   670.   707.   804.   959.   999.
 2    125.   289.   403.   470.   615.   651.   748.   904.   943.
 3    0.0    160.   275.   341.   486.   522.   619.   775.   814.
 4    0.0    115.   233.   296.   440.   477.   574.   729.   768.
 5    0.0     0.    115.   181.   326.   362.   459.   615.   654.
 6    0.0    0.0     0.    63.   207.   244.   341.   496.   535.
 7    0.0    0.0    0.0     0.   144.   181.   278.   433.   472.
 8    0.0    0.0    0.0    0.0    0.0     0.    97.   253.   292.
 9    0.0    0.0    0.0    0.0    0.0    0.0    0.0   156.   195.


TOTAL TRAVEL TIME IN .01 VEH-HRS

 0      1      2      3      4      5      6      7      8      9
 1     45.   175.   243.   346.   441.   489.   971.   256.  6291.
 2     43.   145.   166.   259.   502.   429.   773.   233.  6152.
 3    0.0     8.     9.    34.    45.    70.   181.    39.   950.
 4    0.0     1.     6.    27.    33.    36.    43.     6.   551.
 5    0.0    0.0     4.    17.    35.    42.   149.    46.  1455.
 6    0.0    0.0    0.0     1.     5.    22.    48.    25.   477.
 7    0.0    0.0    0.0    0.0     7.    14.    32.    22.   350.
 8    0.0    0.0    0.0    0.0    0.0    0.0     6.     8.   343.
 9    0.0    0.0    0.0    0.0    0.0    0.0    0.0     5.   257.
                              CURRENT TIME INTERVAL                      CUMULATIVE VALUES
FREEWAY TRAVEL TIME=     234. VEH-HRS      344. PASS-HRS       1893. VEH-HRS      2901. PASS-HRS
        INPUT DELAY=      0.0 VEH-HRS       0.0 PASS-HRS        0.0 VEH-HRS        0.0 PASS-HRS
  TOTAL TRAVEL TIME=     234. VEH-HRS      344. PASS-HRS       1893. VEH-HRS      2901. PASS-HRS
TOTAL TRAV DISTANCE=   10677. VEH-MI.    15693. PASS-MI.      80483. VEH-MI.   123215. PASS-MI.
```

Figure 133. PRIFRE Simulation Results for I-95 Priority Lane (2 persons/vehicle) with Existing Lanes.

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TIME SLICE     8:00 PM                                 GROWTH PERIOD  0           OCCUPANCY SHIFT  1
                  NO. OF PRIORITY LANES = 1
                  RESERVED PRIORITY OPERATIONS                                    UNRESERVED OR NORMAL OPERATIONS
```

SUB SEC	FINAL ORG	DIMO. DES	ORIG. TOTAL	ES	VOL	CAP	V/C	DEN V/M/L	MPH	TRAV TIME	UN NORM	NL	VOL	CAP	WEAVE EFF	V/C	DEN V/M/L	MPH	TRAV TIME	C	LENG	QUEUE FEET	RA
1	1335.	0.0	1335								N	3	1601.	4350.	0.0	0.37	54.	6.	2.01	*	1000.	1000	-266.
2	0.0	0.0	1335	1	226.	1500.	0.15	4.	51.	0.31	U	2	1373.	2900.	0.0	0.47	33.	8.	1.51	*	1390.	1390	-266.
3	1331.	0.0	2666	1	226.	1500.	0.15	4.	51.	0.30	U	5	2704.	7750.	0.0	0.35	103.	5.	2.92	*	1341.	1341	-266.
4	0.0	0.0	2666	1	225.	1500.	0.15	4.	51.	0.73	U	4	2704.	6120.	0.0	0.44	91.	7.	5.03	*	3294.	3294	-266.
5	0.0	57.	2666	1	225.	1500.	0.15	4.	51.	0.20	U	3	2704.	4500.	0.0	0.60	75.	12.	0.85	*	900.	900	-266.
6	230.	0.0	2829	1	226.	1500.	0.15	4.	51.	0.41	U	3	2867.	4500.	0.0	0.64	72.	13.	1.60	*	1663.	1663	-266.
7	130.	0.0	2959	1	226.	1500.	0.15	4.	51.	0.57	U	3	2937.	4500.	0.0	0.67	70.	14.	2.06	*	2577.	2577	-266.
8	0.0	128.	2959	1	226.	1500.	0.15	4.	51.	0.45	U	3	2997.	4500.	0.0	0.67	70.	14.	1.66	*	2075.	2075	-266.
9	357.	0.0	3186	1	225.	1500.	0.15	4.	51.	0.69	U	3	3225.	4500.	0.0	0.72	67.	16.	2.19	*	3091.	3091	-266.
10	0.0	124.	3186	1	226.	1500.	0.15	4.	51.	0.37	U	3	3226.	4500.	0.0	0.72	67.	16.	1.17	*	1644.	1644	-266.
11	145.	0.0	3209	1	226.	1500.	0.15	4.	51.	0.23	U	4	3247.	6120.	0.0	0.53	82.	10.	1.21	*	1054.	1054	-266.
12	0.0	160.	3209	1	226.	1500.	0.15	4.	51.	0.33	U	3	3247.	4500.	0.0	0.72	67.	16.	1.06	*	1506.	1506	-266.
13	124.	0.0	3153	1	226.	1500.	0.15	4.	51.	0.64	U	3	3191.	4500.	0.0	0.71	68.	16.	2.74	*	2795.	2795	-266.
14	0.0	219.	3157	1	226.	1500.	0.15	4.	51.	0.44	U	3	3191.	4500.	0.0	0.71	68.	16.	1.43	*	1982.	1982	-266.
15	0.0	221.	2934	1	225.	1500.	0.15	4.	51.	0.33	U	3	2972.	4500.	0.0	0.66	71.	14.	1.20	*	1478.	1478	-256.
16	149.	0.0	2862	1	226.	1500.	0.15	4.	51.	0.42	U	3	2900.	4500.	0.0	0.64	72.	13.	1.49	*	1880.	1880	-266.
17	0.0	427.	2862	1	226.	1500.	0.15	4.	51.	0.42	U	2	2900.	2900.	0.0	1.00	49.	29.	0.73		1850.	0	0.0
18	162.	0.0	2633	1	227.	1500.	0.15	4.	51.	0.76	U	2	2635.	2900.	0.0	0.91	46.	37.	1.06		3434.	0	0.0
19	0.0	106.	2633	1	226.	1500.	0.15	4.	51.	0.55	U	2	2644.	2900.	0.0	0.91	36.	37.	0.76		2474.	0	0.0
20	0.0	0.0	2534								N	3	2755.	4350.	0.0	0.63	22.	43.	0.13		500.	0	0.0
21	0.0	2755.	2534								N	3	2755.	4350.	0.0	0.63	22.	43.	0.27		1000.	0	0.0

			QUEUE LENGTH VEHICLES	DELAY VEH-HRS
ON-RAMP	1	INPUT POINT	314.07	413.74
		MERGING POINT	0.0	0.0
		TOTAL	314.07	413.74

TRAVEL TIME FOR ONE NON-PRIORITY TRIP .01 MINUTES

0	1	2	3	4	5	6	7	8	9
1	1272.	1304.	2140.	2367.	2766.	2906.	3136.	3319.	3349.
2	860.	1612.	1748.	1975.	2307.	2513.	2744.	2927.	2957.
3	0.	333.	869.	1096.	1434.	1633.	1864.	2047.	2077.
4	0.0	472.	708.	935.	1353.	1473.	1704.	1886.	1927.
5	0.0	0.	336.	563.	980.	1100.	1332.	1514.	1544.
6	0.0	0.0	0.	227.	644.	764.	996.	1178.	1218.
7	0.0	0.0	0.0	0.0	417.	537.	769.	951.	981.
8	0.0	0.0	0.0	0.0	0.0	0.	232.	414.	454.
9	0.0	0.0	0.0	0.0	0.0	0.0	0.	182.	222.

TRAVEL TIME FOR ONE PRIORITY TRIP .01 MINUTES

0	1	2	3	4	5	6	7	8	9
1	355.	500.	604.	662.	790.	923.	997.	1035.	1078.
2	123.	258.	473.	450.	558.	591.	675.	805.	846.
3	0.	145.	250.	307.	435.	468.	552.	683.	724.
4	0.0	103.	209.	265.	394.	427.	510.	642.	682.
5	0.0	0.	105.	162.	290.	323.	407.	538.	578.
6	0.0	0.0	0.	57.	185.	218.	302.	433.	473.
7	0.0	0.0	0.0	0.	128.	161.	245.	376.	416.
8	0.0	0.0	0.0	0.0	0.0	0.	84.	215.	255.
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	131.	171.

	CURRENT TIME INTERVAL		CUMULATIVE VAL	
FREEWAY TRAVEL TIME (NOR)	46. VEH-HRS	55. PASS-HRS	161. VEH-HRS	254
FREEWAY TRAVEL TIME (UNR)	740. VEH-HRS	750. PASS-HRS	3652. VEH-HRS	3699
FREEWAY TRAVEL TIME (RES)	16. VEH-HRS	49. PASS-HRS	129. VEH-HRS	401
INPUT DELAY (NOR)	414. VEH-HRS	574. PASS-HRS	760. VEH-HRS	1072.
INPUT DELAY (UNR)	0.0 VEH-HRS	0.0 PASS-HRS	0.0 VEH-HRS	0.0
TOTAL TRAVEL DISTANCE	11661. VEH/MI.	13011. PASS-MI.	74701. VEH/MI.	90165
TOTAL TRAVEL TIME UNDER PRIORITY OPERATIONS	1205. VEH-HRS	1428. PASS-HRS	4703. VEH-HRS	543
TOTAL TRAVEL TIME UNDER NON-PRIORITY OPERATIONS			1893. VEH-HRS	290
TRAVEL TIME SAVINGS OVER NON-PRIORITY OPERATION =			-2809.3 VEH-HRS	-2532

END OF SIMULATION FOR ABOVE CRITERION

Figure 133. PRIFRE Simulation Results for I-95 Priority Lane (2 persons/vehicle) with Existing Lanes (Continued)

To define a second alternative the parameter card was changed to evaluate the use of the priority lane for 3 or more persons per vehicle. This alternative was also based upon the existing lanes.

Another set of alternatives were also defined. The basic alternative included the addition of another lane within the median. This required that lanes and capacities be modified on the input cards. Figure 127 showed the input data listing for this condition. The two levels of occupancy previously used were coded for this improved condition.

Evaluation of Alternatives

As a result of the previous task a total of six conditions, or alternatives, were defined and measures of effectiveness were obtained for each run. A summary of these results are shown on Table 32.

The designation of one of the existing lanes as a reserved lane for high occupancy vehicles resulted in an overall reduction in total passenger travel time. Due to the reduction in lanes for non-priority vehicles input queues occur. The results in an increase in total travel time for both vehicles and passengers. Vehicle hours of travel under the 2 persons per vehicle restriction is increased by 248 percent (from 1893 to 4703 veh-hrs) and passenger hours are increased 187 percent (from 2901 to 5433 pass. hrs). Increasing the vehicle occupancy to 3 persons per vehicle per hour further decreased overall travel time.

With the addition of one lane of traffic, with no restrictions, a slight decrease in vehicle hours of travel occurs from 1893 to 1762 as well as a decrease in passenger hours of travel, from 2901 to 2698, or approximately a seven (7) percent improvement.

Table 32 - Comparison of PRIFRE Results For Alternative Freeway Operations I-95

	EXISTING LANES			ADDITIONAL LANE		
	No.	With Priority Lane		No.	With Priority Lane	
Measures of Effectiveness	Pr. Ln	2 pers.	3 pers.	Pr. Ln	2 pers.	3 pers.
Freeway Travel Time-Veh/Hrs.	1893	3943	4089	1762	1813	1854
Pass/Hrs.	2901	4361	5355	2698	2158	2523
Input Delay-Veh/Hrs.	-0-	760	1994	-0-	-0-	-0-
Pass/Hrs.	-0-	1072	2815	-0-	-0-	-0-
Total Travel Time-Veh/Hrs.	1893	4703	6083	1762	1813	1854
Pass/Hrs.	2901	5433	8170	2698	2158	2523
Total Travel Distance-Veh/Mi.	80483	73701	68884	80483	80483	80483
Pass/Mi.	123215	90189	96253	123215	97254	111057
Input Queue Length						
Vehicles	-0-	314	999	-0-	(-51.1)	(-92.3)
Veh/Hrs.	-0-	414	1037	-0-	540	175.0
Travel Time Savings						
Over Non-Priority Ophs						
Veh/Hrs.	-0-	(-2809)	(-4189)	-0-	-0-	-0-
Pass/Hrs.	-0-	(-2533)	(-5269)	-0-	-0-	-0-

Further benefits occur in reduced passenger hours of travel with the designation of one lane for vehicles with 2 or more persons per vehicle. A total reduction of 540 passenger hours of travel, or 20%, occurs with only a slight increase in vehicle hours of travel (51.1 hours or 3%). Increasing the vehicle occupancy to 3 persons increases the vehicle hours of travel by 10% while only saving 175, or 10%, passenger hours of travel.

From the comparison of results obtained it is obvious that the largest benefits occur with the addition of a lane and its classification as an HOV lane for two or more persons per vehicle. In actual fact the lane was constructed and originally designated for 3 or more persons (Reference 12.8). It was hoped that with the estimated 3 minutes travel time advantage that a shift in vehicle occupancy would occur. Unfortunately this did not occur and the lane was redesignated for two or more person vehicles.

Summary of Work Effort

The following summarizes the effort required to use PRIFRE for this example problem.

Data Collection - The major work effort to use this model is obtaining data on the origin-destination of vehicles entering the freeway as well as vehicle and bus occupancy. Normally these data are not available and field studies will be required. One method to obtain this data is to have field personnel located at each on-ramp and off-ramp with tape recorders. Two individuals would normally be required at each on-ramp. One would record the number of vehicles with 1,2,3,4 and 5 or more persons per vehicle while the other would record the time and last three digits of the license plates of each entering vehicle. An individual would be located at each off-ramp and also would record the time and license plate number of each exiting vehicle. This information would then be coded, and keypunched for processing by a computer to match the destination of each entering vehicle. It is estimated that approximately 48 manhours of effort "per interchange" is required to obtain O-D and vehicle occupancy data for two hours in the AM and PM periods.

Data Coding - Data coding was rather straight forward and required little time after data was obtained in a usable fashion. Approximately six hours were required for the initial coding and an additional four hours were required to identify and correct coding errors.

Computer Time - Execution time was extremely fast varying from .71 to .79 seconds of CPU time. Core storage of 96k was required for each run.

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CHAPTER 13 - FREQ3CP (FREEWAY OPTIMIZATION MODEL)

In addition to providing exclusive lanes along a freeway for high occupancy vehicles (HOV's), some success has also been obtained by giving priority treatment to HOV's at entrances (on-ramps) to freeways. In addition to providing preferential treatment to entering HOV's to encourage higher utilization of capacity and to reduce energy consumption, ramp control (metering) is also useful to control the flow of entering traffic into the freeway to minimize the travel time and delays for the system as a whole.

The model presented in this chapter, FREQ3CP, has been used in the past to evaluate ramp metering strategies. It has been included in the FHWA Transportation Planning "BACPAC" library for a number of years but no technical support is available. FREQ3CP does provide a useful tool in calculating the effect of various ramp control strategies on freeway operations. However, in its present form it does not evaluate the effect of diverted traffic on the adjacent parallel street system. Work is underway by the University of California at Berkeley to incorporate FREQ3CP's features in models which handle both the freeway and adjacent network. Chapter 14 discusses some of these emergency models.

MODEL DESCRIPTION

The physical system considered by this model is a directional, urban freeway section and the associated ramps. The freeway section is described as a series of contiguous sections which are internally operationally homogenous. The model allows the engineer to design and evaluate entry control strategies at any or all entrance ramps to optimize flow in the system. Impacts of vehicles diverted from the freeway onto surface streets are estimated in a rudimentary fashion.

Figure 134. Typical Ramp Metering Operation

FREQ3CP is an acronym for FREeway Optimization with Queuing, version 3CP (Control and Priority treatment).

The model optimizes flow, based on any of four objective functions, using a linear programming submodel (PREFO). The decision variables are the ramp metering rates. High occupancy vehicles (HOV's) can be given priority treatment at any or all entrance ramps, or exclusive access at some ramps.

The evaluation is accomplished by a macroscopic simulation submodel (FREQ3) which was developed expressly to analyze freeway operations. A number of traffic management strategies can be investigated by FREQ3CP.

FREQ3CP (Ref. 13.1, 13.2 & 13.3) is an extension of an earlier model, FREQ (Ref. 13.4) which performed essentially the same simulation, except the latter version has several additional features. FREQ3CP adds the optimization of ramp control with priority entry.

The program consists of approximately 2000 lines of code with 80% of them actual fortran statements. The program requires approximately 180k bytes of core memory on an IBM computer.

Analyses by FREQ3CP can be obtained for the existing conditions and for optimal control conditions using any of a variety of strategies. The physical system is limited to 20 on ramps, 20 off-ramps and 40 freeway segments.

INPUT REQUIREMENTS

The following basic data are input to FREQ3CP:

1. Analysis Options and Parameters
   a) Control Strategy Option
   b) Formulation Option
   c) Diversion Option
   d) Confidence Coefficient
   e) Physical Limits
   f) Preselected Operational Parameters

2. Freeway Characteristics
   a) Capacities
   b) Weaving Considerations
   c) Speed-flow Characteristics (optional)
   d) Ramp Characteritics

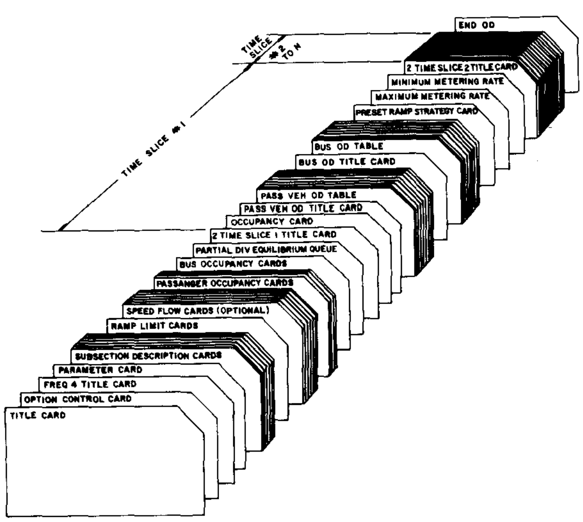


Figure 135. Typical FREQ3CP Data Deck

3. Demand Characteristics
   a) Passenger Occupancy Distributions
   b) Origin-Destination Patterns
   c) Diversion Equilibrium Queue Length

Table 33 summarizes the input requirements for FREQ3CP. Much of the data would normally be available to the analyst (geometry, traffic volumes, etc.) or can be developed (capacities). Like PRIFRE, however, there are two major data items that are not normally available to the traffic engineer.

One major input is a set of origin-destination tables for vehicles entering the freeway. These data are essential and normally would require special field O-D studies to obtain.

The other input requirement is for vehicle occupancy information. These data include the number of vehicles with 1, 2, 3, 4 and 5 or more persons, as well as buses. The data deck layout for inputting the information is shown in Figure 135. Normally four to eight time periods will need to be analyzed to obtain sufficient data for evaluation.

OPERATIONAL SUMMARY

The program reads and checks the user supplied inputs and reports any detected errors. If fatal errors are detected, data checking continues, but the run is aborted. Several non-fatal warnings may be given, which do not abort the run, but alert the user to possible problems with the data or control configuration.

Once the data have been checked and found acceptable, temporary storage files are created and execution begins.

A complete run consists of the following sequential steps (see Figure 136).

1. The freeway simulation submodel (FREQ3) is executed for the existing condition and impacts are reported.

2. The optimization sub-model (PREFO) is executed to determine the optimal meter-

Table 33 - Input Requirements For FREQ3CP

CARD TYPE	PURPOSE	DATA REQUIREMENTS
Title (1 per run)	Provide title of simulation.	Descriptive information.
Option Control (1 per run) (required)	Specify the type of simulation and the controls for this run.	Choice of submodels (with or without freeway simulation and/or ramp metering or not), objective function (passenger, vehicles, pass. miles or veh. miles), type of diversion, confindent limits, output, reports, etc.
Problem Title (1 per run)	Provide title for problem.	Descriptive information.
Parameter (1 per run)	Define freeway perameters.	No. of sections & time periods, output data, speed-v/c curves, growth factors (if desired), type of O-D data, etc.
Capacity (1 per section)	Define freeway section physical and operating characteristics.	No. of lanes, capacity, length, truck factor, speed-v/c curve, if on and/or off ramp is present, and description information.
Ramp Limits (1 per run)	Define ramp capacities or constant metering rate.	General ramp capacity and capacity at special on-ramps.
User Speed-V/C (optional)	Define special speed-V/c curves developed by user.	X (V/C) and Y (speed) coordinates of curve.
Passenger Occupancy (1 per on-ramp)	Define vehicle occupancy and number of buses for each on-ramp.	Percent of vehicle with 1,2,3,4 and 5 or more passengers and buses.
Bus Occupancy (1 per run)	Define bus occupancy for each on-ramp.	Average passenger occupancy of buses for each on-ramp.
Partial Diversion Equilibrium Ramp Queue (1 per run)	Define maximum permissible queue for each on-ramp.	Maximum queue desired on each on-ramp in turns of number of vehicles or delay time.
THE FOLLOWING CARDS ARE REQUIRED FOR EACH TIME SLICE (PERIOD) EVALUATED		
Time Slice Title (1 per run)	Provide title for time period.	Description information (autos and/or Bus O-D data).
Occupancy (1 per period)	Define network average vehicle occupancy and revise on-ramp capacity.	Average number of passengers in each vehicle and revised on-ramp capacities.
O-D Title (1 per O-D Table)	Define title for the origin destination tables that follow.	Descriptive information (autos and/or Bus O-D data).
1 per on-ramp per O-D Data O-D table)	Define the destinations of vehicles entering each on-ramp.	Number of vehicles and bus trips from each on-ramp to each off-ramp.
Preset Ramp Strategy (1 per period)	Define ramp metering strategy for each on-ramp.	Lower limit for the occupancy level of priority vehicles at all on-ramps.
Metering Rate Limit (2 per period)	Define maximum and minimum metering rates.	Maximum and Minimum metering rates (vph) for each on-ramp.
End OD (1 per run)	To terminate current simulation run.	Code END OD.

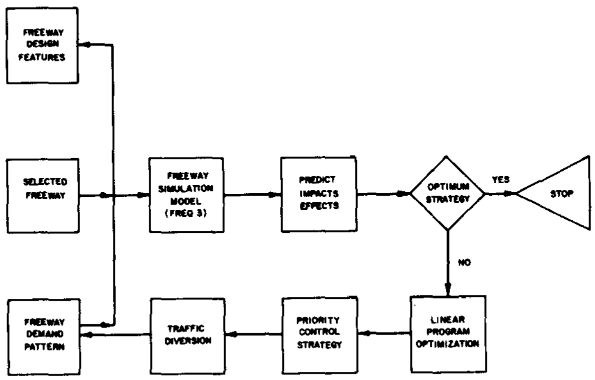


Figure 136. Generalized Flowchart of the FREQ3CP Model

ing system to maximize the user selected objective function. The optimal design is output.

3. FREQ3 is executed again with the results of the optimization submodel to compute the impacts of the specified control strategy, and the results are reported.

This sequence provides the user with impacts for the "before" condition and the "after" affects of the control strategy.

COMPUTATIONAL ALGORITHMS

There are four primary computational functions in FREQ3CP. These are within the program. One is manual and consists of four subfunctions. These are described separately in the following sub-sections.

Simulation Function (FREQ3)

There was little change in this submodel, the algorithms are detailed in Reference 13.4. Algorithms are used to simulate the following tasks:

1. On-ramp queuing;
2. Subsection demands;
3. Merging analysis;
4. Weaving analysis (ramp to ramp only, optional);
5. Bottleneck analysis;
6. Flow on freeway; and
7. Off-ramp queuing.

All algorithms are based on the Highway Capacity Manual techniques (Reference 13.5). The most significant algorithm is the calculation of travel time on the freeway. The program uses the speed vs. volume/capacity (V/C) ratio curves, but the user may also override this by inputting his own curves. See Chapter 12, PRIFRE, for further details on FREQ3.

Optimization Function (FREFO)

The optimization sub-model is a standard linear programming (LP) formulation of the general type,

$$\max \Sigma_i C_i X_i \qquad (13.1)$$

subject to: $${}_i a_{Ki} X_i \le b_k, \qquad (13.2)$$

for all k,
and all $X \geq 0.5i$

The C_i are cost coefficients, X_i are decision variables, $_{Ki}$ are "technology" coefficients and b_k are limits. The basic optimization submodel used in FREQ3CP (PREFO) is documented in Reference 13.1.

There are four objective functions available in FREQ3CP. Any of the following may be maximized:

1. Vehicle input rate,
2. Vehicle-miles of travel,
3. Passenger input rate, or
4. Passenger-miles of travel.

The complete set of objective functions are given as follows:

$$\max \text{ VEHICLE INPUT RATE} = \sum_{i=1}^{n} X_i \quad (13.3)$$

$$\max \text{ VEH. MILES OF TRAVEL} = \sum_{i=1}^{n} \ell_i X_i \quad (13.4)$$

$$\max \text{ PERSON INPUT RATE} = \sum_{i=1}^{n} \sum_{k=1}^{6} O_k X_{ik} \quad (13.5)$$

or

$$\max \text{ PERSON MILES OF TRAVEL} = \sum_{i=1}^{n} \sum_{k=1}^{6} \ell_{ik} O_{ik} X_{ik} \quad (13.6)$$

where: X_i = number of vehicles entering at ramp i;

ℓ_i = average trip length of vehicles entering at ramp i (from origin-destination tables);

O_k = occupancy levels, e.g. O_{ik}=k=1,2,3,4,5 for cars at all ramps and for k=6, the average bus occupancy at ramp i;

X_{ik} = number of vehicles with occupancy level k(=1,2,3,4,5,6) at ramp i; and

ℓ_{ik}, O_{ik} = same as before, but separated into occupancy levels, k; and

n = number of ramps.

The constraints of the linear programming model are also varied. Those which are always used are the capacity and non-negativity constraints. The constraints are discussed below for the passenger-based analysis, since the vehicle-based functions are subsets of the other.

The first set of constraints is that the mainline capacity in any subsection cannot be exceeded, or

$$\sum_{i=1}^{n} F_{11\ell} X_{11} + F_{121} X_{12} + \cdots \quad (13.7)$$

$$+ F_{15\ell} X_{15} + F_{16\ell} e X_{16} \leq C\ell,$$

for ℓ=1,p;

where $F_{ik\ell}$= fraction of traffic from on-ramp i with passenger occupancy K(k=1 through 5 for autos and 6 for buses) passing through subsection ℓ;

e = bus equivalency factor;

C_ℓ = capacity of subsection ; and all the rest as before.

The second set of constraints is that the volume on any on-ramp cannot exceed the demand at that ramp, or

$$X_{ik} \leq D_{ik}, \text{ for } i=1, n \text{ and } k=1, 6; \quad (13.8)$$

where $D_{ik} = \sum_{j=1}^{m} d_{ijk}$ = traffic demand at ramp i with occupancy level k; and where;

d_{ijjk} = traffic demand from on ramp i to off-ramp j, with passenger level k; and

m = number of off-ramps.

It should be borne in mind that k = 6 is for buses. The non-negativity constraint is simply $X_{ik} \geq 0$ for i = 1, n and k = 1, 6.

Several additional constraints are optional. The metering rates can be limited by the following:

$$\sum_{k=1}^{6} X_{ik} \leq M_i \text{ and } \sum_{k=1}^{6} X_{ik} \geq m_i; \quad (13.9)$$

for i = 1, n;

where M_i, m_i = maximum and minimum metering rates at ramp i, respectively.

These minimum constraints may be required, for example, to prevent the ramp queue backing onto a surface street or to keep the violation rate down. The maximum may be appropriate at a ramp which has an excellent alternative route or to discourage short trips. Ramp closing may be accomplished by setting M_i to zero. Exclusive use of a ramp for buses can be accomplished by changing the '6' in (13.6) to '5' and setting M_i = 0. Carpools could be given similar exclusive use by making the upper limit of k equal one less than the desired carpool level. These options are summarized as follows (all for on-ramp i):

1. No control: $X_{ik} = D_{ik}$, k = 1,6.
2. Autos only: $X_{i6} = 0$
3. Priority Vehicles only: $X_{i1} = X_{i2} = ... = X_{iK} = 0$, where K is one less than desired carpool level.
4. Buses only: $X_{i1} = X_{i2} = ... = X_{i5} = 0$.
5. Ramp Closed: $X_{ik} = 0$, k = 1,6.

There are other optional control (optimization) strategies which are more detailed, and the interested reader may consult Reference 13.1.

OUTPUT REPORTS

There are four stages of outputs in FREQ3CP - an input data report, a report of the freeway performance before control, the optimum control report and, finally, the simulation of freeway performance after control. During the simulations there is an output report for each time slice.

The output reports are discussed in the subsections below; however, the following information is helpful for better understanding the output:

1. A priority cut-off-level of 1 for an on-ramp indicates that all vehicles are considered to be priority vehicles, i.e., the metering rate is equal to the demand.

2. An asterisk (*) which is printed after the priority cut-off-level of an on-ramp indicates that the optimum metering rate is less than the original demand, and that this on-ramp should be metered at the rate specified by the model.

3. The program always prints the metering rate for the mainline input (on-ramp No. 1), however, the printed metering rate is always equal to the original demand. Therefore, an asterisk (*) never appears in front of the priority cut-off-level of the mainline input (see number 2 above). Originally, the program was designed with the capability of controlling the mainline input, but the current version of the program automatically sets the maximum and minimum metering rates of the mainline input equal to the original demand, regardless of the values of the specified maximum and minimum rates.

4. Sometimes there is a very small difference (.2% at the most) between the number of passenger- (or vehicle-) miles of travel printed from the PREFO subprogram and the FREQ3 subprogram. The former is more accurate than the latter.

Input Data Report

The first output is a report on the freeway characteristics data, which allows the user to check the inputs for accuracy. This report is shown in Figure 137, which is self explanatory.

Freeway Performance Before Control

Figure 138 shows a typical report on freeway performance during a typical time slice. The table entries are reasonably self explanatory, but the following points may need highlighting:

1. Note that the "O-D Data Demands" and the "Adjusted Volumes" correspond unless demand exceeds the freeway capacity ("FRWY CAP."). In this case the excess demand on the freeway ("DEM.") is reduced

RAMP METE IMPROVE I-95 MIAMI(AIRPORT XWAY TO GOLDN GLADES)- MAX PASS MILES

FREEWAY DESIGN PARAMETERS
FREQ3CP PROBLEM (PM PEAK PERIOD - RAMP METERING WITH RMB,MIN OCC =2)

INPUT DATA

19 SUBSECTIONS
2.00 TIME-SLICES PER HOUR
0 USER-SUPPLIED SPEED FLOW CURVES
0 GROWTH PERIODS AT RATE 0.0
WEAVING EFFECTS CONSIDERED

SUB SEC	NO. LNS	SSEC CAP.	SSEC LENGTH	TRK FAC	DESIGN SPEED	ORG DES	LFT RMP	SUBSECTION LOCATION	
1	3	4350.	2390.	0.970	60	O	0	BEGIN SECTION (LOCS. BEGIN SECTS.)	O1
2	6	9300.	1341.	0.970	60	O	2	AIRPORT X-WAY ON	O2
3	5	7650.	3294.	0.970	60		0	LANE DROP	
4	4	6000.	900.	0.970	60	D	0	62 ST OFF	D1
5	4	6000.	1863.	0.970	55	O	0	62 ST ON	O3
6	4	6000.	2577.	0.970	55	O	0	69 ST- ON	O4
7	4	6000.	2075.	0.970	60	D	0	79 ST OFF	D2
8	4	6000.	3091.	0.970	60	O	0	81 ST ON	O5
9	4	6000.	1644.	0.970	60	D	0	95 ST OFF	D3
10	5	7650.	1054.	0.970	60	O	0	95 ST ON	O6
11	4	6000.	1506.	0.970	60	D	0	103 ST OFF	D4
12	4	6000.	3795.	0.970	60	O	0	103 ST ON	O7
13	4	6000.	1982.	0.970	60	D	0	119 ST OFF	D5
14	4	6000.	1478.	0.970	60	D	0	125 ST OFF	D6
15	4	6000.	1880.	0.970	60	O	0	125 ST ON	O8
16	4	6000.	1890.	0.970	60	D	0	135 ST OFF	D7
17	4	6000.	3434.	0.970	60	O	0	135 ST ON	O9
18	4	6000.	2474.	0.970	60	D	0	151 ST OFF	D8
19	3	4350.	1500.	0.970	60	D	0	END SECTION	D9

* INDICATES USER SUPPLIED SPEED-FLOW CURVE NUMBER

RAMP LIMITS =1500.
ON-RAMP 1 LIMIT=4350.
ON-RAMP 2 LIMIT=4350.

Figure 137. Typical FREQ3CP Input Data Report

TIME SLICE 3 4:30 PM

TIME SLICE 3 OF 6
GROWTH PERIOD 0 OF 0
OCCUPANCY 1.56
QUEUE COLL. SECTION 6 T2= 0.079
QUEUE COLL. SECTION 5 T2~ 0.081
QUEUE OUT OF SECTION 1

SUB SEC	NO. LNS	SSEC LENGTH	O-D DATA DEMANDS ORG.	DES.	DEM.	ADJUSTED VOLUMES ORG.	DES.	VOL.	FRWY CAP.	WEAVE EFF	V/C	DENS. V/M/L	SPEED MPH		TRAVEL TIME	QUEUE-LENGTH	STORAGE RATE
1	3	2390.	2834.	0.	2834.	2023.	0.	2023.	4350.	0.	0.47	22.8	29.6	**	0.92	2390.	811.
2	6	1341.	2838.	0.	5672.	2838.	0.	4861.	9210.	90.	0.53	39.0	20.8	**	0.73	1341.	811.
3	5	3294.	0.	0.	5672.	0.	0.	4861.	7560.	90.	0.64	53.2	18.3	**	2.05	3294.	811.
4	4	900.	0.	143.	5672.	0.	143.	4861.	5910.	90.	0.82	55.7	21.8	**	0.47	900.	811.
5	4	1863.	494.	0.	6023.	494.	0.	5212.	6000.	0.	0.87	55.7	23.4	**	0.91	1863.	788.
6	4	2577.	284.	0.	6307.	284.	0.	5496.	6000.	0.	0.92	55.0	25.0	**	1.17	2577.	504.
7	4	2075.	0.	272.	6307.	0.	258.	5496.	6000.	0.	0.92	56.8	24.2	**	0.97	2075.	504.
8	4	3091.	762.	0.	6797.	762.	0.	5923.	6000.	0.	0.99	50.2	29.5	*	1.19	315.	77.
9	4	1644.	0.	267.	6797.	0.	233.	5923.	6000.	0.	0.99	50.5	29.3	**	0.64	1644.	77.
10	5	1054.	310.	0.	6840.	310.	0.	6000.	7650.	0.	0.78	49.4	24.3	**	0.49	1054.	77.
11	4	1506.	0.	383.	6840.	0.	332.	6000.	6000.	0.	1.00	50.8	29.5		0.58	0.	0.
12	4	3795.	264.	0.	6721.	264.	0.	5932.	6000.	0.	0.99	48.2	30.8		1.40	0.	0.
13	4	1982.	0.	464.	6721.	0.	404.	5435.	6000.	0.	0.91	44.4	30.6	*	0.74	1493.	497.
14	4	1478.	0.	471.	6257.	0.	413.	5032.	6000.	0.	0.84	37.0	34.0	**	0.49	1478.	497.
15	4	1880.	316.	0.	6102.	316.	0.	4935.	6000.	0.	0.82	38.9	31.7	**	0.67	1880.	497.
16	4	1890.	0.	834.	6102.	0.	736.	4935.	6000.	0.	0.82	42.7	28.9	**	0.74	1890.	497.
17	4	3434.	345.	0.	5613.	345.	0.	4543.	6000.	0.	0.76	49.6	22.9	**	1.70	3434.	497.
18	4	2474.	0.	216.	5613.	0.	193.	4543.	6000.	0.	0.76	60.2	18.9	**	1.49	2474.	497.
19	3	1500.	0.	5397.	5397.	0.	4350.	4350.	4350.	0.	1.00	49.2	29.5		0.58	0.	0.
TOTAL		40168.											TOTAL		17.94		

			QUEUE LENGTH VEHICLES	DELAY VEH-HRS
ON-RAMP	1	INPUT POINT	13.17	0.11
		MERGING POINT	0.0	0.0
		TOTAL	13.17	0.11

	CURRENT TIME INTERVAL		CUMULATIVE VALUES	
FREEWAY TRAVEL TIME=	901. VEH-HRS=	1405. PASS-HRS	2169. VEH-HRS=	3391. PASS-HRS
INPUT DELAY=	0. VEH-HRS=	0. PASS-HRS	0. VEH-HRS=	0. PASS-HRS
OUTPUT DELAY=	0. VEH-HRS=	0. PASS-HRS	0. VEH-HRS=	0. PASS-HRS
TOTAL TRAVEL TIME=	901. VEH-HRS=	1405. PASS-HRS	2169. VEH-HRS=	3391. PASS-HRS
TOTAL TRAV DISTANCE=	23600. VEH-MI.=	36816. PASS-MI.	79170. VEH-MI.=	123818. PASS-MI.

Figure 138. Typical FREQ3CP Freeway Performance Report Before Control

ON-RAMP NO.	ORIGINAL DEMAND (VEH)	ORIGINAL DEMAND (PASS)	CONTROL STRATEGY ON PASSENGER BASIS: PRIORITY CUT-OFF LEVEL	FREEWAY INPUT RATE (VEH)	FREEWAY INPUT RATE (PASS)	NON-PRIORITY METERING RATE	PRESET CONTROL STRATEGY
1	1553.	2325.	2	1553.	2325.	1069.	NO METERING
2	1505.	2158.	2	1505.	2158.	1040.	PRIORITY CUT-OFF LIMIT
3	265.	385.	2	265.	385.	182.	PRIORITY CUT-OFF LIMIT
4	153.	222.	2	153.	222.	105.	PRIORITY CUT-OFF LIMIT
5	406.	589.	2	406.	589.	279.	PRIORITY CUT-OFF LIMIT
6	167.	242.	2	167.	242.	115.	PRIORITY CUT-OFF LIMIT
7	142.	206.	2	142.	206.	98.	PRIORITY CUT-OFF LIMIT
8	168.	244.	2	168.	244.	116.	PRIORITY CUT-OFF LIMIT
9	184.	267.	2	184.	267.	127.	PRIORITY CUT-OFF LIMIT
TOTAL	4543.	6638.		4543.	6638.		

	CURRENT TIME INTERVAL		CUMULATIVE VALUES	
TOTAL TRAVEL DISTANCE	24524. VEH-MILES	35894. PASS-MILES	24524. VEH-MILES	35894. PASS-MILES
TOTAL DEMAND	4543. VEHICLES	6638. PASSENGERS	4543. VEHICLES	6638. PASSENGERS
TOTAL INPUT VOLUME	4543. VEHICLES	6638. PASSENGERS	4543. VEHICLES	6638. PASSENGERS
TOTAL DIVERTED DEMAND	0. VEHICLES		0. VEHICLES	
TOTAL DEMAND TRANSFERED TO THE NEXT TIME SLICE	0. VEHICLES		0. VEHICLES	

Figure 139. Typical FREQ3CP Optimization Control Report

to the volume ("VOL.") level and the excess is stored in the upstream subsection.

2. System measures are given below the table for the current time slice and cumulatively.

Several less important reports are also available at this stage. These include updated O-D tables and single trip travel times between all origins and destinations.

Optimization Control Report

Again, for each time slice the freeway performance is reported in a report very similar to Figure 138, except that queuing data at each ramp are also given. In addition to the other secondary reports mentioned earlier for the before condition, reports are given on the demand diverted to surface streets and delayed into the next time slice. Most significantly, the optimal metering rates are given in a table such as Figure 139.

ADDITIONAL FEATURES

FREQ3CP is designed mainly to assist in developing optimal entry control strategies for a general use freeway whose on-ramps are metered, but priority vehicles can bypass the signal. With manual interfacing, priority lane(s) on the freeway can be analyzed as well. Freeway design improvements can also be evaluated with FREQ3CP by appropriately adjusting the capacities and/or speed - V/C curves.

Later versions in the FREQ-series have expanded this model to increase the analysis and correct earlier deficiencies. For example FREQ4CP (Ref. 13.6) added estimation of fuel consumption and vehicle exhaust emissions as well as estimates of spatial and modal responses. Further enhancements resulted in FREQ6PE as a corridor model which analyzes the impacts on surface streets in detail (Ref. 13.7). FREQ6PL (Ref. 13.8) combines the basic FREQ-model with the exclusive lane analysis of PRIFRE (see Chapter 12). Both FREQ6PE and FREQ6PL are being used by numerous localities to test the improvements represented by these advanced models.

APPLICATIONS AND LIMITATIONS

As stated earlier, there are a variety of analyses which can be accomplished using FREQ3CP. The emphasis, of course, is evaluating entry control strategies (eg. ramp metering) and priority treatment for HOV's at ramps (eg. ramp metering bypass). Priority lanes on the freeway can be analyzed, but only by making one run for general traffic and one run for the HOV lane. This process of "fooling" the program is tenuous at best, as the effects of weaving and speed differentials which actually exist between concurrent HOV lanes and general lanes would be very difficult to account for.

Nonetheless, FREQ3CP is an excellent model for the primary purposes for which it was written.

In addition to the quantitative limitations (e.g., 20 on-ramps, 20 off-ramps and 40 sections), and the absence of many of the improvements noted in the previous section, there are several other limitations which should be recognized. These are of two types: a) those which are inherent limitations and b) those which are based on assumptions that may not be fully realistic. The latter are not necessarily critical, but the user should be aware of the possible ramifications.

The qualitative model limitations are summarized below:

1. The effect of diverted traffic is not fully assessed. The assumption is made that these vehicles do not affect surface street operations, but diversion of a significant amount of traffic can clearly be adverse to arterial flow.

2. The effect of extensive ramp queues on surface streets is also not fully assessed. This can be a serious problem and in actual experience, surface streets are often blocked, or traffic is delayed by queues which back onto them. FREQ6PE is a more comprehensive model in this respect.

3. Spatial shift is not estimated. No arterial-to-freeway shift is recognized, nor is "backtracking" to use an upstream ramp (which is not uncommon). Again, FREQ6PE does estimate spatial shifts.

4. The FREQ3CP model does not address temporal shift or demand changes but this is available in FREQ6PE.

5. Traffic flow is considered homogenous in each subsection and in each time slice. While to assume otherwise would require (much more complex and expensive) microscopic simulation, it must be recognized that the results of the FREQ simulation are "average day" in a no-incident environment.

6. The assumption is made that in the no control condition, the freeway and alternative surface routes are in equilibrium (i.e. equal travel time). This assumption is clearly not universely valid.

7. Time spent in a queue is assumed to be valued equally as time in motion. Studies have suggested otherwise; however, this can be tempered by appropriate assignments of ramp cut-off-limits.

8. Finally, the linear programming optimization which maximizes either passenger or vehicle input or miles of travel may not adequately address objectives some users may have. For example, some users may wish to minimize total travel time. Such time based measures are generally nonlinear functions, however, and more complex modeling techniques are required.

A number of the limitations noted have been overcome in later enhancements of the FREQ-series, notably FEQ6PE. Users interested in later versions (including FREQ6PL (an extension of PRIFRE) should contact the Institute of Transportation Studies, University of California at Berkeley.

EXAMPLE APPLICATION

The I-95 freeway system described in the previous chapter was also used to illustrate the use of the FREQ3CP model. The following describes the results of this application.

Problem Description

The previous model, PRIFRE, was used to evaluate the benefits of priority lane operation under existing conditions as well as with construction of a new lane in the median.

The alternatives to be evaluated in this problem are the potential benefits of ramp control, with either controlled metering of all vehicles or priority treatment for high occupancy vehicles. For the purpose of this problem an HOV vehicle will be defined as one with 2 or more persons per vehicle.

Analysis of Existing Conditions

A sketch and summary table similar to the PRIFRE example was prepared. Basically, the only difference was the combining of the first two and last two sections, since no change in freeway geometric or usage will occur under this operation. Figure 140 illustrates this condition.

Since standard coding forms are not available for FREQ3CP an echo listing of the input data is shown on Figure 141. The most noticeable difference between this input data/-set and that of PRIFRE is that the auto O-D tables are placed before the bus O-D tables and that a separate breakdown of percent vehicle occupancy for each on ramp is required. As a result of the submission of these input data a report was obtained on existing operations. The results are similar to those obtained from PRIFRE.

Figure 142 illustrates the outputs from this run. The first section of the output is a listing of the freeway sections, and the characteristics, as well as tables showing the distribution of vehicle and bus occupancy by on-ramps. Information is shown on the demand during the period, volume accommodated, MOE's (V/C ratio, density, speed, travel time) and any queues which have occurred and the rate of storage. Where queues occur information on their location, length and delay in vehicle hours are shown (note time slice 3 in Figure 142 on page 264). Network wide summary statistics for the current time interval and cumulative values are also shown. The results for existing conditions are similar to those obtained in Chapter 12. In actual practice these results are used to compare with actual field operation in order to calibrate the model. Although this was not done in this example, it is a necessary, and often, time consuming work.

Define and Analyze Alternatives

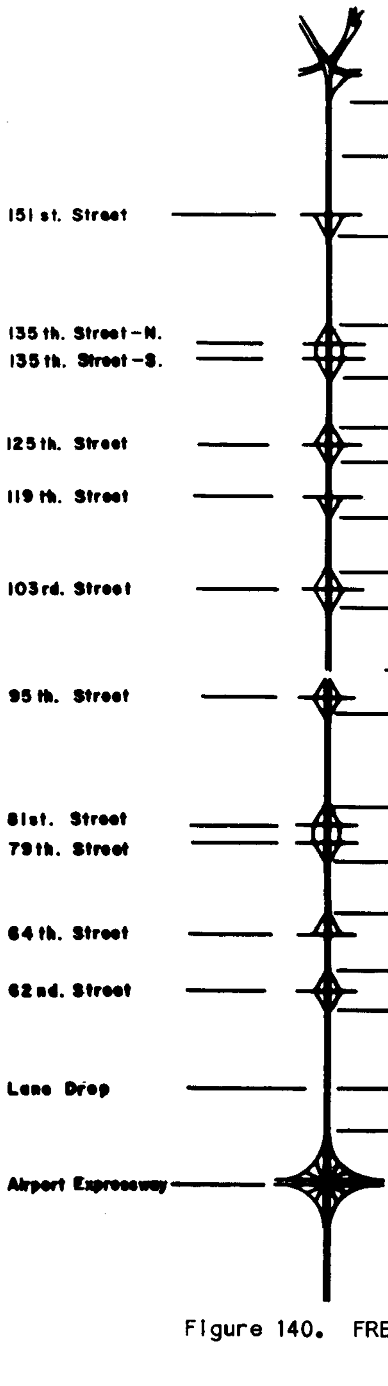
A total of five alternatives were defined. For existing physical conditions, one run was made to optimize vehicle input with a second run to optimize passenger-miles of freeway travel. The only change required between these two alternatives was to change the optimum control card from one objective (maximum vehicle input) to the other (maximum passenger-miles of freeway travel).

The other three alternatives were based upon the addition of another through lane, which was proposed previously as reserved for HOV's. However, in this case operation was evaluated with no controls as well as with control of vehicle entry and priority entry for high occupancy vehicles. These alternatives required that the lanes and capacity of the freeway section be changed (19 cards), as well as the optimum control card.

Figure 143 illustrates the results obtained for existing conditions under ramp metering to maximize vehicle input. The first two reports for each time slice shows the O-D volumes, minimum and maximum metering rates, and the control strategy used for the period as well as the demand that was diverted to the arterial streets and/or transferred to the next time slice. After that report has been printed for each time slice the results of a simulation after controls have been implemented are shown. These are similar to the reports obtained earlier with no ramp controls.

Evaluation of Results

Table 34 summarizes the results obtained for each two alternatives on a system wide basis. With the existing lanes, but with ramp meter-



SECTION DESCRIPTION								
NO.		LENGTH (FT.)	LANES			CAPACITY (vph)		
			EXIST.	PRIOR.	TOTAL	EXIST.	PRIOR.	TOTAL
19	End Section	1500	3	0	3	4350	0	4350
18	off-ramp	2474	3	1	4	4500	1500	6000
17	on-ramp	3434	3	1	4	4500	1500	6000
16	off-ramp	1890	3	1	4	4500	1500	6000
15	on-ramp	1880	4	1	5	5150	1500	7650
14	off-ramp	1478	4	1	5	5150	1500	7650
13	off-ramp	1982	4	1	5	5150	1500	7650
12	on-ramp	3798	4	1	5	5150	1500	7650
11	off-ramp	1506	4	1	5	5150	1500	7650
10	on-ramp	1054	5	1	6	7800	1500	9300
9	off-ramp	1644	4	1	5	5150	1500	7650
8	on-ramp	3091	4	1	5	5150	1500	7650
7	off-ramp	2076	4	1	5	5150	1500	7650
6	on-ramp	2577	4	1	5	5150	1500	7650
5	on-ramp	1863	4	1	5	5150	1500	7650
4	off-ramp	900	4	1	5	5150	1500	7650
3	lane drop	3294	5	1	6	7,800	1500	9300
2	on-ramp	1341	6	1	7	8,450	1500	10,950
1	Begin Section	2390	3	0	3	4350	—	4350

Figure 140. FREQ3CP Section Data for I-95 Example Problem.

```
RAMP METE  IMPROVE I-95 MIAMI(AIRPORT XWAY TO GOLDN GLADES)- MAX VEHICLE INPUT
  MVI     S     T     .9   1.0   .01           22
FREQ3CP PROBLEM (PM PEAK PERIOD - RAMP METERING WITH RMB,MIN OCC =2)
   19    2.      1   60.      0      H
    1      3 4350 2390   .97 000      BEGIN SECTION (LOCS. BEGIN SECTS.) 01
    2      6 9300 1341   .97 000     2AIRPORT X-WAY ON            02
    3      5 7650 3294   .97 00       LANE DROP
    4      4 6000  900   .97 00 D     62 ST OFF                  D1
    5      4 6000 1863   .97 550      62 ST ON                   03
    6      4 6000 2577   .97 550      69 ST ON                   04
    7      4 6000 2075   .97 00 D     79 ST OFF                  D2
    8      4 6000 3091   .97 000      81 ST ON                   05
    9      4 6000 1644   .97 00 D     95 ST OFF                  D3
   10      5 7650 1054   .97 000      95 ST ON                   06
   11      4 6000 1506   .97 00 D     103 ST OFF                 D4
   12      4 6000 3795   .97 000      103 ST ON                  07
   13      4 6000 1932   .97 00 D     119 ST OFF                 D5
   14      4 6000 1478   .97 00 D     125 ST OFF                 D6
   15      4 6000 1830   .97 000      125 ST ON                  08
   16      4 6000 1890   .97 00 D     135 ST OFF                 D7
   17      4 6000 3434   .97 000      135 ST ON                  09
   18      4 6000 2474   .97 00 D     151 ST OFF                 D8
   19      3 4350 1500   .97 00 D     END SECTION                D9
  1500                             1 4350   2 4350
.675.216.051.029.008.021
.685.220.052.030.004.004
.688.221.052.030.009    0
.688.221.052.030.009    0
.688.221.052.030.009    0
.688.221.052.030.009    0
.688.221.052.030.009    0
.688.221.052.030.009    0
.688.221.052.030.009    0
 40. 40.
T   0   2   2   2   2   2   2   2   2
2    TIME SLICE 1     3:30 PM
  1.56
AUTO O-D TABLE
   37   69   73   89   89   94  163   38 849
   40   68   55   75  110   90  141   35 891
    0    8    4   14   13   13   41    7 160
    0    2    5   12   11   11   11    3  93
    0    0    4   12   15   17   44   11 303
    0    0    0    1    3   13   20    8 122
    0    0    0    0    7   11   16    7 101
    0    0    0    0    0    0    9    4 155
    0    0    0    0    0    0    0    5 179
BUS O-D TABLE
                                          2
                                          0




       2   1 NC     2  NC
    05000120012001500120012001200120 0
       900  180  180 240  180  180  180  180
2    TIME SLICE 2    4:00 PM
  1.57
AUTO O-D TABLE
```

```
  2   1 NC     2  NC
05000120012001500120012001200120 0
  900  180  180 240  180  180  180  180
 END OD
```

Figure 141. FREQ3CP Input Data Listing for I-95 Existing Conditions.

RAMP METE IMPROVE I-95 MIAMI(AIRPORT XWAY TO GOLDN GLADES)- MAX VEHICLE INPUT

FREEWAY DESIGN PARAMETERS
FREQ3CP PROBLEM (PM PEAK PERIOD - RAMP METERING WITH RMB,MIN OCC =2) 15.

INPUT DATA

19 SUBSECTIONS
2.00 TIME-SLICES PER HOUR
0 USER-SUPPLIED SPEED FLOW CURVES
0 GROWTH PERIODS AT RATE 0.0
WEAVING EFFECTS CONSIDERED

SUB SEC	NO. LNS	SSEC CAP.	SSEC LENGTH	TRK FAC	DESIGN SPEED	ORG DES	LFT RMP	SUBSECTION LOCATION		
1	3	4350.	2390.	0.970	60	O	0	BEGIN SECTION (LOCS. BEGIN SECTS.)	O1	17.
2	6	9300.	1341.	0.970	60	O	2	AIRPORT X-WAY ON	O2	18.
3	5	7650.	3294.	0.970	60		0	LANE DROP		19.
4	4	6000.	900.	0.970	60	D	0	62 ST OFF	D1	20.
5	4	6000.	1863.	0.970	55	O	0	62 ST ON	O3	21.
6	4	6000.	2577.	0.970	55	O	0	69 ST ON	O4	22.
7	4	6000.	2075.	0.970	60	D	0	79 ST OFF	D2	23.
8	4	6000.	3091.	0.970	60	O	0	81 ST ON	O5	24.
9	4	6000.	1644.	0.970	60	D	0	95 ST OFF	D3	25.
10	5	7650.	1054.	0.970	60	O	0	95 ST ON	O6	26.
11	4	6000.	1506.	0.970	60	D	0	103 ST OFF	D4	27.
12	4	6000.	3795.	0.970	60	O	0	103 ST ON	O7	28.
13	4	6000.	1982.	0.970	60	D	0	119 ST OFF	D5	29.
14	4	6000.	1478.	0.970	60	D	0	125 ST OFF	D6	30.
15	4	6000.	1880.	0.970	60	O	0	125 ST ON	O8	31.
16	4	6000.	1890.	0.970	60	D	0	135 ST OFF	D7	32.
17	4	6000.	3434.	0.970	60	O	0	135 ST ON	O9	33.
18	4	6000.	2474.	0.970	60	D	0	151 ST OFF	D8	34.
19	3	4350.	1500.	0.970	60	D	0	END SECTION	D9	35.

* INDICATES USER SUPPLIED SPEED-FLOW CURVE NUMBER

RAMP LIMITS =1500.
ON-RAMP 1 LIMIT=4350.
ON-RAMP 2 LIMIT=4350.

DISTRIBUTION OF PASSENGER OCCUPANCY

	OCC1	OCC2	OCC3	OCC4	OCC5	BUS
O 1	0.675	0.216	0.051	0.029	0.008	0.021
O 2	0.685	0.220	0.052	0.030	0.004	0.004
O 3	0.688	0.221	0.052	0.030	0.009	0.0
O 4	0.688	0.221	0.052	0.030	0.009	0.0
O 5	0.688	0.221	0.052	0.030	0.009	0.0
O 6	0.688	0.221	0.052	0.030	0.009	0.0
O 7	0.688	0.221	0.052	0.030	0.009	0.0
O 8	0.638	0.221	0.052	0.030	0.009	0.0
O 9	0.638	0.221	0.052	0.030	0.009	0.0

BUS OCCUPANCY

O 1	O 2	O 3	O 4	O 5	O 6	O 7	O 8	O 9
40.	40.	0.	0.	0.	0.	0.	0.	0.

*FREEWAY PERFORMANCE SIMULATION-BEFORE CONTROL

TIME SLICE 1 3:30 PM 48.

TIME SLICE 1 OF 6
GROWTH PERIOD 0 OF 0
OCCUPANCY 1.56

SUB SEC	NO. LNS	SSEC LENGTH	O-D DATA DEMANDS ORG.	DES.	DEM.	ADJUSTED VOLUMES ORG.	DES.	VOL.	FRWY CAP.	WEAVE EFF	V/C	DENS. V/M/L	SPEED MPH	TRAVEL TIME	QUEUE-LENGTH	STORAGE RATE
1	3	2390.	1503.	0.	1503.	1503.	0.	1503.	4350.	0.	0.35	10.4	48.1	0.56	0.	0.
2	6	1341.	1505.	0.	3008.	1505.	0.	3008.	9300.	0.	0.32	10.2	49.2	0.31	0.	0.
3	5	3294.	0.	0.	3008.	0.	0.	3008.	7650.	0.	0.39	12.5	48.0	0.78	0.	0.
4	4	900.	0.	77.	3008.	0.	77.	3008.	6000.	0.	0.50	16.4	46.0	0.22	0.	0.
5	4	1863.	265.	0.	3196.	265.	0.	3196.	6000.	0.	0.53	16.1	49.7	0.43	0.	0.
6	4	2577.	153.	0.	3349.	153.	0.	3349.	6000.	0.	0.56	16.9	49.5	0.59	0.	0.
7	4	2075.	0.	147.	3349.	0.	147.	3349.	6000.	0.	0.56	18.7	44.9	0.53	0.	0.
8	4	3091.	406.	0.	3608.	406.	0.	3608.	6000.	0.	0.60	20.5	44.0	0.80	0.	0.
9	4	1644.	0.	141.	3608.	0.	141.	3608.	6000.	0.	0.60	20.5	44.0	0.42	0.	0.
10	5	1054.	167.	0.	3634.	167.	0.	3634.	7650.	0.	0.48	15.6	46.5	0.26	0.	0.
11	4	1506.	0.	203.	3634.	0.	203.	3634.	6000.	0.	0.61	20.7	43.9	0.39	0.	0.
12	4	3795.	142.	0.	3573.	142.	0.	3573.	6000.	0.	0.60	20.3	44.1	0.98	0.	0.
13	4	1982.	0.	248.	3573.	0.	248.	3573.	6000.	0.	0.60	20.3	44.1	0.51	0.	0.
14	4	1478.	0.	254.	3325.	0.	254.	3325.	6000.	0.	0.55	18.5	44.9	0.37	0.	0.
15	4	1880.	168.	0.	3239.	168.	0.	3239.	6000.	0.	0.54	17.9	45.2	0.47	0.	0.
16	4	1890.	0.	445.	3239.	0.	445.	3239.	6000.	0.	0.54	17.9	45.2	0.47	0.	0.
17	4	3434.	184.	0.	2978.	184.	0.	2978.	6000.	0.	0.50	16.2	46.1	0.85	0.	0.
18	4	2474.	0.	118.	2978.	0.	118.	2978.	6000.	0.	0.50	16.2	46.1	0.61	0.	0.
19	3	1500.	0.	2860.	2860.	0.	2860.	2860.	4350.	0.	0.66	22.7	42.1	0.41	0.	0.
	TOTAL	40168.											TOTAL	9.96		

Figure 142. FREQ3CP Simulation Result for I-95 Existing Conditions.

TIME SLICE 3 4:30 PM

TIME SLICE 3 OF 6
GROWTH PERIOD 0 OF 0
OCCUPANCY 1.56
QUEUE COLL. SECTION 6 T2= 0.079
QUEUE COLL. SECTION 5 T2= 0.081
QUEUE OUT OF SECTION 1

SUB SEC	NO. LNS	SSEC LENGTH	O-D DATA DEMANDS ORG.	DES.	DEM.	ADJUSTED VOLUMES ORG.	DES.	VOL.	FRWY CAP.	WEAVE EFF	V/C	DENS. V/M/L	SPEED MPH	TRAVEL TIME	QUEUE-LENGTH	STORAGE RATE
1	3	2390.	2834.	0.	2834.	2023.	0.	2023.	4350.	0.	0.47	22.8	29.6 **	0.92	2390.	811.
2	6	1341.	2838.	0.	5672.	2838.	0.	4861.	9210.	90.	0.53	39.0	20.8 **	0.73	1341.	811.
3	5	3294.	0.	0.	5672.	0.	0.	4861.	7560.	90.	0.64	53.2	18.3 **	2.05	3294.	811.
4	4	900.	0.	143.	5672.	0.	143.	4861.	5910.	90.	0.82	55.7	21.8 **	0.47	900.	811.
5	4	1863.	494.	0.	6023.	494.	0.	5212.	6000.	0.	0.87	55.7	23.4 **	0.91	1863.	788.
6	4	2577.	284.	0.	6307.	284.	0.	5496.	6000.	0.	0.92	55.0	25.0 **	1.17	2577.	504.
7	4	2075.	0.	272.	6307.	0.	258.	5496.	6000.	0.	0.92	56.8	24.2 **	0.97	2075.	504.
8	4	3091.	762.	0.	6797.	762.	0.	5923.	6000.	0.	0.99	50.2	29.5 *	1.19	315.	77.
9	4	1644.	0.	267.	6797.	0.	233.	5923.	6000.	0.	0.99	50.5	29.3 **	0.64	1644.	77.
10	5	1054.	310.	0.	6840.	310.	0.	6000.	7650.	0.	0.78	49.4	24.3 **	0.49	1054.	77.
11	4	1506.	0.	383.	6840.	0.	332.	6000.	6000.	0.	1.00	50.8	29.5	0.58	0.	0.
12	4	3795.	264.	0.	6721.	264.	0.	5932.	6000.	0.	0.99	48.2	30.8	1.40	0.	0.
13	4	1952.	0.	464.	6721.	0.	404.	5435.	6000.	0.	0.91	44.4	30.6 *	0.74	1493.	497.
14	4	1478.	0.	471.	6257.	0.	413.	5032.	6000.	0.	0.84	37.0	34.0 **	0.49	1478.	497.
15	4	1880.	316.	0.	6102.	316.	0.	4935.	6000.	0.	0.82	38.9	31.7 **	0.67	1880.	497.
16	4	1890.	0.	834.	6102.	0.	736.	4935.	6000.	0.	0.82	42.7	28.9 **	0.74	1890.	497.
17	4	3434.	345.	0.	5613.	345.	0.	4543.	6000.	0.	0.76	49.6	22.9 **	1.70	3434.	497.
18	4	2474.	0.	216.	5613.	0.	193.	4543.	6000.	0.	0.76	60.2	18.9 **	1.49	2474.	497.
19	3	1500.	0.	5397.	5397.	0.	4350.	4350.	4350.	0.	1.00	49.2	29.5	0.58	0.	0.
TOTAL		40168.											TOTAL	17.94		

		QUEUE LENGTH VEHICLES	DELAY VEH-HRS
ON-RAMP 1	INPUT POINT	13.17	0.11
	MERGING POINT	0.0	0.0
	TOTAL	13.17	0.11

	CURRENT TIME INTERVAL		CUMULATIVE VALUES	
FREEWAY TRAVEL TIME=	901. VEH-HRS=	1405. PASS-HRS	2169. VEH-HRS=	3391. PASS-HRS
INPUT DELAY=	0. VEH-HRS=	0. PASS-HRS	0. VEH-HRS=	0. PASS-HRS
OUTPUT DELAY=	0. VEH-HRS=	0. PASS-HRS	0. VEH-HRS=	0. PASS-HRS
TOTAL TRAVEL TIME=	901. VEH-HRS=	1405. PASS-HRS	2169. VEH-HRS=	3391. PASS-HRS
TOTAL TRAV DISTANCE=	23600. VEH-MI.=	36816. PASS-MI.	79170. VEH-MI.=	123818. PASS-MI.

TIME SLICE 6 6:00 PM

173.

TIME SLICE 6 OF 6
GROWTH PERIOD 0 OF 0
OCCUPANCY 1.57

SUB SEC	NO. LNS	SSEC LENGTH	O-D DATA DEMANDS ORG.	DES.	DEM.	ADJUSTED VOLUMES ORG.	DES.	VOL.	FRWY CAP.	WEAVE EFF	V/C	DENS. V/M/L	SPEED MPH	TRAVEL TIME	QUEUE-LENGTH	STORAGE RATE
1	3	2390.	1333.	0.	1333.	1333.	0.	1333.	4350.	0.	0.31	9.1	48.8	0.56	0.	0.
2	6	1341.	1332.	0.	2665.	1332.	0.	2665.	9300.	0.	0.29	8.9	49.8	0.31	0.	0.
3	5	3294.	0.	0.	2665.	0.	0.	2665.	7650.	0.	0.35	10.9	48.8	0.77	0.	0.
4	4	900.	0.	68.	2665.	0.	68.	2665.	6000.	0.	0.44	14.2	47.1	0.22	0.	0.
5	4	1863.	233.	0.	2830.	233.	0.	2830.	6000.	0.	0.47	14.1	50.2	0.42	0.	0.
6	4	2577.	137.	0.	2967.	137.	0.	2967.	6000.	0.	0.49	14.8	50.0	0.59	0.	0.
7	4	2075.	0.	130.	2967.	0.	130.	2967.	6000.	0.	0.49	16.1	46.1	0.51	0.	0.
8	4	3091.	360.	0.	3197.	360.	0.	3197.	6000.	0.	0.53	17.6	45.4	0.77	0.	0.
9	4	1644.	0.	126.	3197.	0.	126.	3197.	6000.	0.	0.53	17.6	45.4	0.41	0.	0.
10	5	1054.	147.	0.	3218.	147.	0.	3218.	7650.	0.	0.42	13.5	47.5	0.25	0.	0.
11	4	1506.	0.	181.	3218.	0.	181.	3218.	6000.	0.	0.54	17.8	45.3	0.38	0.	0.
12	4	3795.	125.	0.	3162.	125.	0.	3162.	6000.	0.	0.53	17.4	45.5	0.95	0.	0.
13	4	1982.	0.	220.	3162.	0.	220.	3162.	6000.	0.	0.53	17.4	45.5	0.50	0.	0.
14	4	1478.	0.	224.	2942.	0.	224.	2942.	6000.	0.	0.49	15.9	46.2	0.36	0.	0.
15	4	1880.	149.	0.	2867.	149.	0.	2867.	6000.	0.	0.48	15.4	46.4	0.46	0.	0.
16	4	1390.	0.	393.	2867.	0.	393.	2867.	6000.	0.	0.48	15.4	46.4	0.46	0.	0.
17	4	3434.	162.	0.	2636.	162.	0.	2636.	6000.	0.	0.44	14.0	47.2	0.83	0.	0.
18	4	2474.	0.	103.	2636.	0.	103.	2636.	6000.	0.	0.44	14.0	47.2	0.60	0.	0.
19	3	1500.	0.	2533.	2533.	0.	2533.	2533.	4350.	0.	0.58	19.4	43.6	0.39	0.	0.
TOTAL		40168.											TOTAL	9.72		

	CURRENT TIME INTERVAL		CUMULATIVE VALUES	
FREEWAY TRAVEL TIME=	458. VEH-HRS=	719. PASS-HRS	4052. VEH-HRS=	6347. PASS-HRS
INPUT DELAY=	0. VEH-HRS=	0. PASS-HRS	0. VEH-HRS=	0. PASS-HRS
OUTPUT DELAY=	0. VEH-HRS=	0. PASS-HRS	0. VEH-HRS=	0. PASS-HRS
TOTAL TRAVEL TIME=	458. VEH-HRS=	719. PASS-HRS	4052. VEH-HRS=	6348. PASS-HRS
TOTAL TRAV DISTANCE=	21436. VEH-MI.=	33655. PASS-MI.	145010. VEH-MI.=	227188. PASS-MI.

END OF SIMULATION FOR ABOVE CRITERION

Figure 142. FREQ3CP Simulation Result for I-95 Existing Conditions (Continued).

*TIME SLICE 3 OF 6
THE STRATEGY IS SUCH THAT THE V/C DOES NOT EXCEED 0.99 WITH 0.90 PROBABILITY
TAKING INTO CONSIDERATION THE FLUCTUATION OF THE MAINLINE INPUT
THE MAINLINE INPUT IS ASSUMED TO BE NORMALLY DISTRIBUTED WITH VARIANCE= 1.00 *MEAN **************
2 OD TABLES USED TO DETERMINE PASSENGER OCCUPANCY

COMBINED ORIGIN-DESTINATION TABLE--ALL VEHICLES

ORIGIN-DESTINATION TABLE(VEHICLES PER HOUR)

ORIGIN DOWN / DESTINATION ACROSS	1	2	3	4	5	6	7	8	9
0									
1	71.	132.	141.	171.	172.	181.	315.	72.	1647.
2	74.	127.	104.	142.	208.	168.	265.	67.	1683.
3	0.	14.	7.	26.	23.	33.	77.	13.	301.
4	0.	2.	10.	23.	20.	20.	20.	4.	185.
5	0.	0.	8.	23.	27.	30.	82.	20.	572.
6	0.	0.	0.	2.	5.	23.	36.	14.	230.
7	0.	0.	0.	0.	13.	20.	29.	13.	189.
8	0.	0.	0.	0.	0.	0.	17.	7.	292.
9	0.	0.	0.	0.	0.	0.	0.	8.	337.
SUM(DEST)	145.	275.	270.	387.	468.	475.	841.	218.	5436.
SUM(ORIG)	2902.	2838.	494.	284.	762.	310.	264.	316.	345.

METERING LIMITS

	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9
MAXIMUM	MAIN	5000.	1200.	1200.	1500.	1200.	1200.	1200.	1200.
MINIMUM	LINE	900.	180.	180.	240.	180.	180.	180.	180.

CAPACITIES TAKE 1. ITERATIONS TO CONVERGE

CONTROL STRATEGY ON VEHICLE BASIS

ON-RAMP NO.	ORIGINAL DEMAND (VEH)	(PASS)	PRIORITY CUT-OFF LEVEL	FREEWAY INPUT RATE (VEH)	(PASS)	NON-PRIORITY METERING RATE	PRESET CONTROL STRATEGY
1	2902.	4527.	0	2902.	4527.	0.	NO METERING
2	2838.	4427.	0*	1531.	2338.	0.	PRIORITY CUT-OFF LIMIT
3	494.	771.	0	494.	771.	0.	PRIORITY CUT-OFF LIMIT
4	284.	443.	0	284.	443.	0.	PRIORITY CUT-OFF LIMIT
5	762.	1189.	0*	240.	374.	0.	PRIORITY CUT-OFF LIMIT
6	310.	484.	0	310.	484.	0	PRIORITY CUT-OFF LIMIT
7	264.	412.	0	264.	412.	0.	PRIORITY CUT-OFF LIMIT
8	316.	493.	0*	180.	281.	0.	PRIORITY CUT-OFF LIMIT
9	345.	538.	0*	180.	281.	0.	PRIORITY CUT-OFF LIMIT
TOTAL	8515.	13284.		6385.	9960.		

	CURRENT TIME INTERVAL		CUMULATIVE VALUES	
TOTAL TRAVEL DISTANCE	35364. VEH-MILES	55167. PASS-MILES	91613. VEH-MILES	143233. PASS-MILES
TOTAL DEMAND	8515. VEHICLES	13284. PASSENGERS	18934. VEHICLES	29596. PASSENGERS
TOTAL INPUT VOLUME	6385. VEHICLES	9960. PASSENGERS	16304. VEHICLES	26273. PASSENGERS
TOTAL DIVERTED DEMAND	2130. VEHICLES		2130. VEHICLES	
TOTAL DEMAND TRANSFERED TO THE NEXT TIME SLICE	0. VEHICLES		0. VEHICLES	

DEMAND(VEH/T.S.) DIVERTED TO ARTERIAL STREETS

DISTRIBUTION PATTERN

ON-RAMP NO.	DIVERTED DEMAND (VEH/T.S.)	DESTINATION NO. 1	2	3	4	5	6	7	8	9
1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	1307.	50.	86.	70.	96.	140.	113.	179.	45.	528.
3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
5	522.	0.	0.	8.	23.	27.	30.	82.	20.	332.
6	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
7	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
8	136.	0.	0.	0.	0.	0.	0.	17.	7.	112.
9	165.	0.	0.	0.	0.	0.	0.	0.	8.	157.
SUM(DEST)	2130.	50.	86.	78.	119.	167.	143.	278.	80.	1129.

DEMAND(VEH/T.S.) TRANSFERED TO THE NEXT TIME SLICE

DISTRIBUTION PATTERN

ON-RAMP NO.	TRANSFERED DEMAND (VEH/T.S.)	DESTINATION NO. 1	2	3	4	5	6	7	8	9
1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
6	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
7	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
8	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
9	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
SUM(DEST)	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

Figure 143. FREQ3CP Simulation Result for Optimal Priority Control (max. veh. input) Under Existing Condition.

TIME SLICE 3 4:30 PM

TIME SLICE 3 OF 6
GROWTH PERIOD 0 OF 0
OCCUPANCY 1.56

SUB SEC	NO. LNS	SSEC LENGTH	O-D DATA DEMANDS ORG.	DES.	DEM.	ADJUSTED VOLUMES ORG.	DES.	VOL.	FRWY CAP.	WEAVE EFF	V/C	DENS. V/M/L	SPEED MPH	TRAVEL TIME	QUEUE-LENGTH	STORAGE RATE
1	3	2390.	2902.	0.	2902.	2902.	0.	2902.	4350.	0.	0.67	23.1	41.9	0.65	0.	0.
2	6	1341.	1531.	0.	4433.	1531.	0.	4433.	9300.	0.	0.48	15.9	46.5	0.33	0.	0.
3	5	3294.	0.	0.	4433.	0.	0.	4433.	7650.	0.	0.58	20.0	44.4	0.34	0.	0.
4	4	900.	0.	95.	4433.	0.	95.	4433.	6000.	0.	0.74	27.0	41.0	0.25	0.	0.
5	4	1863.	494.	0.	4832.	494.	0.	4832.	6000.	0.	0.81	25.6	47.3	0.45	0.	0.
6	4	2577.	284.	0.	5116.	284.	0.	5116.	6000.	0.	0.85	27.3	46.9	0.63	0.	0.
7	4	2075.	0.	189.	5116.	0.	189.	5116.	6000.	0.	0.85	33.5	38.2	0.62	0.	0.
8	4	3091.	240.	0.	5167.	240.	0.	5167.	6000.	0.	0.86	33.9	38.1	0.92	0.	0.
9	4	1644.	0.	192.	5167.	0.	192.	5167.	6000.	0.	0.86	33.9	38.1	0.49	0.	0.
10	5	1054.	310.	0.	5285.	310.	0.	5285.	7650.	0.	0.69	25.1	42.0	0.28	0.	0.
11	4	1506.	0.	268.	5285.	0.	268.	5285.	6000.	0.	0.88	35.0	37.7	0.45	0.	0.
12	4	3795.	264.	0.	5280.	264.	0.	5280.	6000.	0.	0.88	35.0	37.7	1.14	0.	0.
13	4	1982.	0.	301.	5280.	0.	301.	5280.	6000.	0.	0.88	35.0	37.7	0.60	0.	0.
14	4	1478.	0.	332.	4980.	0.	332.	4980.	6000.	0.	0.83	32.5	38.3	0.44	0.	0.
15	4	1880.	180.	0.	4828.	180.	0.	4828.	6000.	0.	0.80	30.6	39.4	0.54	0.	0.
16	4	1890.	0.	564.	4828.	0.	564.	4828.	6000.	0.	0.80	30.6	39.4	0.54	0.	0.
17	4	3434.	180.	0.	4444.	180.	0.	4444.	6000.	0.	0.74	27.1	40.9	0.95	0.	0.
18	4	2474.	0.	137.	4444.	0.	137.	4444.	6000.	0.	0.74	27.1	40.9	0.69	0.	0.
19	3	1500.	0.	4307.	4306.	0.	4307.	4306.	4350.	0.	0.99	46.8	30.7	0.56	0.	0.
	TOTAL	40168.											TOTAL	11.37		

	CURRENT TIME INTERVAL		CUMULATIVE VALUES	
FREEWAY TRAVEL TIME=	903. VEH-HRS=	1409. PASS-HRS	2191. VEH-HRS=	3425. PASS-HRS
INPUT DELAY=	0. VEH-HRS=	0. PASS-HRS	0. VEH-HRS=	0. PASS-HRS
OUTPUT DELAY=	0. VEH-HRS=	0. PASS-HRS	0. VEH-HRS=	0. PASS-HRS
TOTAL TRAVEL TIME=	903. VEH-HRS=	1409. PASS-HRS	2191. VEH-HRS=	3425. PASS-HRS
TOTAL TRAV DISTANCE=	36183. VEH-MI.=	56445. PASS-MI.	92432. VEH-MI.=	144511. PASS-MI.

TIME SLICE 6 6:00 PM

TIME SLICE 6 OF 6
GROWTH PERIOD 0 OF 0
OCCUPANCY 1.57

SUB SEC	NO. LNS	SSEC LENGTH	O-D DATA DEMANDS ORG.	DES.	DEM.	ADJUSTED VOLUMES ORG.	DES.	VOL.	FRWY CAP.	WEAVE EFF	V/C	DENS. V/M/L	SPEED MPH	TRAVEL TIME	QUEUE-LENGTH	STORAGE RATE
1	3	2390.	1380.	0.	1380.	1380.	0.	1380.	4350.	0.	0.32	9.5	48.6	0.56	0.	0.
2	6	1341.	1332.	0.	2712.	1332.	0.	2712.	9300.	0.	0.29	9.1	49.8	0.31	0.	0.
3	5	3294.	0.	0.	2712.	0.	0.	2712.	7650.	0.	0.35	11.1	48.7	0.77	0.	0.
4	4	900.	0.	69.	2712.	0.	69.	2712.	6000.	0.	0.45	14.4	46.9	0.22	0.	0.
5	4	1863.	233.	0.	2876.	233.	0.	2876.	6000.	0.	0.48	14.3	50.2	0.42	0.	0.
6	4	2577.	137.	0.	3013.	137.	0.	3013.	6000.	0.	0.50	15.1	50.0	0.59	0.	0.
7	4	2075.	0.	132.	3013.	0.	132.	3013.	6000.	0.	0.50	16.4	46.0	0.51	0.	0.
8	4	3091.	360.	0.	3240.	360.	0.	3240.	6000.	0.	0.54	17.9	45.2	0.78	0.	0.
9	4	1644.	0.	128.	3240.	0.	128.	3240.	6000.	0.	0.54	17.9	45.2	0.41	0.	0.
10	5	1054.	147.	0.	3259.	147.	0.	3259.	7650.	0.	0.43	13.7	47.4	0.25	0.	0.
11	4	1506.	0.	184.	3259.	0.	184.	3259.	6000.	0.	0.54	18.0	45.2	0.38	0.	0.
12	4	3795.	125.	0.	3200.	125.	0.	3200.	6000.	0.	0.53	17.6	45.4	0.95	0.	0.
13	4	1982.	0.	223.	3200.	0.	223.	3200.	6000.	0.	0.53	17.6	45.4	0.50	0.	0.
14	4	1478.	0.	227.	2978.	0.	227.	2978.	6000.	0.	0.50	16.2	46.1	0.36	0.	0.
15	4	1880.	149.	0.	2900.	149.	0.	2900.	6000.	0.	0.48	15.6	46.3	0.46	0.	0.
16	4	1890.	0.	398.	2900.	0.	393.	2900.	6000.	0.	0.48	15.6	46.3	0.46	0.	0.
17	4	3434.	162.	0.	2664.	162.	0.	2664.	6000.	0.	0.44	14.1	47.1	0.83	0.	0.
18	4	2474.	0.	104.	2664.	0.	104.	2664.	6000.	0.	0.44	14.1	47.1	0.60	0.	0.
19	3	1500.	0.	2560.	2560.	0.	2560.	2560.	4350.	0.	0.59	19.6	43.5	0.39	0.	0.
	TOTAL	40168.											TOTAL	9.75		

	CURRENT TIME INTERVAL		CUMULATIVE VALUES	
FREEWAY TRAVEL TIME=	465. VEH-HRS=	730. PASS-HRS	3869. VEH-HRS=	6060. PASS-HRS
INPUT DELAY=	0. VEH-HRS=	0. PASS-HRS	0. VEH-HRS=	0. PASS-HRS
OUTPUT DELAY=	0. VEH-HRS=	0. PASS-HRS	0. VEH-HRS=	0. PASS-HRS
TOTAL TRAVEL TIME=	465. VEH-HRS=	730. PASS-HRS	3869. VEH-HRS=	6060. PASS-HRS
TOTAL TRAV DISTANCE=	21736. VEH-MI.=	34125. PASS-MI.	168024. VEH-MI.=	263191. PASS-MI.

END OF SIMULATION FOR ABOVE CRITERION

Figure 143. FREQ3CP Simulation Result for Optimal Priority Control (max. veh. input) Under Existing Condition (Continued).

Table 34 - Comparison of FREQ3CP Results For Alternative Ramp Control Strategies on I-95.

	EXISTING LANES		ADDITIONAL LANES	
Measures of Effectiveness	Exist. Operations	With Ramp Controls	Typical Operations	With Ramp Controls
Freeway Travel Time-Veh/Hrs.	4,839	3,876	4,052	3,869
Pass/Hrs.	7,583	6,072	6,347	6,060
Input Delay-Veh/Hrs.	48	-0-	-0-	-0-
Pass/Hrs.	75	-0-	-0-	-0-
Output Delay-Veh/Hrs.	-0-	-0-	-0-	-0-
Pass/Hrs.	-0-	-0-	-0-	-0-
Total Travel/Time-Veh/Hrs.	4,887	3,876	4,052	3,869
Pass/Hrs.	7,658	6,072	6,348	6,060
Total Travel Distance-Veh/Mile	133,205	164,671	145,010	168,624
Pass/Mile	208,629	257,959	227,180	253,191
Diverted Vehicles	-0-	2,770	---	2,130
Passenger	-0-	4,321	---	3,323

ing to control vehicle entry, a total of 2720 vehicles and 4321 passengers were diverted to the adjacent arterial street system. As a result of this diversion vehicle and passenger-hours of travel were significantly reduced (21%).

With the additional through lane a significant increase in the vehicle miles of travel occurred on existing conditions (from 133,205 to 164,671 or 23.6%). With ramp metering to control vehicle entry, further improvement is obtained (from 164,671 to 168,624 or 16.3%). However, implementation of ramp controls for the existing condition results in significantly improved operation compared with adding lanes providing no controls. Since the cost of ramp metering is significantly less than the addition of a freeway lane, this alternative should be investigated further. This additional study would have to look at the affect of diverted vehicles on the adjacent street system.

Summary of Work Effort Required

The following summarizes the effort required to use the FREQ3CP model to evaluate ramp control strategies.

Data Collection - The data collection effort is substantiated and is similar to that described for PRIFRE. Unlike PRIFRE, which used average vehicle occupancy, it is possible to have different rates for each on-ramp. However, the same rate was applied for each ramp in this problem.

Data Coding - Since the data had been previously coded for PRIFRE most of the information could be easily coded. Initial data coding required approximately four hours for the first case. However, approximately eight hours were required to review and correct errors in the data.

Computer Time - Execution time for the FREQ3CP model required between 6.1 and 6.2 seconds of CPU time to run each condition. A total of 168k of core storage was required.

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CHAPTER 14 - FUTURE DEVELOPMENTS

The application of computer modeling to solve problems in traffic operations has proven to be a useful, and in many cases, necessary means of optimizing and evaluating traffic control strategies. This is a field that is constantly evolving. The models described in the Handbook are updated frequently to incorporate new strategies, simplify input data requirements, reduce computer running time, etc. The user must attempt to stay abreast of these new developments to maximize the effectiveness of computer modeling efforts.

Figure 144. Computer Models Can Be Useful

EMERGING MODEL DEVELOPMENTS

The development of the theories that support the computer models used by traffic engineers has slowed somewhat in recent years. The current emphasis is in the application of existing theories and on the refinement of the computation logic and data management aspects of the models. The following sections briefly describe some of the more significant models which are in various stages of development.

TRAFLO: A Macroscopic Simulation for Urban Traffic Management

The objective of the TRAFLO model (Ref. 14.1) is to provide an efficient tool which can be used to test and evaluate traffic management strategies that are applied over a large area. This model is being developed in response to the need for the philosophy of "Transportation System Management" as a replacement for the narrower concept of "traffic control". The model will be designed to satisfy the following requirements:

1. The model must provide values of all relevent measures of effectiveness (MOE) which describe traffic operations on urban streets and freeways. The scope, accuracy and level of detail of these MOE must be adequate for the purpose of evaluating traffic management strategies;

2. The model must exhibit the flexibility necessary to accommodate the widest possible range of such strategies, including those which affect route and model choice;

3. The model must be able to represent a region of approximately 2,000 intersections, whose traffic environment includes networks of freeways, arterials, and grid networks of surface streets;

4. The model must be designed to satisfy these requirements with a reasonable demand on computer resources. It should be operational on virtually any general purpose computer;

5. The program must be easy to use, requiring as little information as possible so as to minimize the cost, effort and level of expertise needed for its implementation.

6. The computer program of the model must be easy to understand, to maintain, to update, and to extend in scope.

The simulation is macroscopic in nature with three separate levels of detail:

1. Level 1 is the most detailed level of traffic representation. It is designed to explicitly treat traffic control devices, include all channelization options, and describe the traffic operations at grade intersections in considerable detail. Careful distinction is made between general traffic operations reflecting the flow of private automobiles, and mass transit vehicles servicing passengers at bus stations located along fixed routes. In addition, trucks and car-pool vehicles are explicitly considered. Other features include actuated signal control logic, right-turn-on-red, pedestrian interference, and source/sink flow. A wide range of MOE is provided as output.

2. Level 2, which will be computationally faster than Level 1, is less detailed and includes fewer features. Nevertheless, the traffic flow patterns are carefully described in the form of statistical histograms. These histograms express flow rate as a function of time on each network link, stratified by turning movement; buses are treated in somewhat more detail. Platoon dispersion is treated explicitly and service rates at the intersection are related to turn movement and to the signal control. This level provides the same output MOE as does Level 1.

3. Level 3, which will be the fastest computationally, is the least detailed and is applicable only to arterials. The platoon structure of traffic is not represented; traffic flow and signal control are described in terms of aggregate variables. However, traffic is stratified by turn movement to reflect the differing service rates associated with each. Bus traffic is treated explicitly, as is signal coordination and the time-dependent behavior of traffic. Congested conditions are accommodated and spillback is considered. While the detailed behavior of traffic at intersections is not explicitly represented, the associated impedances are modeled.

The structure of the TRAFLO model is shown in Figure 145.

A separate model treats freeway operations which can be partitioned into a number of subsystems to save computer costs.

TRAFLO also incorporates a traffic assignment model to extend the functions of the package to include transportation planning in addition to traffic engineering. An existing assignment model named TRAFFIC (Ref. 14.2) is interfaced internally to the traffic simulation model to facilitate the use of the program.

TRAF: A System of Simulation Models

The following describes this model system and its status as presented at a recent conference on Application of Traffic Simulation Models by Guido Redelat (Ref. 14.3).

"To address the problem of improving human efficiency in connection with traffic simulation, the Office of Research of FHWA is developing a system of traffic simulation models named TRAF (Ref. 14.4). This system is designed to represent traffic flow on any existing highway facility.

"Since TRAF will be a single source of traffic simulation programs, the user need be concerned with only one set of documentation

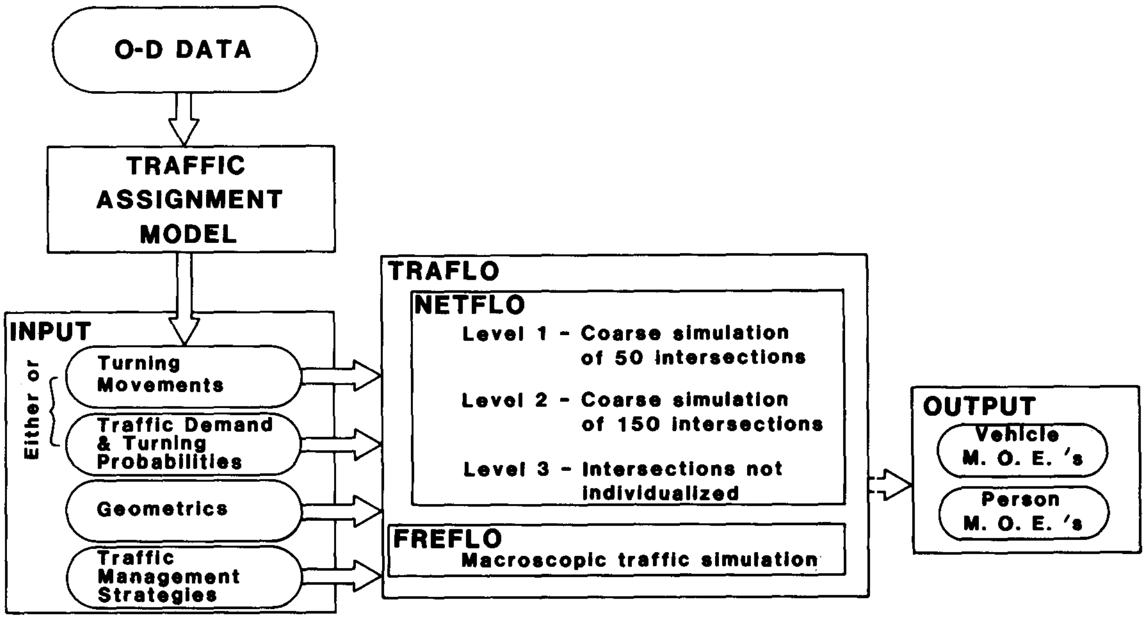

Figure 145. Structure of the TRAFLO Model

and one set of input and output format. This standardization will put an end to the confusion caused by the diversity of simulation approaches and format. It will also reduce considerably the overall learning effort in connection with the application of traffic simulation.

"In the development of TRAF, special consideration is given to the task of producing the best possible program documentation. Instead of the detailed flow charts that were previously used to document many simulation models, TRAF uses a modified system of hierarchy plus input-process-output (HIPO) charts, which are more effective in depicting the logical structure of the programs. Numerous comments are included in the code and each variable of the program is defined in every subroutine where it appears.

"The code itself is carefully planned for minimum branching, and it is completely modular (subroutines are short and perform only one function). A standard code format has been established that makes the programs easy to read and presents the logic as clearly as possible.

"Also, an integrated traffic simulating system will facilitate the maintenance and support activities for two reasons: (a) with only one simulation system to maintain and support, these operations can be centralized; and (b) these activities can be automated to a large extent by using a specialized "operating system."

"The creation of TRAF does not involve new model development, but the enhancement of what is regarded as the best traffic simulation logic available. This logic is in the form of modularized subroutines that are being stored in a master file. A program tailored to a particular application can be generated by an operating system that selects

	Microscopic	Macroscopic
URBAN NETWORKS	NETSIM	NETFLO
FREEWAYS	FRESIM	FREFLO
TWO-LANE ROADS	ROADSIM	-

Figure 146. Components of Models That Are Being Integrated Into TRAF

the needed subroutines, adjusts their dimensions, and integrates them. This flexibility will minimize the waste of computer resources because the programs contain only the user's selected features and dimensions required by the desired applications.

"The models that are being integrated into TRAF are shown in Figure 146. The names of these component models consist of a prefix and a suffix. The prefixes NET, FRE, and ROAD indicate urban networks, freeways, and two-lane, two-way rural roads, respectively. The suffix SIM means microscopic and FLO macroscopic.

"NETSIM, the microscopic model for urban networks, was created 10 years ago and has been almost continuously enhanced since then (Ref. 14.5). Recently it has been reprogrammed to conform to TRAF programming standards and further enhanced.

"The macroscopic models for urban networks and freeways, NETFLO and FREFLO, form a subsystem called TRAFLO; that is, the macroscopic portion of TRAF. NETFLO was developed according to TRAF programming standards, and FREFLO is essentially the existing MACK freeway model, reprogrammed and adapted to the TRAF environment. NETFLO is beginning its implementation phase, while FREFLO is going through enhancement and testing.

FRESIM, the microscopic freeway model, will be primarily the freeway portion of INTRAS (Ref. 14.6), a microscopic freeway corridor model that has been tested and implemented. FRESIM will be enhanced and reprogrammed before becoming part of TRAF.

"Finally, ROADSIM, the microscopic two-lane, two-way rural road model is basically the TWOWAF model developed by the National Cooperative Highway Research Program (Ref. 14.7). It is being reprogrammed and integrated into the TRAF system.

"The TRAF operating system is shown in Figure 147. It is a computer program consisting of the following major components:

1. A master file where the modularized subroutines of the component models are stored;
2. A file maintenance program that automatically modifies the content of the master file;
3. A program generator that reads the features specified by the user, selects the subroutines that simulate these features, and forms an application program that satisfies user's specification; and
4. A report generator that produces various informative computer printouts.

"At present, there are no plans at FHWA for developing new traffic simulation models. A survey of the computer technology and prediction of computer developments in the near future is considered necessary before the needs for new models can be determined and plans for their development formulated.

"Emphasis is now given to testing and implementing the models of the TRAF family; first as stand-alone program and then as a system. The implementation of the TRAF

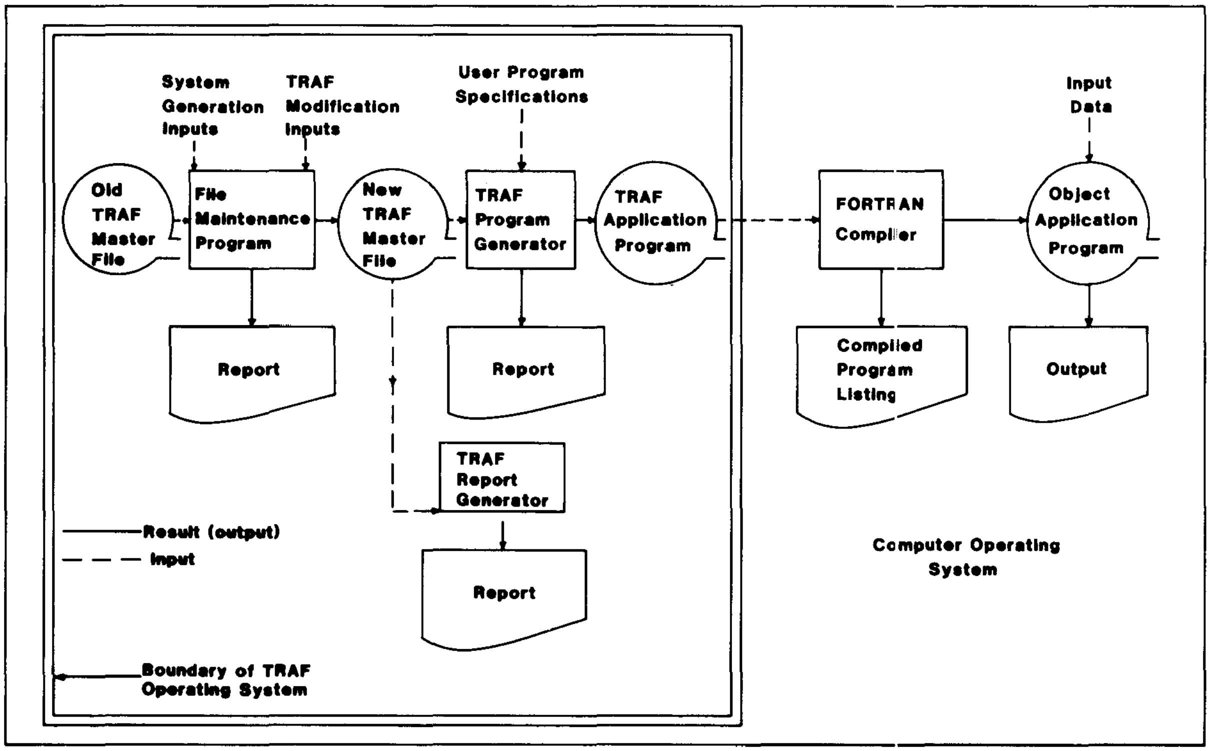

Figure 147. Functional Operation of the TRAF Model

system will be done gradually, starting with traffic simulation on urban networks and the macroscopic simulation of traffic on freeways. The next step will be implementing traffic simulation on the above facilities plus two-lane, two- way rural roads. Finally, the entire TRAF system will be implemented-- including the macroscopic freeway simulation.

"The integration of the various component models into the TRAF system is essentially an enhancement operation; no new model is being created. But in addition to the integration process, each of the component models is being reprogrammed, which is an enhancement, and its conceptual design is being improved. The NETSIM logic, for example, has not only been refined but it has also been substantially extended to simulate more complex traffic situations."

ITDS: Integrated Traffic Data System

The Integrated Traffic Data System (ITDS) is a "stand-alone" microcomputer system composed of hardware and software elements which jointly perform the following functions:

1. Provide for a centralized microcomputer data base to store traffic data in a predetermined format and organization; and,

2. Utilizes this data base to generate input data sets for various traffic simulation models and signal timing optimization programs.

The software elements of ITDS shall consist of the following:

1. Data Base (DB) - file required to store data in memory or on any mass storage device (tape, disk, etc.).

2. Data Base Management System (DBMS) - software required to provide the system with necessary "intelligence" to identify, store, retrieve, modify, and process the data stored in the DB.

3. Interface Programs - software required to perform the following functions:

   a. Preprocessor - reformats the data retrieved from the DB into a format compatible with the input requirements of each traffic model and generates the required input data sets to run any of the models (simulation and optimization).

   b. Post-processor - stores and reformats the portions of the optimization programs output that report the results of the calculations of signal timing and phasing, and saturation flows. As envisioned, the specified portions of the optimization programs' output will be stored in a designated file for future use as input to other models. It will be up to the user to decide whether these output portions will be permanently saved and stored in the DB.

4. Communications Interface - software required to transmit the generated input data sets to, and retrieve the output from, a host computer where the models will run.

ITDS shall have the capability of being connected to a main frame computer. This requirement is based on the fact that current traffic models were designed to run in main frame computers. Conceptually, ITDS will be used to generate input data sets, transmit them to a host computer for processing, and retrieve and reformat (in the case of optimization programs exclusively) the results. A diagram of the ITDS concept is presented in Figure 148.

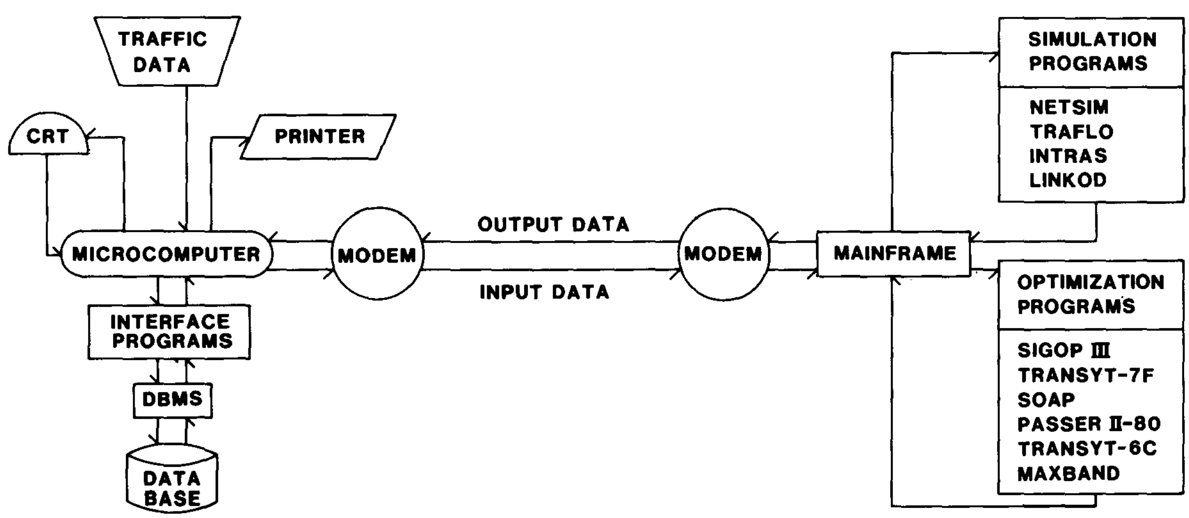

Figure 148. Integrated Traffic Data System Concept

The process of generating the input data sets will be "menu" driven where the user will answer questions or fill in blanks interactively and on-line assistance to the user will be provided. The system will alert the user of any data elements that are required as input to any model and not stored in the data base.

ITDS will operate on 8-bit microcomputers utilizing single and multiple user operating systems. One important feature of the system is that control of changes in the data elements stored in the data base will be provided. In other words, only designated users, by means of some special access code, could modify, store, and/or delete data elements from the data base. This is highly desirable and provides adequate management of the system, especially when several people use the system simultaneously or in parallel.

University of California Models

Two of the models described in this Handbook are freeway operations models developed by The Institute for Transportation Studies (ITS), University of California at Berkeley. Dr. Adolph D. May and his associates have been extremely active in the field of traffic operations simulation and optimization modeling. The PRIFRE and FREQ3CP models are two of the most widely used freeway operations models in the areas of priority lanes for high occupancy vehicles and entrance ramp control (ramp metering), respectively.

The ITS has also modified the TRANSYT 6 model (Ref. 14.8) to include estimates of fuel consumption and vehicle exhaust emissions as well as demand responses in terms of spatial and modal shifts. This version is TRANSYT 6C (Ref. 14.9) which is available from ITS.

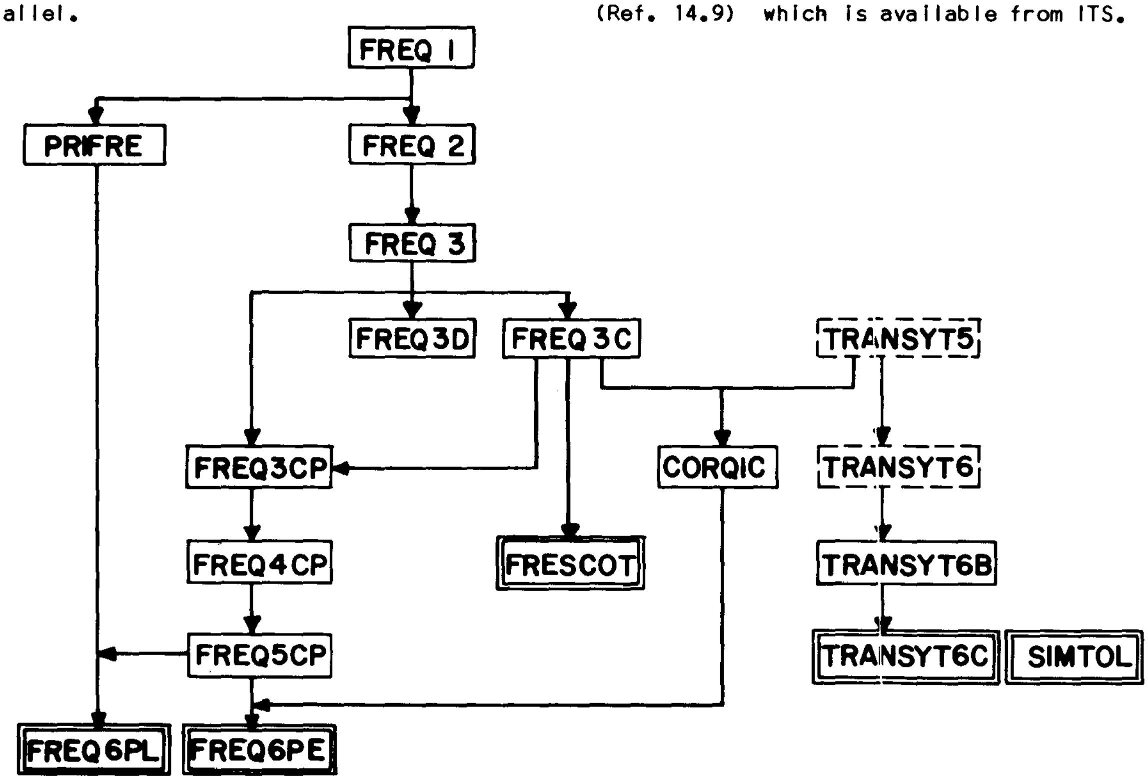

Figure 149. A System of Traffic Operations Optimization and Evaluation Models

The complete family of traffic operations models developed by the ITS is shown in Figure 149. The most current models in the freeway series are FREQ6PL (Ref. 14.10) and FREQ6PE (Ref. 14.11) which have advanced PRIFRE and FREQ3CP, respectively, to include more extensive fuel and emissions estimates and demand responses. Of particular importance are the more detailed analyses of effects on alternative arterial routes.

At the present time, the ITS is not further pursuing the arterial network area, but they are actively developing further enchancements to the freeway models, particularly with respect to FREQ6PE. Further research is presently concentrated on development of an updated model called FREQ7PE.

This research involves a refinement of the fuel consumption and exhaust emissions as well as the flexibility of the program, which will be able to accept user-supplied predictions. Some features include user-supplied maximum queue length on on-ramps and user-supplied metering rates and temporal shifts. This model overcomes the limitations previously discussed for the FREQ3CP model.

AAP: An Arterial Analysis Package for Signal Timing Design and Evaluation

The Arterial Analysis Package (AAP) (Ref. 14.12) is based on existing signal design and analysis programs, most of which are described in previous chapters. TRANSYT 6C optimizes signal offsets and shifts for a given cycle length by minimizing the performance index (a linear combination of stops and delays). SOAP specializes in individual intersections, determining optimum signal timing (cycle length, splits, and phase sequence) and dial assignments for multiple time periods, all under either pretimed or actuated control conditions. PASSER II determines cycle lengths, phase sequences, offsets and splits so that the bandwidth along an arterial is maximized.

In their original forms, these programs each have unique input and output formats. This complicated the preparation of inputs so a common data base for all component programs was developed to facilitate the use of these programs as an integrated system.

The AAP will provide traffic engineers with a set of easily usable analysis programs. The need to be familiar with a separate input format for each of the programs will be eliminated. It will also enable the analyst with limited computer experience to access and use the programs. However, it will require significant amounts of programmer and systems analyst time to bring up on the IBM computer systems.

Other Signal Progression Models

Mixed-integer linear prgramming has been used by Dr. J. D. C. Little and his associates in two optimization model applications. The EXPRESS model (Ref. 14.13) is a maximal bandwidth optimization model for arterial progression design and MITROP (Ref. 14.14) is a signal optimization model that minimizes delay in a network. The maximal bandwidth model using the mixed integer linear programming approach is presently being enhanced by Little, under a contract from the Federal Highway Administration. The resulting model will be known as MAXBAND (Ref. 14.15).

TECHNOLOGICAL ADVANCES

Computer modeling of traffic operations is supported by several areas of technology.

The utility of computer models to the traffic engineer may be expected to improve, therefore, as technology advances. The three main areas for improvement are:

New Theories of Traffic Control

The development of theories for describing and optimizing the control of traffic appears to be in a fairly mature stage. Federally funded activities in this area have deminished somewhat in the past few years as the emphasis has shifted more to refinement and maintenance of existing models. Some work is progressing on the application of optimal control theory to oversaturated signal systems, which may eventually find its way into operational models. Minimization of energy consumption due to stops and delay at traffic signals may be expected to generate further theoretical development as energy problems intensify (as discussed earlier). Energy consumption in highway lighting systems has also attracted some interest. A linear programming model has been developed to examine traffic volumes throughout an illuminated network and to maximize the exposure of traffic to highway lighting under energy constraints (Ref. 14.16).

Another theoretical development of interest to the traffic engineer is the optimization of traffic signal progression based on the concept of "Forward Progression Opportunities" (Ref. 14.17).

A forward progression opportunity is simply the opportunity presented to the motorist to travel forward on one link of an arterial system without being stopped by a signal. This concept expands upon the maximal bandwidth approach by considering the progression opportunities which present themselves within the route, but do not necessarily extend throughout the full length of the route.

When system optimization is based on maximizing forward progression opportunities, rather than simply maximizing bandwidth, improvements in progression quality and other traffic operations measures can be realized. The TRANSYT-6C model has been modified for this purpose. Comparisons have indicated that worthwhile improvements can be realized in a variety of situations. The model is presently being incorporated into TRANSYT-7F.

Hardware Advancements

The advances in computer technology of the past few years have greatly reduced the constraints of memory storage and execution time which limited the capability of previous generations of traffic operations models. This trend may be expected to continue. A more significant trend from the perspective of the user, however, is the increasing availability of intelligent terminals and self contained desk-top microprocessor systems. While these devices cannot replace a large scale computer in the execution of any of the models described in this Handbook, they offer valuable assistance in the preparation of input data and in the presentation of interactive video graphics displays. A series of color graphics display is currently under development for both the NETSIM and FREQ6PE models under USDOT support. The Arterial Analysis Package described earlier in this chapter also features some restricted capabilities for producing graphics displays of time-space diagrams showing the quality of progression in an arterial signal system.

Already, several scaled down versions of several of the models described in this Handbook are operational in self-contained 16/32 bit microprocessor systems, namely SOAP and maximal bandwidth analyses (with partial progression opportunities). Furthermore, other programs include arterial movement analysis, accident reconstruction, etc. Finally, several functions of the SOAP program are also available for use on desk-top programable calculators.

Software Advances

The most significant advances in the software area lies in the management techniques for software development which have recently become very popular. The concept of "Structured Programming" offers two important advantages over the more conventional techniques.

1. It provides for more effective involvement of the traffic engineer in the development of analysis programs, by

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16. Abstract

This document pr ... r modeling concepts, discusses some o ... ting computer models for traffic oper ... cribes ten (10) of the more practical c

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9 - PRIFRE (Fr
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Each model is p ... input requirements, significant com ... d example applica-tions.

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