An Interactive Simulation Program For Intersection Design And Operational Analysis

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**An Interactive Simulation Program For Intersection Design And Operational**

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**Abstract (Limit: 200 words)**
A microscopic, stochastic model for intersection design and traffic flow analysis is presented in this report. A simulation program, INTERSIM, based on this modeling, is developed. The INTERSIM program can be used to evaluate alternative control schemes and geometric configurations. INTERIM can also assist in solving traffic operation and management problems, e.g., determining optimum signal phasing and timing of intersections via an iterative process. The most common situations encountered in practice are examined. These include: four-way and T-intersections with up to three lanes on each approach; stop sign control; signal control (fixed time or vehicle actuated) with various phasing schemes; detector placement and functions, multi-use lanes; protected and permissive left-turn movements; and right turns on red, among others. The proposed modeling applies to both over-saturated and under-saturated traffic conditions. INTERSIM is superior to the other intersection simulation programs due to its ease of operation and fast execution speed.

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AN INTERACTIVE SIMULATION PROGRAM
FOR INTERSECTION DESIGN AND
OPERATIONAL ANALYSIS

FINAL REPORT

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Prepared for
THE DEPARTMENT OF TRANSPORTATION
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The opinions, findings and conclusions expressed in this publication
are those of the author and not necessarily those of the Minnesota
Department of Transportation.
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1. INTRODUCTION

Road reconstruction and maintenance budgets have recently increased significantly, affecting the availability of funding for new construction. Traffic engineers search for new ways of managing traffic operation and designs for intersections in urban areas. The operation of an intersection can change dramatically during intersection reconstruction. Therefore, it is advantageous to evaluate alternative methods of traffic control and geometric intersection configurations to be implemented during the reconstruction period. In addition, it is desirable to evaluate several geometric and operational alternatives, to ensure that the reconstruction yields the desired results. Empirical methods, such as those detailed in the 1985 HIGHWAY CAPACITY MANUAL (HCM)\(^1\), exist to perform such analyses.

However, due to the complexity and the quantity of calculation required for the HCM method, results derived using manual pencil and calculator methods may tend to be error-prone, especially if several alternatives are considered. Although there are several computerized versions of the HCM procedures now available, these computational models are still likely to underestimate or overestimate the impacts of geometric design or traffic control changes due to the empirical nature of HCM. The HCM itself states that the delay equation it uses yields reasonable results for values of degree of saturation up to 1.0 and may be used with caution for values up to 1.2, but should not be used for higher values.
More realistic results can usually be obtained through the use of computer simulation methods. However, most existing simulation programs, such as TEXAS\textsuperscript{2} and NETSIM\textsuperscript{3}, require extensive and complex input management. For example, TEXAS provides seven different frequency distributions for arrival headways, and selecting an inappropriate distribution can radically affect the results. Although it can be used for simulation of individual intersections, NETSIM was developed for network traffic analysis. Consequently, its input requirements are much more extensive than are necessary for an isolated intersection. Users unfamiliar with the program require approximately 20 hours to develop the link-node diagram and to code the data. Experienced users need approximately 12 hours even for simple cases.\textsuperscript{4} In addition, because they are so complex, users must become very familiar with such programs before using them efficiently and with reasonable confidence.

Other programs, such as TRANSYT-7F, were not only developed for analysis of a traffic network (rather than a single intersection), but also are not true simulation programs. Results are derived through series of complex equations and algorithms, vehicles are not treated on an individual basis (microscopically), and variable demand patterns over short periods of time cannot be analyzed effectively.

Consequently, a method for quickly verifying that a feasible solution will indeed perform as expected, is desirable. To meet this need, a computer program, INTERSIM (INTERsection SIMulation), has been developed to simulate traffic flow for a wide variety of control and geometric alternatives at isolated intersections. In order to make simulation more appealing and easily accessible, INTERSIM was designed as an interactive, microcomputer-based program. Its development is based on previous research and programming.\textsuperscript{5} The INTERSIM program is attractive for several reasons. Data entry is simple, and the quantity of
data required is relatively small. The reported measures of effectiveness correspond to the most commonly-used measures employed by traffic engineers. Finally, the program allows the user to visually follow the intersection operation on a graphics screen by displaying a schematic representation of the intersection and the vehicles as they approach the intersection and join and depart the queue. In general, INTERSIM can be applied by traffic engineers or researchers as an operational tool to evaluate alternative intersection control strategies, including signal plans. It should be noted that as a design tool for intersection operation and management, INTERSIM cannot presently optimize signal settings. The user must run the program repeatedly with different signal settings to search for the optimum solution. The inclusion in INTERSIM of signal phasing and timing optimization has been identified as one area in which further development should be performed.

Following is a discussion of the modeling, control, and geometric aspects employed by the program. The program has been tested using approximately one hundred different cases. Some of the results are illustrated in the curve form, and compared to results obtained from NETSIM. NETSIM was the only computer model against which INTERSIM was tested. One of the primary reasons INTERSIM was developed was the lack of models capable of simulating an intersection. Only NETSIM and TEXAS were available for this purpose, and documented testing of TEXAS had not been performed outside of the agency which developed that program. Time and budget limitations of this project did not permit the University of Minnesota to perform independent testing of TEXAS. Unfortunately, these limitations also made testing of INTERSIM against field data impossible, since collected field data were unavailable and resources were inadequate to collect field data as part of this project.
A summary of the program input and output options is also presented, followed by a section describing the limitations of the program and potential improvements are included. Finally, the INTERSIM user's guide has been included as an appendix. This appendix can be used as a stand-alone document in the operation of the INTERSIM program and interpretation of results.

2. BACKGROUND

Ten years ago, few microcomputer software programs were available in transportation domain. Traffic engineers were often reluctant to access computers because of the complexities of the mainframe. However, recent developments and advances in microcomputer versions of traffic modeling have provided the practicing engineer with the opportunity to easily evaluate different traffic operational strategies at intersections using traditional methods or simulation methods. The availability of these computer programs assists traffic engineers by considerably reducing the amount of time spent in developing and evaluating alternative improvements to traffic systems. Traffic signal systems, in particular, can take advantage of the currently available models.

Since the 1960's, much effort has been expended to develop computer models that provide accurate and quantifiable estimates to assess proposed improvements at intersections. Such models as SIGNAL,\(^6\) CAPCALC85,\(^7\) FREESIAp and SIAP,\(^8\) SOAP84,\(^9\) and TEXAS are representative.\(^10\) These models generally fall into two categories; computational models and simulation models. Computational models(e.g., SOAP84) involve the application of mathematical equations to calculate solutions directly. These equations may represent fundamental mathematical truths, they may be derived from basic principles, or they may simply reflect an established relationship among several variables. On the other
hand, simulation models, such as TEXAS, are mathematical representations of the sequence of events which comprise a process. Simulation models as well as computational models are frequently incorporated into computer programs, because of the ability of computers to perform repeated calculations at incredible speeds. Unfortunately, most of these programs have been found to be inappropriate and outdated due to lack of maintenance. Besides INTERSIM, there is only one simulation program, TEXAS, which was designed specifically for the isolated intersection. TEXAS was developed by the University of Texas in 1977. It is a very powerful simulation evaluation tool, which can provide rigorous analysis of a particular set of input conditions. However, TEXAS has several significant limitations. Perhaps its greatest drawback is its complexity. It is extremely difficult to prepare the input data in such a way that the program runs properly. Besides its complexity, the program requires a color graphics adaptor, a color monitor, and a math coprocessor. If the computer being used lacks any of these features, the program will not run. Also, the TEXAS animated graphics are not displayed simultaneously with the simulation. Because TEXAS is not an integrated program, it records graphics display data onto a disk while simulating. Therefore, execution of TEXAS requires three discrete steps: (1) preparing input data; (2) simulation; and (3) watching the graphics display of the simulation on the screen. To accomplish these three steps, users must execute three independent programs.
3. MODELING ASPECTS

This section describes the modeling which the INTERSIM program utilizes. First, the overall modeling strategy is discussed. This is followed by a description of the modeling techniques employed to determine vehicle arrivals, departures and measures of effectiveness.

3.1 MODELING CHOICE

To develop a simulation model, one must initially decide whether to look at the process either macroscopically or microscopically. The macroscopic simulation model examines the traffic stream as a continuous fluid in terms of average speed, flow rate, and density, among other variables. The behavior of individual vehicles is ignored. The only concern is the aggregate behavior of the vehicles. Conversely, microscopic modeling, which is based on car-following theory and individual vehicle behavior, tracks vehicles following one another in a network. Both modeling alternatives have been employed in computer simulation. Because they model vehicles on an individual basis rather than as part of a continuous traffic stream, programs which employ microscopic modelling inherently have a greater potential for generating more accurate and precise results than do those which employ macroscopic modelling. Macroscopic modeling is generally used for arterial networks and freeway simulations, where details of the operation are less significant than the overall picture. For the same simulation, a microscopic simulation requires more computer memory and execution time than does a macroscopic simulation, because the number of variables and procedures resulting from the increased detail, is quite large. However, for the isolated intersection, accuracy is of paramount importance. Furthermore, certain details concerning the flow of traffic at intersections simply cannot effectively be treated macroscopically. Such details include lane changing, stop
sign control, right turns on red, etc. Because these details are important for isolated intersection simulation, the microscopic modeling has been employed in the INTERSIM program.

3.2 SIMULATION PRINCIPLES

Traffic simulation studies are concerned with a system's performance over a period of time. Therefore, one of the most important considerations in designing a model is the timekeeping method used. Timekeeping in a simulation has two functions. First, timekeeping updates the status of the traffic system. Secondly, timekeeping provides synchronization of the various elements and occurrence of events. The actions of each element depend upon the state and actions of other elements. For example, a vehicle's departure at an intersection depends on signal indication: the actions must be coordinated or synchronized in time. The traffic model must be designed to move through time. Events must occur in the proper order and with the proper time interval between successive events. Two basic timekeeping techniques can be used in microscopic computer simulations of traffic conditions: (1) time-scan, in which the conditions are updated based on time; and (2) event-scan, in which the conditions are updated based on the occurrence of certain events.

In a time-scan process, traffic conditions such as arrivals, departures, queue sizes (vehicles), queue lengths (feet), speeds and locations of vehicles, and signal indications are updated on a fixed time interval basis, generally every second. This procedure is analogous to taking a snapshot of the system each second, whether or not anything changed within the system. This technique is especially useful when it is important to track the locations, speeds, and characteristics of individual vehicles. Although this procedure normally provides very precise results, it is very time-consuming requiring large
quantities of computer memory. The simulation program TEXAS utilizes this procedure.

In an event-scan process, traffic conditions are updated based on the occurrence of certain events. These events usually consist of vehicle arrivals and departures and signal indication changes. An event-scan simulation requires substantially less computer time and memory because the quantity of detailed information maintained for every vehicle is less. The INTERSIM program employs elements of both time-scan and event-scan simulation. Because the simulation can be viewed on a graphics screen, it is desirable to show the traffic conditions at the intersection at regular time intervals (e.g., every one second). However, time constraints and memory requirements make certain detailed analyses, such as shock wave propagation within a queue or tracking of vehicles once they have passed through the intersection, too difficult. Therefore, these types of analyses are not performed. Consequently, within each one-second time frame, an event-scan analysis of vehicle movements and signal indication changes is performed. The program then tallies all events occurring within that one second. At the completion of the one-second event-scan, all events occurring within that time frame are displayed on the graphics screen.
3.3 VEHICLE GENERATION

Generation of vehicle arrivals is one of the most important steps in traffic simulation. There are two types of models which can be used: deterministic and stochastic models. Deterministic models are identities or definitions that relate certain variables or parameters when a process output is uniquely determined by a given input. Stochastic models characteristically have an uncertain output for a given input. As an example, assume that an arrival rate of 500 vehicles is indicated for a one-hour time period. With a deterministic model, every time the simulation is run, 500 vehicles will arrive in the one hour time period. With a stochastic model, the number of vehicles arriving in one hour will more than likely be more or less than 500 vehicles. Over several runs, however, the average will be 500 vehicles.

Traditionally, a variety of probability distributions in the stochastic models are widely used to assign vehicle arrivals and their movements. The movements include left turns, through, and right turns. NETSIM, for example, uses a uniform distribution to produce arrivals at input links. TEXAS uses probability density functions such as log-normal, negative exponential and others to assign arrival times.

When simulation tools are intended to be used, actual flow arrival patterns are seldom available. Thus, in simulation the arrivals are derived from a probability distribution. For truly isolated intersections, traffic flow conditions are difficult to predict due to the absence of adjacent signalized intersections. Therefore, selecting an appropriate distribution is sometimes based on personal experience. The typical user of INTERSIM does not have detailed knowledge of the various probability distributions, especially as they
pertain to an existing or proposed site. Therefore, to simplify data entry and reduce confusion for the user, INTERSIM employs default probability distributions. In the testing performed here the guidelines of Gerlough et al.\textsuperscript{11} were followed, with very satisfactory results when compared with NETSIM. More specifically, if $F$ represents the demand to capacity flow rate ratio ($V/C$) then for $F < 0.3$ (low flow) the Poisson distribution is employed to estimate actual flow rate. If $F > 0.7$ (heavy flow), the binomial distribution is commonly used. Finally, if $0.3 < F < 0.7$ (moderate flow) a composite pattern is recommended, i.e.,

\[ (F-0.3)v_2 - (F-0.7)v_1 \]

arrivals = \---------------------

\[ 0.7 - 0.3 \]

where:

$v_1, v_2$ = the arrival flow generated by the Poisson and binomial distributions respectively.

For stop sign control, the time used as the arrival time for each vehicle is the time at which the vehicle arrives at the back of the queue, or, if no queue is present, at the stop line. For signal control, the arrival time is the time at which the vehicle arrives at the back of the queue or 1000 feet upstream of the intersection, whichever occurs first.
3.4 VEHICLE ADJUSTMENT

For approaches which have more than one lane, an arrival adjustment is needed. This procedure distributes arrivals of through vehicles between the lanes so that the total demand in each lane is as balanced as possible with the demand in other lanes on the approach. The following figure (Fig. 1) and steps illustrate the adjustment procedure.

<table>
<thead>
<tr>
<th>lane 1</th>
<th>q1 □□□□□□□□□□</th>
</tr>
</thead>
<tbody>
<tr>
<td>lane 2</td>
<td>q2 □□□□□□□□□□</td>
</tr>
<tr>
<td>lane 3</td>
<td>q3 □□□□□□□□□□</td>
</tr>
</tbody>
</table>

**Fig. 1 Arrival adjustment**

Step #1.

If the number of lanes in an approach \(N\) = 1, no adjustment is needed.

Step #2a.

If the number of lanes in an approach \(N\) > 2, and if lane 1 is an exclusive left turn lane:

(1) Left turn arrivals enter lane 1.

(2a) When \(N=2\), through and right turn arrivals enter lane 2.

(2b) When \(N=3\), right turn arrivals enter lane 3. In this case, at most two through vehicles can be generated in any one second. If one through vehicle arrives, it will join the shorter of the queues in lanes 2 and 3 (e.g. \(q_2\) in Fig.1).
For two through arrivals, one is assigned to each of the two lanes (2 and 3).

Step #2b.

If the number of lanes in an approach \((N) > 2\), and if lane 1 is a shared lane (utilized by both through and left-turning vehicles):

(1) Left turn arrivals enter lane 1.

(2a) When \(N=2\), right turn arrivals enter lane 2. If one through vehicle arrives, it will join the shortest of the two queues. If two through vehicles arrive, one joins each lane's queue, separately.

(2b) When \(N=3\), right turn arrivals enter lane 3. In this case, three through vehicles may be generated during any second. If one through vehicle is generated, it joins the shortest queue (e.g. \(q_3\) in Fig. 1). If a second through vehicle is generated during the same one-second period, it will join the shorter of the remaining two queues (e.g. \(q_2\) in Fig. 1). For three through arrivals, one vehicle joins each of the three lane queues.
3.5 VEHICLE DEPARTURES

Vehicle departures are a function of several parameters entered by the user. The first parameter is the saturation flow rate, which is the maximum rate at which vehicles will cross the stop line if unimpeded by opposing vehicles or by the intersection control. The second parameter is the lost time which a vehicle will experience due to intersection control, acceleration and queueing. It is assumed that the first five vehicles in a platoon may be affected by a lost time due to a driver reaction and acceleration time. The third parameter is the critical gap, which is the average minimum time headway between vehicles in a major traffic stream which a driver turning through or into the traffic stream feels is acceptable.

3.5.1 Departures under Signalized Control

(a) Through and right turning movement during green indications

The departures of through traffic and right turning traffic during green indications are the simplest case to process at intersections. The departure procedure can be described as follows.
If the right-of-way is given to the front vehicle in a lane, then if the vehicle belongs to the first five vehicles, then the departure time = AT + MH + LT;
otherwise the departure time = AT + MH.

where, AT is the departure time of the previous vehicle, in seconds.
MH is the minimum headway, in seconds, as determined from saturation flow rate, and
LT is the lost time, in seconds, dependent on position in the platoon of vehicles.

Here, it is assumed that the minimum headway (in seconds) is a constant equal to 3600/saturation flow rate (in vehicles per hour). The suggested values of lost time are given by 2.64 - (0.44*PLT), where PLT is the vehicle position in a platoon, from 1 to 5. The arrival time is updated continuously during the simulation period. This ensures that vehicles are discharged properly when the signal indication changes.

(b) Left turning movement
There are two kinds of left turning movements. One is a protected left turn movement, and the other is the unprotected or mixed left turn movement. For protected left turns, exclusive left turn lanes and left turn phases are required. The departures of such vehicles are the same as described in (a).
When left turn traffic is not heavy enough to justify an exclusive left turn lane, an optional or shared lane serving both left turn and through movements is often employed. With no exclusive left turn phase, two problems can develop. First, left turn vehicles may conflict with the opposing through vehicles, as shown in Figure 2. Second, the left turn vehicle which is waiting for an acceptable gap will block the shared lane, so that following through vehicles cannot proceed through the intersection.

To handle the first problem, gap acceptance level is studied. The literature on this subject is quite extensive.\textsuperscript{11,12} Most of the research has been devoted to empirical studies leading to design and operational procedures. For example, statistical theory was used to establish regression equations based on observed data.\textsuperscript{13}

![Fig. 2 Conflicting between left-turn and opposing through movement](image)

Such regression equations are used to estimate the capacity of left turn traffic. Mathematical treatment of the gap-acceptance maneuver has also been attempted\textsuperscript{11}. Various probability distributions were used as gap acceptance functions such as uniform distribution, negative exponential distribution, and normal distribution, etc. In some existing simulation programs, regardless of
the methods used (empirical equations or mathematical analysis), gap acceptance procedures were not employed. Although the traffic performance looks better in those cases, the measures of effectiveness are not realistic.

For intersections with no adjacent intersections, the gaps in the conflicting streams are usually randomly distributed as arrival flow is not strongly platooned. To be more reliable, a log-normal distribution is adopted to generate gap acceptance levels in the INTERSIM program, i.e.,

\[ p(x) = \frac{1}{x\sigma\sqrt{2\pi}} e^{-\frac{(\log x - \mu)^2}{2\sigma^2}} \]

where:

- \( x \) = a continuous random variable;
- \( \sigma \) = standard deviation;
- \( \mu \) = mean value.

Values of critical gap may be selected from the HIGHWAY CAPACITY MANUAL. When seeking an acceptable gap, all opposing movements (each opposing lane) need to be examined in turn. Only if all the gaps in opposing lanes are acceptable can a left turning vehicle complete the turn. Otherwise, the left turn vehicle must wait until at least the next gap. The blocking problem will be discussed in a later section.
(c) Right turns on red (RTOR)

The implementation of right turns on red is used to facilitate the full utilization of the available capacity of an approach. The INTERSIM program provides this optional function. RTOR, shown in Figure 3, can be treated the same as the treatment of unprotected left-turn movements except that there are more constraints. Actually, RTOR is also a kind of gap-searching procedure. The right turning vehicle cannot make a turn until the following constraints are satisfied: (1) on the approach being considered this option (RTOR) must be selected; (2) the current phase to the approach is red; (3) the first vehicle in queue on the approach wants to make a right turn; and (4) the gap in the opposing stream is acceptable.

Fig. 3 Conflicting between right-turn-on-red and opposing through movement
3.5.2 Departures under Stop Sign Control

The INTERSIM program simulates only all-way stop sign control. The difficulty with this type of control is that the right-of-way is not clearly assigned, and each movement seeks gaps in other conflicting streams at the intersection. Therefore, departures represent a selection process, i.e. determining which vehicle arrived first. The basic departure principle is that the program assigns the right-of-way first to the vehicle, among those at the stop lines, which arrived earliest; then to other vehicles which movements do not conflict with that of the first vehicle. The calculation of departure time is determined by adding the arrival time at the stop line and the lost time. In this case, the lost time remains constant since all departing vehicles experience a complete stop for the stop sign. Similar to signalized control, the arrival time is updated during the entire simulation. Figure 4 shows an example of the movement of vehicle departures at a stop-sign-controlled intersection. Vehicles 1 and 2 on the northbound approach have the right-of-way and are passing through the intersection. Meanwhile, vehicles 3 and 4 are allowed to make their right turns because they do not conflict with vehicles 1 and 2 or with each other. Other vehicles at the intersection are not permitted to proceed.

Fig. 4 Vehicle departures at stop-sign-controlled intersection
3.6 LANE SWITCHING

The blocking problem, mentioned previously, is caused by a left turning vehicle which is waiting in the shared lane for an acceptable gap in the opposing traffic stream. To solve this problem, a lane-switching technique is incorporated. Lane switching is based on real traffic phenomena. Whenever an approaching driver finds that a left turn vehicle blocks his path, and when the queue size in another lane is shorter than that he will join, he may switch from one lane to another. Figure 5 is a depiction of a lane change. Several assumptions are made in this program. First, 80 percent of vehicles may switch between lanes if it is possible. Second, left turn vehicles may not switch to the middle lane or to the right-most lane, and switch back later. Third, when lane changing occurs, only the rearmost vehicle in a queue will make the switch and only if it is a through vehicle. If the rear vehicle is not a through vehicle, the program automatically searches forward in the queue until a through vehicle is found. Fourth, during each second and for each lane, at most one vehicle is permitted to change lanes. Obviously, one-lane approaches do not have lane changing. Also, lane changing can only partly solve a blocking problem. For further improvement, left-turn or right-turn bays should be introduced.

The center line of an approach

<table>
<thead>
<tr>
<th>lane 1</th>
<th>□ □ □ □ □ □ □ □ □</th>
</tr>
</thead>
<tbody>
<tr>
<td>lane 2</td>
<td>□ □ □ □ □ □ □ □ □</td>
</tr>
<tr>
<td></td>
<td>□ □ □ □ □ □ □ □ □</td>
</tr>
<tr>
<td>lane 3</td>
<td>□ □ □ □ □ □ □ □ □</td>
</tr>
</tbody>
</table>

Fig. 5 Lane switching
3.7 Demand Pattern

Demand pattern is a special function required by MnDOT. With this feature, the program user can apply the demand fluctuation characteristics from one intersection to a second intersection without collecting demand data in the same detail. Suppose that the user has saved 5-minute-based field data already. He can utilize these peaking characteristics to an intersection for which only 60-minute counts are available. In this way, the program does not generate arrivals based on a 60-minute period but rather on a 5-minute based period. This ensures that the arrival pattern contains same fluctuation over the simulation. More specifically, assume that the user has the following field data:

<table>
<thead>
<tr>
<th></th>
<th>NB</th>
<th>SB</th>
<th>EB</th>
<th>WB</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:00 --</td>
<td>275</td>
<td>250</td>
<td>100</td>
<td>125</td>
</tr>
<tr>
<td>7:15 --</td>
<td>300</td>
<td>280</td>
<td>110</td>
<td>130</td>
</tr>
<tr>
<td>7:30 --</td>
<td>315</td>
<td>290</td>
<td>115</td>
<td>145</td>
</tr>
<tr>
<td>7:45 --</td>
<td>260</td>
<td>240</td>
<td>85</td>
<td>110</td>
</tr>
</tbody>
</table>

If the user has 5-minute based field data, the program writes his data directly into a user-specified file. Otherwise, such as in the above case, the program converts the 15-minute-based data to 5-minute-based data first (shown in the following table), and then saves them. This is the procedure used in creating the demand pattern file.
<table>
<thead>
<tr>
<th>Time</th>
<th>NB</th>
<th>SB</th>
<th>EB</th>
<th>WB</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:00 -- 7:05</td>
<td>92</td>
<td>83</td>
<td>33</td>
<td>42</td>
</tr>
<tr>
<td>7:05 -- 7:10</td>
<td>92</td>
<td>83</td>
<td>33</td>
<td>42</td>
</tr>
<tr>
<td>7:10 -- 7:15</td>
<td>92</td>
<td>83</td>
<td>33</td>
<td>42</td>
</tr>
<tr>
<td>7:15 -- 7:20</td>
<td>100</td>
<td>93</td>
<td>37</td>
<td>43</td>
</tr>
<tr>
<td>7:20 -- 7:25</td>
<td>100</td>
<td>93</td>
<td>37</td>
<td>43</td>
</tr>
<tr>
<td>7:25 -- 7:30</td>
<td>100</td>
<td>93</td>
<td>37</td>
<td>43</td>
</tr>
<tr>
<td>7:30 -- 7:35</td>
<td>105</td>
<td>97</td>
<td>38</td>
<td>48</td>
</tr>
<tr>
<td>7:35 -- 7:40</td>
<td>105</td>
<td>97</td>
<td>38</td>
<td>48</td>
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<td>7:40 -- 7:45</td>
<td>105</td>
<td>97</td>
<td>38</td>
<td>48</td>
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<td>7:45 -- 7:50</td>
<td>87</td>
<td>80</td>
<td>28</td>
<td>37</td>
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<td>7:50 -- 7:55</td>
<td>87</td>
<td>80</td>
<td>28</td>
<td>37</td>
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<tr>
<td>7:55 -- 8:00</td>
<td>87</td>
<td>80</td>
<td>28</td>
<td>37</td>
</tr>
</tbody>
</table>

When the user intends to use a demand pattern, the program performs as following:

1. For each approach, calculate the percentage that each 5-minute based demand contributes to the total demand;

2. Multiply the user-entered volume for each boundary and movement by the percentage for that approach to obtain estimated 5-minute demands.

For example, if the user obtains 60-minute count data:
<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>NB</td>
<td>SB</td>
<td>EB</td>
<td>WB</td>
<td></td>
</tr>
<tr>
<td>LT THRU RT</td>
<td>LT THRU RT</td>
<td>LT THRU RT</td>
<td>LT THRU RT</td>
<td></td>
</tr>
<tr>
<td>7:00 -- 8:00</td>
<td>80</td>
<td>150</td>
<td>60</td>
<td>120</td>
</tr>
</tbody>
</table>

then the program will process his data in following pattern:

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>NB</td>
<td>SB</td>
<td>EB</td>
<td>WB</td>
<td></td>
</tr>
<tr>
<td>LT THRU RT</td>
<td>LT THRU RT</td>
<td>LT THRU RT</td>
<td>LT THRU RT</td>
<td></td>
</tr>
<tr>
<td>7:00 -- 7:05</td>
<td>6</td>
<td>12</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>7:05 -- 7:10</td>
<td>6</td>
<td>12</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>7:10 -- 7:15</td>
<td>6</td>
<td>12</td>
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<td>9</td>
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<td>7:15 -- 7:20</td>
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<tr>
<td>7:20 -- 7:25</td>
<td>7</td>
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<td>5</td>
<td>11</td>
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<tr>
<td>7:25 -- 7:30</td>
<td>7</td>
<td>13</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>7:30 -- 7:35</td>
<td>7</td>
<td>14</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>7:35 -- 7:40</td>
<td>7</td>
<td>14</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>7:40 -- 7:45</td>
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<td>7:50 -- 7:55</td>
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<td>11</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>7:55 -- 8:00</td>
<td>6</td>
<td>11</td>
<td>5</td>
<td>9</td>
</tr>
</tbody>
</table>

It should be noted there is no requirement to save or use a demand pattern. A demand pattern may be used for any site and for any time period for which the user feels the pattern saved adequately reflects the traffic fluctuation pattern.
3.8 Measures of Effectiveness (MOE's)

Any new traffic control system or modification to an existing system is intended to satisfy a goal or a set of goals. Measures of effectiveness (MOE's) are used to provide a quantitative basis for determining the capability of traffic control systems and their strategies to attain the desired goals. The main MOE's in this program consist of the number of arrivals, delay, the number of stops, and fuel consumption. Following are the definitions for each MOE.

3.8.1 Delay

Without a doubt, delay expressed in one form or another is the most widely used MOE in traffic control. In urban street intersections, delay is commonly defined as the time lost at the intersection by those vehicles that are stopped, i.e., the difference between arrival time and departure time. Therefore, the delay \( D \) is

\[
D = \sum_{i=1}^{n} N_i
\]

where \( N_i \) = number of vehicles in queues in an intersection at the \( i^{th} \) second;

\( n \) = total simulation time in seconds.
3.8.2 Number of Stops

The number of stops is another common MOE which is used to evaluate traffic operation. In this program, the number of stops consists of primary stops and secondary stops. Primary stops are an accumulation of arrivals at the stop line or at the back of the queue during the red signal indication, and arrivals at the back of the queue during green and yellow indications if a queue exists. For each vehicle, at most one primary stop can be accumulated, that occurring when the vehicle becomes queued for the first time. Under heavy flow conditions, however, a vehicle in a long queue may stop two or more times before passing through an intersection. In this case, secondary stops are defined as those stops encountered while within the queue. In summary, during each second and in each lane:

Primary stops are accumulated as follows:
(1). Regardless of phase indication, if there is an arrival and a queue exists, one stop is accumulated.
(2). During the red phase, regardless of the queue size, one stop is accumulated if there is one arrival.

Secondary stops are accumulated as follows:
(1). In an unprotected left-turning lane, if the left-turning vehicle blocks traffic,
   stops = stops + (queue size-1)/4 + 1.

(2). When signals change from yellow to red,
   stops = stops + queue size.
3.8.3 Fuel Consumption

Elements model is adopted in this program for calculating fuel consumption. This model expresses fuel consumption as a function of the three principle elements of driving patterns (idle, cruise and stop-start maneuvers):¹⁴

\[ F = f_1 TT + f_2 D + f_3 PS \]

where:  
\( F \) = fuel consumption in gallons;  
\( TT \) = total travel in veh-miles;  
\( D \) = stopped delay time in veh-hours;  
\( PS \) = the number of primary stops  
\( f_1 \) = fuel consumption per unit distance while cruising, in gallons per mile;  
\( f_2 \) = fuel consumption per unit time while idling, in gallons per hour;  
\( f_3 \) = fuel consumption per primary stop in gallons per stop.

In fact, the factors \( f_1 \) and \( f_3 \) in the preceding equation are the functions of approach speeds at the intersection \( (V_c, \text{in miles per hour}) \), and they are determined by the following formulae:

\[ f_1 = 7.1137E-2 + 2.14/V_c + 3.9629E-5 \ V_c; \]
\[ f_2 = 2.14; \]
\[ f_3 = 0.2113 \ V_c + 1.38E-2 \ V_c^2 + 2.3608E-6 \ V_c^4; \]

In addition, the total vehicles serviced, the maximum queue size (in vehicles), and the average queue size (in vehicles) are calculated for the simulation. All the results are presented in the sub-interval reports and in the summary report.
4. CONTROL ALTERNATIVES

Three types of control can be simulated by the INTERSIM program: (1) four-way stop sign control, with a stop sign on each approach; (2) pretimed signal control, with a fixed cycle length, phasing sequence, and phase time; and (3) actuated signal control, with both semi-actuated and full-actuated options. The strategy of stop sign control is very simplistic and need not be discussed further.

4.1 Pretimed Control

Pretimed control assigns the right-of-way at an intersection according to a predetermined schedule. The sequence of right-of-way assignments (phases), and the length of the time interval for each signal indication in the cycle is fixed, usually based on historic traffic patterns. Although there are no limitations on the number of phases that can be utilized, as a general rule for pretimed control they should be held to a minimum. The MANUAL OF TRAFFIC SIGNAL DESIGN\textsuperscript{15} indicates that more than three phases tend to increase cycle length and delay as they reduce the green time available for other phases. Intersection efficiency is impaired by starting delays, additional change intervals, and longer cycles. However, in actuated control, multiple phases may not cause these undesirable effects if properly operated and timed.
4.2 Phasing Arrangements

To maximize the capabilities of the program, multiple phasing options have been included in the INTERSIM program. These additional options include allowing split phasing in both pairs of directions so that vehicles in all directions can be serviced by an exclusive phase. Left-turn phases on any combination of approaches can also be selected. It is then possible to select exclusive left-turn phases only for northbound and eastbound traffic, if desired. Finally, the program includes the capability to utilize leading as well as lagging exclusive left-turn phases.

As a result, the INTERSIM program is capable of simulating practically any phasing arrangement that can be handled by a standard eight-phase dual-ring NEMA controller. Situations which cannot be simulated by INTERSIM include: left turns are both protected (exclusive phase) and permissive (turn on green ball for thru traffic); through vehicles and right-turning vehicles originating from the same approach are not accommodated by the same signal phase; pedestrian activity; and phase overlaps. All of these items have been proposed as future improvements to the program.

The dual-ring controller configuration and phase sequencing is shown in Fig. 6. Phases are serviced from left to right. Phases in the same timing ring cannot time concurrently. Phases not in the same ring can time concurrently, provided they are on the same side of the barrier. When concurrently-timed phases must terminate due to opposing phase calls from across the barrier, the two phases simultaneously yield right-of-way (signal change to yellow). If the demand from across the barrier requires concurrent phase timing, the right-of-way is given (signal change to green) simultaneously to the called phases.
**Fig. 6. NEMA Phasing for Dual-Ring Eight-Phase Controller**

<p>| | | | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
</tbody>
</table>

**NEMA Phase Designations**

**Leading Left Turn Arrow**
Both Directions

**Lagging Left Turn Arrow**
Both Directions

**Leading Left Turn Arrow**
Northbound
**Lagging Left Turn Arrow**
Southbound

**Leading Left Turn Arrow**
Southbound
**Lagging Left Turn Arrow**
Northbound

**Fig. 7. Potential Northbound-Southbound Phase Assignments**
The INTERSIM program automatically assigns a phase number to each possible vehicle movement at an intersection. This assignment, an example of which is shown in Fig. 7, is based on the geometric configuration and on the phasing arrangement selected by the user. In directions for which there is no left-turn arrow, the left-turning movement is serviced by the same phase as the through and right-turning traffic for the same direction of travel. Left-turning traffic serviced by both a protected and a permissive phase cannot be simulated accurately using INTERSIM.

4.3 Actuated Control

Traffic-actuated control at an isolated intersection attempts to adjust green times continuously in accordance with real-time measures of traffic demand obtained from vehicle detectors, and in some cases, to adjust the sequence of phasing (through skipping of phases with no traffic demand). In principle, vehicle actuated control performs much better than fixed time control when it is properly designed, timed and maintained, but, if this is not achieved in practice, vehicle actuated control has no advantage over certain fixed time types. There are many types of operational modes associated with traffic actuated control, such as semi- and full-actuated mode, volume-density mode, queue-length mode, and recently developed adaptive mode. The INTERSIM program implements the semi- and full-actuated control to fit the most commonly used controllers. The information on the movement of traffic at intersections,
required as input to real-time signal control algorithms, can be provided by means of simulated detectors located on each approach. A maximum of two detectors may be located in any one lane, which means up to 6 such detectors may be within any one approach. The detector's functions include call only, extend only, or call and extend. If two detectors are specified for a lane, one detector is assumed to be located at the stop line and the other can be placed upstream of the stop line. A series of smaller, closely-spaced detectors can be simulated by specifying a single large detector whose length equals the length covered by the detector series. Although the TRAFFIC CONTROL SYSTEM HANDBOOK\textsuperscript{17} suggests that 120 feet be selected as an upper limit for detector placement, research has shown that detector placement within 120 feet to 600 feet from the stop line are more efficient in some cases.\textsuperscript{18} Therefore, 600 feet was chosen as the upper limit of distance from stop line in the INTERSIM program. There are 16 logical combinations of detector function available in the program if two detectors are placed in each lane. However, several combinations are not as efficient as the most commonly used ones. When dealing with actuated control problems using INTERSIM, the following two combinations are strongly recommended:

\begin{tabular}{|l|l|}
\hline
Detectors at stop line & Detectors upstream of stop line \\
\hline
  call only          & extend only \\
  call only          & call+extend \\
\hline
\end{tabular}

In situations with only 1 detector in a lane, the recommended function for that detector is both call and extend.
5. GEOMETRIC ASPECTS

This section contains descriptions of the geometric alternatives that can be simulated using the INTERSIM simulation program. These geometric alternatives were identified by MnDOT at the start of the project as those most frequently encountered during intersection construction and reconstruction.

INTERSIM can handle either a four-approach intersection or a three-approach intersection (T-intersection). Because the T-intersection can be oriented in any one of the four cardinal directions, there are a total of five possible basic configurations. On each approach, from one to three lanes can be specified with the following limitation: if stop signs are used to control the intersection or if the intersection is a three-approach intersection, a maximum of only two lanes can be specified on each approach. The number of lanes and lane usage for four-approach and T-intersection are shown in Fig. 8 and 9, respectively.
Fig. 8. Lane Usage at Four-Approach Intersection

Fig. 9. Lane Usage at T-Intersection:
(a) Single-Lane Approaches;
(b) Two-Lane Approaches
6. PROGRAM SUMMARY

This section contains a brief summary of the input requirements and the output obtained from the INTERSIM program. Input data for any simulation can be saved in a disk file after data entry is complete. These data can be recalled and easily changed to accommodate future simulations requiring a minimum of input.

6.1 Program Input

Following is a list of the input required for all simulations, regardless of geometric configuration and type of control:

1. Basic intersection configuration (four-way or three-way) and orientation.
2. Type of control (four-way stop sign, pretimed signal, actuated signal).
3. Number of lanes on each approach.
4. Selection of shared use of left-most lane.
5. Selection of lane switching.
6. Saturation flow rate for each lane on each approach, in vehicles/hour.
7. Intersection clearance time for each vehicle movement, in seconds. This is the time required for a vehicle making a particular movement to pass through the intersection far enough for a vehicle making a conflicting movement to proceed.
8. Initialization time, in minutes. This is a time period preceding the actual simulation during which vehicles are loaded into the system. During the initialization period, no delay, stops, or queue-size statistics are tabulated, so that the values included in the outputs include only calculations performed during the actual simulation. If an initialization period is not used, the program assumes that there are no vehicles at the intersection when the simulation begins.

9. The number of simulation time slices (periods). The total simulation period can be subdivided into intervals of equal duration to allow for demand variations during different times of the day. The number of simulation time slices and the duration of the time slices determine the total simulation period, which can be up to 24 hours long.

10. Duration of the individual time slice, in minutes.

11. Vehicle demands, in vehicles/time period. The user enters demand values on each approach for each time period indicated in item 10. Demand values are also entered for the initialization period, if applicable. The input is the number of left-turning, through, and right-turning vehicles on the approach during the time period.

In addition to the input just described, which is required for all simulations, situations using signal control require additional inputs dealing with the signal operation and the behavior of drivers in platoons and of drivers making left turns across opposing traffic. A list of these signal-related input items follows:
1. Selection of right turns on red, by approach.

2. Signal phasing arrangement. This item deals with the usage of split or non-split phasing, exclusive left-turn phases, and, if left-turn phases are used, whether they precede (lead) or follow (lag) the through-movement phases.

3. Signal timing for each phase. Items entered here include green time (for actuated signals, minimum and maximum green times), yellow clearance time, all-red clearance time, extension interval, and whether or not the phase is on minimum recall.

4. Lost times, in seconds. Lost times, the additional time taken by vehicles near the front of a platoon when the signal turns green, are entered for first five vehicles in the platoon.

5. Average acceptable gap, in seconds, for opposed left-turning traffic and for right turns on red. This is the average time headway between through vehicles traveling in the opposite direction that is sufficient for a left (or right) -turning driver to decide to turn left (or right).

6. For the traffic-actuated control, the following parameters must be specified: placement of detectors upstream of the stop line, in feet; detector performance (call only, extend only, or call and extend); detector length, in feet; speed of vehicle movement in miles per hour.
6.2 Program Output

The INTERSIM program can generate output to the printer, to the monochrome screen, to the graphics screen, and to the secondary storage device (floppy disk or hard disk).

The graphics screen visually depicts the simulation during the simulation process. An example of a typical graphics screen display is shown in Fig. 10. The upper left corner of the screen shows the current time slice being simulated and the current time within the time slice. In the center of the screen is a graphic representation of the intersection, defined by red lines (on the graphics screen). The example shown is a four-approach intersection with two lanes on each approach. Beside each approach, also outlined in red, is the representation of the signal indications to vehicles on the approach. Although the color display has been converted to black-and-white for print, the relative position of the various indications can be seen in the example.
Fig. 10   Graphics Screen Display During Simulation
The current display to eastbound and westbound vehicles is a red ball, and the current display to northbound and southbound vehicles is a red arrow to left-turning vehicles and green ball to through and right-turning vehicles. The current queue size in each lane can also be determined. Each vehicle is represented by a small yellow rectangle in the lane. The last item shown in the example is an indication of which lanes experienced departures during the current second of simulation and in which direction those departing vehicles proceeded. Departures are indicated by green lines emanating from the stop line drawn on and then erased from the graphics screen. The example shows a departure from the southbound rightmost lane (when viewed going in the direction of travel on the approach) that proceeded straight through the intersection and a northbound departure from the rightmost lane, which turned right and proceeded eastbound.

Output to the monochrome screen, if used, during the simulation consists of a minute-by-minute update of the current values for the measures of effectiveness being evaluated. The measures of effectiveness include delay, stops, and maximum queue sizes for each approach/lane combination. The current time slice and time within the current time slice are displayed at the top of the screen similar to the graphics screen.

Three types of output are sent to the printer when the entire simulation has been completed. The first output item to the printer is a summary of the input for the current simulation. This summary is optional and is selected or deselected during the input portion of the program. The other two types of output are identical in format except for the title at the top of each page. Printed first is a summary report for the entire simulation. Following this one-page summary report are summary reports for each time slice, allowing the user to evaluate during which time slice potential problems may arise.
For both types of summary report, values are output for each approach/lane combination and for the entire intersection. The measures of effectiveness for which values are printed are: (1) the total number of vehicles that arrived; (2) the total number of vehicles that were serviced; (3) the total delay, in vehicle-hours; (4) the average delay, in second/vehicles, based both on the number of vehicles arrived and on the number of vehicles serviced; (5) the number of primary stops; (6) the number of secondary stops; (7) the average number of total stops per vehicle, again based both on vehicles arrived and on vehicles serviced; (8) the maximum queue size; (9) the average queue size; and (10) the fuel consumption.

For the user's convenience to re-examine the simulation results in the future, or if printer is not available when running this program, INTERSIM automatically prompts the user before a simulation starts to save the output file to disk, if desired.

6.3 Program Execution Time

The modeling and programming efficiency allows very satisfactory execution and data entry times. The latter takes only about 10 minutes/intersection to someone familiar with the program; this time can be expected to triple for beginners. Execution to simulation time is approximately 1:10 when the intersection activity is not depicted on the graphics screen and otherwise adjustable. An adjustable delay specified by the user to allow the user to follow, at his or her own rate, the performance of the alternative being simulated. Thus, if one is not interested in visual inspection of the traffic flow at the intersection, the results of a one-hour simulation may be obtained in only six minutes.
7. TEST RESULTS

Normally, test of this program against field data would be mandatory after programming was completed. However, data collection at many locations requires significant time and funding. Also, some measures of effectiveness are not easily obtained from field observations. For example, it is very difficult to define vehicle stops and to distinguish a stopped vehicle from a very slow moving vehicle (e.g. speed=5 mph) in the field. Due to these restrictions, extensive model testing against field data could not be performed. As an alternative, a comparison between two microscopic simulation programs, INTERSIM and NETSIM, was performed. NETSIM was selected as the criterion because it has been validated and calibrated by numerous state transportation agencies, research agencies, and universities around the United States, and has proven to be a relatively powerful and reliable simulation tool.

Approximately 100 cases were designed and tested to validate INTERSIM. These 100 cases included stop sign control and signal control (both pretimed and actuated), six geometric configurations as shown in Table 1, eight phasing schemes as shown in Table 2, and a wide range of traffic volumes. The traffic flow under over-saturated conditions was also examined using INTERSIM. Unfortunately, NETSIM does not accurately reflect over-saturated conditions. In addition, for stop sign control, NETSIM produces unreasonable high delay for relatively low traffic demands. Realizing that NETSIM produces unreliable results in these cases, the comparisons of such cases are not included in this report.
Table 1. Geometric Configurations of Intersections

<table>
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<tr>
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</table>
Table 2. Phasing Schemes of Intersections

<table>
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<th>4-Approach Intersection</th>
</tr>
</thead>
<tbody>
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<tr>
<td>TYPE C</td>
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<td>TYPE H</td>
<td><img src="image15" alt="Diagram" /></td>
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</tbody>
</table>
From the onset of the current contract there have been no known, tested models available which could accurately depict intersection operations under saturated and over-saturated conditions. Consequently, the only way to adequately test an intersection simulation program under these conditions is to use collected field data. As was indicated earlier, adequate field data was not available, and data collection could not have been accomplished under the budget limitations of the current project.

Each test was based on one hour of simulation, and the following assumptions were made:

1. capacity = 1500 -- 1800 vehicles./hour./lane;
2. average critical gap = 4.0 -- 5.5 seconds.;
3. functions of the detectors: call only at stop line, extend only upstream of stop line;
4. distance of the upstream detector from stop line = 120 feet.

The results obtained from both NETSIM and INTERSIM are illustrated in Figures 11 to 20. A summary of the deviation between NETSIM and INTERSIM for all cases is tabulated in Table 3. These results suggest that estimates obtained from the INTERSIM program are satisfactory, as they deviate less than 10% from the NETSIM data. It was also observed in comparing curves that there is a tendency in most cases for the delay from INTERSIM to be less than that from NETSIM, but for more stops to be estimated. In fact, the INTERSIM program is still different from NETSIM in some aspects. First, INTERSIM does not calculate the delay after vehicles pass through the intersection. NETSIM does. Second, INTERSIM only calculates the stopped delay. NETSIM calculates not only stopped delay but also the delay caused by the interaction among the vehicles. Third, car-following theory is incorporated into the NETSIM program, so that the vehicle may slow down before it reaches the stop line accumulating delay but not stopping. For this reason, NETSIM produces fewer stops than INTERSIM does. It is hoped that in the future sufficient funding will be made available to compare INTERSIM results with actual field data.
Fig. 11. Comparison Curves Between NETSIM and INTERSIM

<table>
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<td>Phasing Scheme: TYPE C</td>
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<table>
<thead>
<tr>
<th>Pretimed Control</th>
<th>Actuated Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DELAY (Veh-Hrs)</strong></td>
<td><strong>DELAY (Veh-Hrs)</strong></td>
</tr>
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</tbody>
</table>

Note: 1. NETSIM results ———
2. INTERSIM results ———
3. $X$ = Degree of Saturation; $V$ = Volume.
Fig. 12. Comparison Curves Between NETSIM and INTERSIM

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<table>
<thead>
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</thead>
<tbody>
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<td>DELAY (Yeh-Hrs)</td>
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<tr>
<td>0.5 0.6 0.7 0.8</td>
<td>1150 1300 1450 1600</td>
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</tbody>
</table>

Note:
1. NETSIM results
2. INTERSIM results
3. $X = \text{Degree of Saturation}; \ V = \text{Volume.}$
Fig. 13. Comparison Curves Between NETSIM and INTERSIM

<table>
<thead>
<tr>
<th>Geometric Configuration: TYPE 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phasing Scheme: TYPE E</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pretimed Control</th>
<th>Actuated Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DELAY (Yeh-Hrs)</strong></td>
<td><strong>DELAY (Yeh-Hrs)</strong></td>
</tr>
<tr>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>0.5 0.6 0.7 0.8 X</td>
<td>1800 2000 2200 2400 V</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>STOP</th>
<th>STOP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1800</td>
<td>1800</td>
</tr>
<tr>
<td>1600</td>
<td>1600</td>
</tr>
<tr>
<td>1400</td>
<td>1400</td>
</tr>
<tr>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>0.5 0.6 0.7 0.8 X</td>
<td>1800 2000 2200 2400 V</td>
</tr>
</tbody>
</table>

Note: 1. NETSIM results ————
2. INTERSIM results ————
3. X = Degree of Saturation; V = Volume.
Fig. 14. Comparison Curves Between NETSIM and INTERSIM

<table>
<thead>
<tr>
<th>Geometric Configuration: TYPE 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phasing Scheme: TYPE F</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pretimed Control</th>
<th>Actuated Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>DELAY (Yeh-Hrs)</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>30</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>0.5 0.6 0.7 0.8</td>
<td>2000 2200 2400 2600</td>
</tr>
<tr>
<td>X</td>
<td>V</td>
</tr>
</tbody>
</table>

STOP

Note: 1. NETSIM results  
2. INTERSIM results  
3. X = Degree of Saturation; V = Volume.
Fig. 15. Comparison Curves Between NETSIM and INTERSIM

Geometric Configuration: TYPE 3
Phasing Scheme: TYPE C

<table>
<thead>
<tr>
<th>Pretimed Control</th>
<th>Actuated Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>DELAY (Yeh-Hrs)</td>
<td>DELAY (Yeh-Hrs)</td>
</tr>
<tr>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td>80</td>
<td>160</td>
</tr>
<tr>
<td>5000</td>
<td>4000</td>
</tr>
</tbody>
</table>

Note: 1. NETSIM results    
     2. INTERSIM results     
     3. $X = \text{Degree of Saturation}; V = \text{Volume}$. 
Fig. 16. Comparison Curves Between NETSIM and INTERSIM

Geometric Configuration: TYPE 3
Phasing Scheme: TYPE D

<table>
<thead>
<tr>
<th>Pretimed Control</th>
<th>Actuated Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DELAY (Yeh-Hrs)</strong></td>
<td><strong>DELAY (Yeh-Hrs)</strong></td>
</tr>
<tr>
<td>120</td>
<td>60</td>
</tr>
<tr>
<td>90</td>
<td>45</td>
</tr>
<tr>
<td>60</td>
<td>30</td>
</tr>
<tr>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>0.5  0.6  0.7  0.8  X</td>
<td>2400  2700  3000  3300  V</td>
</tr>
</tbody>
</table>

Note: 1. NETSIM results ————
2. INTERSIM results ————
3. X = Degree of Saturation; V = Volume.
Fig. 17. Comparison Curves Between NETSIM and INTERSIM

Geometric Configuration: TYPE 4
Phasing Scheme: TYPE G

<table>
<thead>
<tr>
<th>Pretimed Control</th>
<th>Actuated Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DELAY (Yeh-Hrs)</strong></td>
<td><strong>DELAY (Yeh-Hrs)</strong></td>
</tr>
<tr>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>0.5 0.6 0.7 0.8</td>
<td>2400 2700 3000 3300</td>
</tr>
</tbody>
</table>

**Note:**
1. NETSIM results
2. INTERSIM results
3. \( X = \) Degree of Saturation; \( V = \) Volume.
Fig. 18. Comparison Curves Between NETSIM and INTERSIM

<table>
<thead>
<tr>
<th>Geometric Configuration: TYPE 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phasing Scheme: TYPE H</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pretimed Control</th>
<th>Actuated Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DELAY (Veh-Hrs)</strong></td>
<td><strong>DELAY (Veh-Hrs)</strong></td>
</tr>
<tr>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Graph" /></td>
</tr>
<tr>
<td><img src="image3.png" alt="Graph" /></td>
<td><img src="image4.png" alt="Graph" /></td>
</tr>
</tbody>
</table>

Note: 1. NETSIM results  ———
2. INTERSIM results  ———
3. X = Degree of Saturation; V = Volume.
Fig. 19. Comparison Curves Between NETSIM and INTERSIM

Geometric Configuration: TYPE 5
Phasing Scheme: TYPE B

<table>
<thead>
<tr>
<th>Pretimed Control</th>
<th>Actuated Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>DELAY (Yeh-Hrs)</td>
<td>DELAY (Yeh-Hrs)</td>
</tr>
<tr>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
</tr>
</tbody>
</table>

Note: 1. NETSIM results  
2. INTERSIM results  
3. $X =$ Degree of Saturation; $V =$ Volume.
Fig. 20. Comparison Curves Between NETSIM and INTERSIM

Geometric Configuration: TYPE 6
Phasing Scheme: TYPE A

<table>
<thead>
<tr>
<th>Pretimed Control</th>
<th>Actuated Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DELAY (Yeh-Hrs)</strong></td>
<td></td>
</tr>
<tr>
<td><img src="image1" alt="Graph of Delay" /></td>
<td></td>
</tr>
<tr>
<td><img src="image2" alt="Graph of Delay" /></td>
<td></td>
</tr>
<tr>
<td><strong>STOP</strong></td>
<td></td>
</tr>
<tr>
<td><img src="image3" alt="Graph of STOP" /></td>
<td></td>
</tr>
<tr>
<td><img src="image4" alt="Graph of STOP" /></td>
<td></td>
</tr>
</tbody>
</table>

Note: 1. NETSIM results ———
2. INTERSIM results ———
3. $X = \text{Degree of Saturation}; \quad V = \text{Volume.}$
Table 3. The Summary of Deviations Between NETSIM and INTERSIM

<table>
<thead>
<tr>
<th>Intersection</th>
<th>TYPE 1</th>
<th>TYPE 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pretimed</td>
<td>Actuated</td>
</tr>
<tr>
<td></td>
<td>Delay (Delay)</td>
<td>Stopped (Stops)</td>
</tr>
<tr>
<td>4 - Approach</td>
<td>6.1% 5.4%</td>
<td>8.4% 8.4%</td>
</tr>
<tr>
<td>4 - Intersection</td>
<td>TYPE 3</td>
<td>TYPE 4</td>
</tr>
<tr>
<td></td>
<td>Pretimed</td>
<td>Actuated</td>
</tr>
<tr>
<td></td>
<td>Delay (Delay)</td>
<td>Stopped (Stops)</td>
</tr>
<tr>
<td></td>
<td>6.4% 6.4%</td>
<td>6.7% 10.3%</td>
</tr>
<tr>
<td>5 - Intersection</td>
<td>TYPE 5</td>
<td>TYPE 6</td>
</tr>
<tr>
<td></td>
<td>Pretimed</td>
<td>Actuated</td>
</tr>
<tr>
<td></td>
<td>Delay (Delay)</td>
<td>Stopped (Stops)</td>
</tr>
<tr>
<td></td>
<td>6.9% 11.3%</td>
<td>9.5% 9.8%</td>
</tr>
</tbody>
</table>
8. CONCLUSIONS AND RECOMMENDATIONS

In this report, an effort was made to develop a microscopic model for analyzing traffic flow at intersections. Based on the proposed vehicle generator, vehicles are generated randomly following Poisson and Binomial distributions. In vehicle departures, on the other hand, both protected and unprotected left turning traffic and right turns on red are effectively dealt with. The measures of effectiveness obtained from the output of the program are sufficient to meet the usual needs of traffic engineers. Due to its microscopic nature, the program can be expected to yield results which are more accurate and precise than results obtained using macroscopic modelling. Meanwhile, the simulation results suggest that this model is applicable to most traffic conditions with different degrees of saturation experienced in the field. Therefore, within the limits of the program's operation, and within the geometric and demand limitations tested, the program appears to be an efficient and reliable tool which can be used to evaluate current or future intersection control strategies. A wide range of control alternatives for either four-way or T-intersection, including pretimed, vehicle actuated, and stop sign equipment, may be compared.

As with any other form of analytical tools, this program has its limitations. It is recommended that further research be conducted to eliminate the following assumptions and limitations.

1. In addition to all-way stop sign control, simulation of one-way stop sign control for T-intersection and two-way stop sign control for four-approach intersections should be incorporated into the program.
2. The geometric capabilities should be increased. For instance, left turning and right turning pockets should be added to the intersection configurations, because these turning bays are commonly used in practice.

3. The provision for coordination, i.e. the effect of adjacent signals, should be taken into account. Nearby signals clearly affect the arrival patterns, tending to establish platoons.

4. More detector functions such as delayed calls and lock detector call for each phase could be added to the program in order to enhance detector capabilities. In addition, the maximum number of detectors per lane may need to be increased beyond the current value of two.

5. To enable maximum flexibility in simulating actuated signal control, simulation of volume-density capabilities should be added to the program.

6. It is proposed that the program be modified to simulate pedestrian traffic, including pedestrian arrivals and departures, and pedestrian signal timing parameters.

7. The traffic signal simulation should be modified to accommodate protected-permissive left turns and phase overlaps. In short, the program should allow the user to assign to each phase which movements can be accommodated.

8. The program should be modified to enable signal phasing and timing optimization without requiring the user to perform a trial-and-error procedure.
9. Data should be collected in the field and used to further validate INTERSIM. MnDOT should participate in identifying specific situations which need to be simulated and validated and in identifying sites at which appropriate data can be collected.
REFERENCES


APPENDIX

INTERSIM USER'S GUIDE
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1. INTRODUCTION

INTERSIM (INTERsection SIMulation) is a microscopic simulation program, which provides a computerized method of evaluating alternative control strategies for the isolated intersection. It is developed for intersection design and operational analysis. The program runs on an IBM-PC or compatible for easy data entry and inspection of results. Either four-way or T-intersections can be simulated with either all-way stop sign control or traffic signal control (both actuated and pretimed). Input to the program, entered interactively, includes the geometric configuration, the number of lanes on each approach, lane-by-lane saturation flow rate, speeds, vehicle clearance times, and demands. Phasing arrangement and signal timing are entered when signal control is simulated. Detector information is entered when traffic actuated control is simulated. In addition, shared lane usage, right turns on red, and employing a previously-saved demand pattern can be selected if desired. Measures of effectiveness such as delays, stops, and queue sizes are printed after the simulation is completed. If desired, and if a graphics monitor is being used, the user can watch vehicle arrivals and departures, queue formation and dissipation, and traffic signal indication changes as the simulation proceeds.

It is assumed that the user is familiar to some extent with the principles of traffic signal phasing and timing, and with the
operation of local intersection control equipment. The program
has been designed to be self-explanatory and self-checking. The
former means that users do not need to refer to this manual
unless they have never used the program before. All items to be
input or selected are fully explained at the top of the screens.
The latter means that if the data input exceed the valid range
defined by the program, the user will be asked to re-enter the
data. To be more convenient, some default values have been
prepared for users.

On the INTERSIM program disk, there are five files, two of which
are necessary to operate the program, and sample input and output
files, and demand pattern file. These files are:

<table>
<thead>
<tr>
<th>File</th>
<th>Description</th>
<th>Required/Optional</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTERSIM.EXE</td>
<td>(program file)</td>
<td>Required</td>
</tr>
<tr>
<td>CGA.BGI</td>
<td>(program file)</td>
<td>Required</td>
</tr>
<tr>
<td>SAMPLE.DAT</td>
<td>(sample input)</td>
<td></td>
</tr>
<tr>
<td>SAMPLE.OUT</td>
<td>(sample output)</td>
<td></td>
</tr>
<tr>
<td>README</td>
<td>(if needed)</td>
<td></td>
</tr>
</tbody>
</table>

These files may be copied to other disks, including hard disks,
and the program may be operated on any drive. The only
requirement is that the program files must reside on the current
logged drive and the current sub-directory, if applicable, when
running the program.
2. PROGRAM LIMITATIONS

The INTERSIM program can be used to evaluate current or future traffic control strategies at intersections. But, like other analytical tools, this program has its limitations, which are described as follows.

(1) For stop sign control, the program can only simulate all-way stop sign control.

(2) The maximum number of lanes in each approach is 3 for the signalized control, and 2 for stop sign control. Left or right turning bays and multiple exclusive turn lanes (e.g., dual left-turn lanes) are not simulated.

(3) Special treatment of vehicle types such as trucks and buses is not performed.

(4) Platooned arrival patterns are not simulated because the effect of adjacent intersections are not taken into account.

(5) In vehicle actuated control, this program can only deal with semi- and full-actuated control, not including volume-density control or pedestrian actuated control.

(6) The INTERSIM program is not an optimization simulation program; therefore, deriving an optimum control strategy requires several iterations.
3. HARDWARE AND SOFTWARE REQUIREMENTS

Following is a list of the minimum hardware and software requirement for running the INTERSIM simulation program:

1. An IBM personal computer or compatible with a minimum of 256K memory.
2. At least one disk drive with a minimum of 360K storage capacity.
3. A monochrome monitor and monochrome display adapter and/or a color monitor with graphic capability and color graphics display adapter.
4. An IBM or Epson dot matrix printer with a minimum of 80 columns available at 10 characters/inch.
5. A PC-DOS or MS-DOS operating system, version 2.00 or later.
4. INTERSIM OPERATION

4.1 Program Execution

To start the program, simply type: INTERSIM <Enter> after the operating system prompt, where <Enter> represents the 'ENTER' key on IBM microcomputers (carriage Return on some others). At this time, the program is loaded into the computer's memory from the disk, and the following message is displayed on the screen:

INTERSIM can be executed using any of three monitor configurations. If you have only a monochrome monitor, color plots of input data which you enter and animation of the intersection during the simulation will be unavailable to you. If you have only a color monitor or both a color monitor and monochrome monitor, color plots will be displayed after entering input data. Actual data entry will take place via the monochrome monitor, if available; otherwise, via the color monitor.

1. YOU HAVE BOTH MONOCHROME & COLOR MONITORS
2. YOU HAVE ONLY MONOCHROME MONITOR
3. YOU HAVE ONLY COLOR MONITOR

ENTER YOUR CHOICE : 1

It is very important to choose the correct monitor configuration. An incorrect selection can result in data entry and display problems. After your selection, the program will automatically create a file named MONITOR.SYS, which contains your choice. Subsequently, when you use this program, the program reads the
MONITOR.SYS file automatically and this screen is skipped. If you select an incorrect configuration, return to the Disk Operating System (DOS) from the main menu, erase the MONITOR.SYS file and restart this program. Remember that if you move INTERSIM from one computer to another, copy only CGA.BGI along with the program.

4.2 Drive, Directory and File Name

When the user tries to read a file or to write a file or to list files, a drive and directory may be specified. A file name consists of a path of zero or more directory names separated by backslashes, followed by the actual file name:

```
Drive:\DirName\...\DirName\FileName
```

If the directory path begins with a backslash, the path starts in the root directory; otherwise, it starts in the current directory. If Drive and the colon are omitted, the default (i.e. current) drive is used. "\DirName\... \DirName" is the root directory and subdirectory path to the file name. If Drive and Directory Name are omitted, the file is read from, written to, or listed using the current drive and directory. "FileName" consists of a name of up to eight characters, optionally followed by a period and an extension of up to there characters. The maximum length of the entire file name is 79 characters.
4.3 Main Menu

MAIN MENU

1. BUILD NEW DATA FILE
2. RETRIEVE OLD DATA FILE FROM DISK
3. EDIT CURRENT DATA FILE
4. SAVE CURRENT DATA TO DISK FILE
5. PRINT CURRENT DATA FILE FOR CHECKING
6. LIST FILES ON THE DISK
7. START SIMULATION
8. EXIT TO DOS

ENTER YOUR CHOICE : 1

This main menu manages all functions of this program:

Option 1. BUILD NEW DATA FILE

If this is your first time running INTERSIM, or you do not want to utilize an old data file, select this option. The program then assigns default values to every input parameter in the input screens which follow.

Option 2. RETRIEVE OLD DATA FILE FROM DISK

To retrieve an old data file, select this option. After the file is read into the computer's memory, you can start simulation immediately by pressing 7, or you can press 3 if you wish to change some parameters. For more details on the retrieving procedure, refer to Section 4.3.1.
Option 3. EDIT CURRENT DATA FILE

With this option, the user can enter the editing state to revise some or all of the simulation parameters from the editing menu, i.e. the input menu.

Option 4. SAVE CURRENT DATA TO DISK FILE

The user is urged to save his data file for future use by specifying a file name in this program. If you do not save your data file and select option 8, the program will remind you to save your data with the following message before you leave the program:

WARNING: WITHOUT SAVING DATA FILE, THE DATA FILE WILL BE LOST

Do you wish to save your data file before leaving INTERSIM (Y/N):

For more details on the save procedure, refer to 4.3.2.

Option 5. PRINT CURRENT DATA FILE FOR CHECKING

Data files can be printed to (1) review before editing if you forget the contents of the old data file, or (2) check before simulation. Data files can be printed by themselves or as part of the simulation output. The program can only print the data file currently in computer memory. If you want to print another data file, you must first load that file.
Option 6. LIST FILES ON THE DISK

By selecting option 6, you can list any files in any drive and in any directory (or sub-directory). You can list all files (i.e. *.* ) or only the files with user-specified extension names.

Enter path name (Drive:\DirName\...\DirName\FileName):
Enter file name option (*.DAT/*.PAT/*.OUT):
(To list all entries */.*/ press ENTER)

Option 7. START SIMULATION

Immediately prior to the execution of the main simulation procedures, you will be asked the following questions:

DO YOU WANT THE SIMULATION RESULTS PRINTED? (Y/N):
RANDOM NUMBER SEED (Default Value=8877):
Output File Name (Drive:\DirName\...\DirName\FileName):
(Press ENTER if you do NOT wish to save output file)

* If no printer is available, do not press the 'Y' key.
* For the random number seed, the user can specify any value which is greater than 0 and less than 100,000,000. If the user agrees with the default value, press the ENTER key.
For the same data set and same random number seed, the program produces the same results repeatedly. On the other
hand, using a different random number seed for two simulations will produce different results.

* When writing output files to your diskette, the program automatically adds the output file name extension, .OUT, to the end of the file name you entered. This extension identifies the output files on your disk to distinguish them from the data files. The user can certainly choose his own extension name. Unfortunately, you cannot use this program to print any output files produced in previous runs. To do that, leave INTERSIM first and use the DOS command "MODE" or other utility softwares to format your printer from 80 columns to 132 columns. Refer to the "MODE" command in your DOS reference manual for the proper syntax.

* Simulation in both graphics and text modes can be terminated immediately by pressing the key 'q' or 'Q' (for quit), and the program returns to the main menu.

If an output file name is entered which is identical to a file name which already exists on the disk, the following message will ask whether you wish to overwrite the old (existing) file.

--------------------------------------------
FILE ALREADY EXIST. do you wish to overwrite it (Y/N)?
--------------------------------------------

If 'Y'(yes) is pressed, the old file is erased and new data is saved under the same name. You are prompted for another name if you press 'N'(no).
Option 8. EXIT TO DOS

This option returns you to the Disk Operating System (DOS).

In this program, to enter any information, the ENTER key must be pressed to indicate to the program that the information for that particular item is complete.

4.3.1 Retrieve Procedure

If you wish to edit an old data file, select option 2, loading the file. At this time the following screen is displayed:

```
Enter the name of the file containing the data previously saved. File name extension .DAT is attached automatically by the program. If Drive and the colon are omitted, the default drive is used. If Drive and Directory Name are omitted, the file is read from the current drive and the current directory.

File Name (Drive: \DirName\...\DirName\FileName):
```

If your file has the extension name .DAT, you do not need to enter .DAT, since the program searches for your data file by automatically adding the file name extension .DAT. Otherwise you should give the full name. Data values retrieved from the file are used as the default values for the input parameters.
4.3.2 Save Procedure

Similarly, the data saving procedure is given by option 4.

Enter the file name under which you want to save the current data. The program will automatically attach the .DAT file name extension. If Drive and the colon are omitted, the default drive is used. If Drive and Directory Name are omitted, the file is read from the current drive and the current directory.

File Name (Drive:\DirName\...\DirName\FileName):

By entering a file name above, the data you have entered is saved on the disk and can be recalled at some time in the future. Notice that the program automatically adds the file name extension .DAT onto the end of the file name you entered. This extension identifies the data files on your disk. The user can certainly specify his own extension name. The program is very flexible in that you can save data before or after a simulation. This feature allows rapid editing of data and re-simulation of slightly changed conditions. Like saving output files, it is important to use different file names for data files to avoid writing over an old file.
4.3.3 Type of Control

Type of control decides which input menu you are going to use. In addition to the monochrome screen display shown below. Figure 1 is displayed on the color monitor, if you are using one.

TYPE OF CONTROL
A. Four-Way Stop Sign Control
B. Pre-Timed Signal Control
C. Actuated Signal Control
SELECT TYPE OF CONTROL (A-C): C

4.3.4 Intersection Configurations

Following the screen for type of control is the selection of the intersection configuration. Shown in Figure 2 is the display on the color monitor.
TYPE OF CONTROL

A. ALL-WAY STOP SIGN CONTROL

B. PRE-TIMED SIGNAL CONTROL

C. ACTUATED SIGNAL CONTROL

Figure 1. Alternatives for Type of Control
BASIC GEOMETRY

A  B  C  D  E

Figure 2. Basic Geometric Alternatives
4.4 Input Menu

INPUT MENU FOR SIGNAL CONTROL

1. NUMBER OF LANES 9. MOVEMENT CLEARANCE TIME
2. RIGHT-TURNS-ON-RED 10. LOST TIME
3. LANE USAGE 11. CRITICAL GAP
4. SPEEDS 12. SIMULATION PARAMETERS
5. DETECTORS 13. TRAFFIC DEMANDS
6. SIGNAL PHASING 14. ANIMATION CHOICE
7. SIGNAL TIMING 15. SAVE CURRENT DATA TO DISK
8. SATURATION FLOW RATE 16. RETURN TO MAIN MENU

ENTER YOUR CHOICE: 1

For all data entry screen, default values are shown for the items being entered. The blinking cursor is then placed directly underneath the default value. At this time you can either press
<Enter>, in which case you have indicated to the program that you wish to use the default or the current value, or you can select another option simply by pressing the appropriate key or keys. When you have completed data entry for a category of items, generally all of the items contained on one screen, the program asks if the data you have just entered on the screen are correct. Respond by pressing either the 'Y' key to indicate 'Yes' or the 'N' key to indicate 'No'. If you indicate that the data entered is not correct, the program requires you to re-enter the data.

There are two input menus in this program: one for stop sign control, the other for signal control. Which menu appears depends on the type of control you have selected. Items 5, 6, and 7 in the input menu for signal control shown above are not included in the input menu for stop sign control.

In addition, unlike the main menu, when you have completed an item from the input menu, the program prompts you using the next item in order as the default at "ENTER YOUR CHOICE". For instance, at the beginning the choice number is 1. After you finish item 1 and get back to the input menu, the choice number at "ENTER YOUR CHOICE" is 2, and so on. This encourages you to enter data in an orderly fashion. Certainly, if you wish to change only some parameters, you can select any item you want.
4.4.1 Number of Lanes

<table>
<thead>
<tr>
<th>NUMBER OF LANES PER APPROACH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northbound (maximum=3): 2</td>
</tr>
<tr>
<td>Southbound (maximum=3): 2</td>
</tr>
<tr>
<td>Eastbound (maximum=3): 3</td>
</tr>
<tr>
<td>Westbound (maximum=3): 3</td>
</tr>
</tbody>
</table>

For four-approach intersections controlled by signals, the maximum number of lanes on each approach is three; otherwise, the maximum number of lanes is two. After the number of lanes is entered for all approaches, the color graphics screen is updated with a depiction of the detailed geometric configuration similar to the one shown in Fig. 3. In addition the monochrome screen is changed to summarize the number of lanes entered, as shown below:

<table>
<thead>
<tr>
<th>NUMBER OF LANES PER APPROACH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northbound=2    Southbound=2 Eastbound=3 Westbound=3</td>
</tr>
<tr>
<td>Is this correct (Y/N)?</td>
</tr>
</tbody>
</table>

4.4.2 Right Turns On Red and Lane Usage

The program default value for right turns on red is 'NO'. Right
Figure 3. Graphics Display of Detailed Geometric Alternative
turns on red can be selected on an approach basis from the screen below.

**RIGHT TURNS ON RED PERMITTED**

Northbound (Y/N) : Y
Southbound (Y/N) : Y
Eastbound (Y/N) : Y
Westbound (Y/N) : Y
Is this correct (Y/N)?

The shared lane usage option permits the user to specify the function of the left-most lane on multi-lane approaches, i.e. whether or not the through vehicles may share the lane with the left-turning vehicles.

**LANE USAGE**

On multi-lane approaches, the leftmost lane can be either an exclusive left-turn lane or a lane shared by both through and left-turning vehicles.

Left lane shared by through and left-turning vehicles:

Northbound (Y/N) : Y
Southbound (Y/N) : Y
Eastbound (Y/N) : Y
Westbound (Y/N) : Y
Is this correct (Y/N)?
For single-lane approaches, no shared lane problem exists. In such instances, the above data entry screen does not appear on the screen. Instead, the following message is displayed:

-----------------------------------------------
LANE SWITCHING CANNOT BE PERFORMED
IN AN APPROACH WITH A SINGLE LANE.
press any key to continue...
-----------------------------------------------

4.4.3 Speeds

The program default value is 30 miles per hour. Variations from the default can be entered from the following data entry screen.

**APPROACH SPEEDS**

For each approach, enter the average speed, in miles per hour, of vehicles arriving on the approach.

Northbound : 30
Southbound : 30
Eastbound : 30
Westbound : 30

Is this correct (Y/N)?
4.4.4 Detector Information

The following screen deals with the specification of detector functions, the length of the detection area, and the distance between the detectors and the stop line. The program assumes there are at most two detectors in any one lane. One may be placed at the stop line, and another may be placed upstream of the stop line. If only one detector is selected in a lane, it will perform both call and extend functions. Otherwise, the user must specify each detector's function, using the function codes 'N' for no detector existing, 'C' for call only, 'E' for extend.

<table>
<thead>
<tr>
<th>DETECTOR LOCATION - NORTHBOUND</th>
</tr>
</thead>
<tbody>
<tr>
<td>A maximum of 1 detector at the stop line and 1 detector upstream of the stop line can be specified for each approach lane. Indicate the function of each detector (an 'N' indicates that there is no detector in that location) and the length of the detector area. For an upstream detector, also indicate the distance from stop line to the closest point of the detection area. Length plus Distance should not exceed 600 feet. The lane number is labeled from left to right.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lane1</th>
<th>Lane2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function (N/C/E/B)</td>
<td>C</td>
</tr>
<tr>
<td>Length (feet) of Detection Area</td>
<td>6</td>
</tr>
<tr>
<td>STOP LANE DETECTOR</td>
<td></td>
</tr>
</tbody>
</table>

| Function (N/C/E/B) | E | E |
| Length (feet) of Detection Area | 6 | 6 |
| Distance (feet) from stop line | 120 | 120 |
| UPSTREAM DETECTOR |

Is this correct (Y/N)?
only, and 'B' for both call and extend. The program default values for detector functions are 'C' at the stop line and 'E' upstream of the stop line. The length of detection area is usually 6 feet, and the program uses 120 feet as the default distance from the stop line for upstream detectors.

4.4.5 Phasing and Timing

In the data entry screen shown below, the first two options represent situations in which no northbound movement is serviced simultaneously with any southbound movement. If there is some

<table>
<thead>
<tr>
<th>NORTHBOUND-SOUTHBOUND PHASING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Split phasing occurs when vehicles on opposing approaches -- in this case, Northbound and Southbound, are accommodated by separate, non-overlapping green intervals.</td>
</tr>
<tr>
<td>1. Northbound phase followed by Southbound phase</td>
</tr>
<tr>
<td>2. Southbound phase followed by Northbound phase</td>
</tr>
<tr>
<td>Select 1, 2, 3 : 3</td>
</tr>
</tbody>
</table>

overlapping of movements, for example, northbound and southbound through vehicles being serviced simultaneously, the third option should be selected. If the third option is selected and either of the approaches being considered has a left-turn lane, you are required to provide the input shown in the screen below. In that screen, you indicate for each approach whether or not there is an
exclusive left-turn phase and, if so, whether that left-turn phase precedes (leads) or follows (lags) the phase servicing the through movement.

**NORTHBOUND-SOUTHBOUND PHASING**

Is there a left-turn phase Northbound (Y/N)? Y
Is the left-turn phase
1) leading, or
2) lagging
Select 1 or 2: 1

Is there a left-turn phase Southbound (Y/N)? Y
Is the left-turn phase
1) Leading, or
2) Lagging
Select 1 or 2: 1

Data entry screens above are repeated for eastbound and westbound phasing. When all phasing has been selected, it is displayed on the graphics screen as shown in Fig.4 and 5, and you are asked to verify that the phasing selected matches the desired operation. If not, all of the phasing is re-entered as described above.

**Timing for:**

Southbound Left-turning
Southbound through
Southbound Right-turning

Minimum Green Time (7-255 sec): 16.00
Maximum Green Time (16.00-255 sec): 60.00
Extension Interval (0-9.9 sec): 4.00
Yellow Clearance Interval (3-9.9 sec): 3.00
All-Red Clearance Interval (0-5 sec): 1.00

Are these movements on RECALL (Y/N)? N

Is this correct (Y/N)?
Northbound-Southbound PHASING

Figure 4. Graphics Depiction of Northbound/Southbound Phasing
Figure 5. Graphics Depiction of Eastbound/Westbound Phasing
The timing parameters shown above are for an actuated signal. If
a pretimed signal is selected only one green time is entered for
each phase, no extension interval is entered, and the recall
option does not apply. The minimum green time is the minimum time
that the signal will be displayed green for the movements shown
at the top of the screen each time that phase comes up. The
maximum green time is the maximum time that the green signal will
be displayed for the movements shown after a call for a
conflicting phase is received. If another phase is timing
concurrently with the phase shown, the maximum green time is
controlled by the phase which would extend the green display the
longest amount of time. The extension interval is the amount of
time to extend the green display after a vehicle departs the
extend detector located either at the stop line or upstream of
the stop line. The earliest end of green for a phase is
controlled by the minimum of the current extension counter and
the maximum green time for the phase. The yellow clearance time
is the amount of time that the yellow signal indication is
displayed to the vehicle movements shown, and the all-red
clearance time is the time after yellow clearance interval during
which a red indication is displayed both to the movements just
serviced and to the movements to be serviced next. The recall
option is used to automatically put in a call for the phase after
leaving the phase; consequently, a recalled phase is guaranteed
not to be skipped, even if no demand exists for the phase. If the
recall option is used, the minimum green time is guaranteed for
the recalled phases.
4.4.6 Saturation Flow Rates

SATURATION FLOW RATES

Saturation flow rate (in vehicles per hour) is the maximum number of vehicles which could cross the stop line on an approach lane if there is a constant flow of vehicles, no control (stop sign or signal), and no vehicle executing conflicting movements (e.g., southbound through vehicles conflicting with northbound left-turning vehicles. The valid range for saturation flow rate in each lane is from 100 to 2500 vehicles per hour.

Northbound Left lane : 1700
Northbound Right lane : 1700
Southbound Left lane : 1700
Southbound Right lane : 1700
Eastbound Left lane : 1700
Eastbound Right lane : 1700
Westbound Left lane : 1700
Westbound Right lane : 1700

Is this correct (Y/N)?

The screen above is used to input the saturation flow rate for each lane on each approach. The saturation flow rate, entered in units of vehicles per hour, is the maximum number of vehicles which could be accommodated if the lane were not controlled by a stop sign or signal and no conflicting flows were present. For signal control, this value is used as the maximum rate at which through and right-turning vehicles can depart the stop line if unimpeded by left-turning traffic coming from the opposing direction. The program default values are 1700 vehicles per hour.
4.4.7 Movement Clearance Times

**MOVEMENT CLEARANCE TIMES**

For each of the three types of movement -- left-turning, through, and right-turning -- you should enter the average (in seconds) that a vehicle making such a movement is physically located within the intersection. As for saturation flow rates, determine the clearance time assuming a constant flow of vehicles, no control, and no conflicting movements. Valid range is from 0.0 to 5.0 seconds.

Northbound Left-turning: 3.0
Northbound Through: 2.0
Northbound Right-turning: 2.0

Southbound Left-turning: 3.0
Southbound Through: 2.0
Southbound Right-turning: 2.0

Eastbound Left-turning: 3.0
Eastbound Through: 2.0
Eastbound Right-turning: 2.0

Westbound Left-turning: 3.0
Westbound Through: 2.0
Westbound Right-turning: 2.0

Is this correct (Y/N)?

Movement clearance times are entered in the screen above. These clearance times are the times which a vehicle executing the specified movement will remain within the intersection, effectively blocking vehicles wishing to make a movement from another approach which conflicts with the current movement. To calculate movement clearance time, subtract the time at which a vehicle crosses the stop line from the time at which a conflicting vehicle can proceed. The program default values are 3.0 seconds.
4.4.8 Lost Time

LOST TIME DUE TO STOP AND DRIVER REACTION TIME

Lost time (in seconds) is the additional delay to a vehicle caused by driver reaction time and by having to accelerate from a stopped condition. The valid range is from 0.0 to 5.0 seconds.

<table>
<thead>
<tr>
<th>Location in Queue</th>
<th>Lost time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.200</td>
</tr>
<tr>
<td>2</td>
<td>1.760</td>
</tr>
<tr>
<td>3</td>
<td>1.320</td>
</tr>
<tr>
<td>4</td>
<td>0.880</td>
</tr>
<tr>
<td>5</td>
<td>0.440</td>
</tr>
</tbody>
</table>

Is this correct (Y/N)?

The lost times can be defined as the additional delay to vehicles near the front of a platoon of vehicles due to stopping and due to driver reaction time. If stop sign control is being evaluated, only the lost time for the first vehicle in the queue is entered, since it is assumed that as each vehicle reaches the stop line, it becomes the first vehicle in a new queue. The program default values are the ones shown above.

4.4.9 Critical Gap

Critical gaps, which are entered above, are the average time headways in an opposing flow of traffic which is perceived by the driver of a left-turning vehicle or a right-turning vehicle as being adequate to safely execute a left turn or a right turn.
CRITICAL GAPS

Critical gaps are the average time headway between two consecutive vehicles which is acceptable to a driver who must cross (turning left against opposing flow or passing through crossing flow) or merge with (turning right) the vehicle stream. The valid range for critical gap is from 4.0 to 8.5 seconds.

Critical gap (sec) for Left-turning vehicles: 5.500
Critical gap (sec) for Right-turning vehicles: 5.500

Is this correct (Y/N)?

through an opposing stream. A value for critical gap is entered only if signal control is being used. The program default values are 5.5 seconds.

4.4.10 Simulation Parameters

Before the user enters his simulation time data, he will be asked the following question:

Do you want to utilize a saved demand pattern (Y/N)?

The demand pattern feature allows the user to employ the demand fluctuation characteristics from one intersection at a second intersection without collecting demand data in the same detail. Answering "Yes" to the above question indicates to the program that it should apply the peaking characteristics, previously saved in a user-specified file, to the demand data the user is
about to enter. The user may have 5- or 15-minute peaking characteristics which are to be applied to an intersection for which only 60-minute counts are available. For more detailed information concerning the demand pattern feature, refer to the appropriate section in the final report.

**SIMULATION TIME DATA**

The intersection may be simulated for a period of up to 24 hours, consisting of one or more time slices. All time slices are of equal duration. The duration of a time slice may be from 5 minutes to 60 minutes, in various increments. In addition, an initialization time may be specified. The initialization time is a period of simulation, from 0 to 15 minutes long, prior to the first time slice. During initialization, vehicles are loaded into the system. If no initialization time is specified, the system is assumed to be empty at the start of the first time slice. No statistics are recorded during the initialization period.

<table>
<thead>
<tr>
<th>Initialization Time (0-15 minutes)</th>
<th>: 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration of Each Time Slice</td>
<td>: 60</td>
</tr>
<tr>
<td>(5/10/15/20/30/60 minutes)</td>
<td></td>
</tr>
<tr>
<td>Start Time for Simulation (hh:mm)</td>
<td>: 08:00</td>
</tr>
<tr>
<td>(hh=00-23;mm=00/15/30/45)</td>
<td></td>
</tr>
<tr>
<td>Total Simulation Time (minutes)</td>
<td>: 60</td>
</tr>
</tbody>
</table>

Is this correct (Y/N)?

The initialization time, up to 15 minutes, is used to load the initially empty system with vehicles to create a beginning state for the intersection simulation. During the initialization time, delay, stop, and queue statistics are not recorded, so that the
values reported at the end of the program do not contain data from this initial period.

The actual simulation follows the initialization period. The actual simulation can be as long as 24 hours and can be split into several time sub-intervals (called time slices in the program) which are equal in duration. The maximum duration of each time slice is 60 minutes, but cannot be less than 5 minutes. Utilizing several time slices has two significant advantages.

First, since vehicle demands are entered for each time slice, the peaking characteristics of an intersection can be simulated. Second, because output is obtained on a time slice-by-time slice basis, it is possible to determine during which time periods problems may develop at an intersection. If the user employs a saved demand pattern, the start time and the terminating time of the simulation must be within the time frame for the demand pattern data.

4.4.11 Vehicle Demand Data

In the screen below, the number of vehicles making each possible movement on each approach during the indicated time slice is entered. After the demand data for each time slice is entered, a bar graph representing the demand for the time slice is displayed on the color monitor. An example of such a display is shown in Fig. 6. Each movement is displayed using a different color.
VEHICLE DEMAND DATA -- Time Slice 1 (08:00--09:00)

Northbound Demand (vph)
Left-turning : 43
Through : 643
Right-turning: 170

Southbound Demand (vph)
Left-turning : 43
Through : 643
Right-turning: 170

Eastbound Demand (vph)
Left-turning : 250
Through : 496
Right-turning: 83

Westbound Demand (vph)
Left-turning : 250
Through : 496
Right-turning: 83

Is this correct (Y/N)?

Due to the capacity of the screen, the next screen will give you a summary of the data you just entered and ask you if the data are correct.

VEHICLE DEMAND DATA -- Time Slice 1 (08:00--09:00)

<table>
<thead>
<tr>
<th></th>
<th>L.T.</th>
<th>THRU</th>
<th>R.T.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northbound</td>
<td>43</td>
<td>643</td>
<td>170</td>
</tr>
<tr>
<td>Southbound</td>
<td>43</td>
<td>643</td>
<td>170</td>
</tr>
<tr>
<td>Eastbound</td>
<td>250</td>
<td>496</td>
<td>250</td>
</tr>
<tr>
<td>Westbound</td>
<td>250</td>
<td>496</td>
<td>250</td>
</tr>
</tbody>
</table>

Is this correct (Y/N)?
Figure 6. Bar Graph of Demand for One Time Slice
In addition, if you create two or more time slices and you do not use a saved demand pattern, the program asks if you wish to save this demand pattern for the future use. The saving procedure is the same as for saving a general data file, with the program employing the file name extension .PAT unless overridden.

--------------------------------------------------
You have created more than one time slice now.
Do you want to save this demand pattern (Y/N)?
--------------------------------------------------

4.4.12 Option of Visual Simulation

ANIMATION

The intersection simulation can be shown visually on the graphics screen as it proceeds, depicting vehicles on all approaches as they become queues and as they are serviced. However, the visual representation significantly slows down the simulation. Consequently, if you desire results quickly, you should not select this option.

Do you want the simulation displayed on the graphics screen(Y/N)? Y

A delay factor of 500 will result in a simulation of approximately 1 second of simulated time per 1 second of actual time on a standard IBM PC. Enter the delay factor (an integer from 0 to 10000) you would like for the screen display of the simulation: 500

This screen determines whether or not a visual representation of the simulation as it proceeds will be displayed on the color graphics monitor. An example of the visual representation of the
simulation is represented in Fig. 7. In that figure it can be seen that the current time slice and the current simulated clock time within that time slice are displayed in the upper left corner. The center of the screen consists of a graphic representation of the current intersection conditions, including the current signal indications for all approaches, the current queue size in each lane on each approach (each queued vehicle is represented by a yellow rectangle on the color screen), and any departures which occurred during the current second of simulation. Departures are indicated by green lines emanating from the stop line in the appropriate lane on each approach. The trajectory of the green line indicates the movement executed by the departing vehicle. The example shows the departure of a through vehicle southbound and a northbound vehicle making a right turn to the eastbound direction.

If the visual simulation option is not selected, the final simulation results can be obtained in a fraction of the time. Because the program requires time to draw and update on the graphics screen, requesting the visual simulation significantly slows the program. Various tests performed indicate that without the visual simulation, simulation of a one-hour time period requires approximately ten minutes of computer time on an IBM-AT or compatible.
Time Slice 1
Hr: Min: Sec
3: 4: 29

Figure 7. Graphics Screen Display During Simulation
The user can interrupt the simulation by pressing the "Esc" key at any time to toggle the visual display of the simulation on the graphics screen off and on. To avoid users' facing a blank screen, the exchange between text mode and graphics mode occurs only at the end of a completed minute in simulation. The "Esc" key is also pressed to return to graphics mode from the text mode.
5. SAMPLE INPUT AND OUTPUT

The sample input summary and output obtained from INTERSIM are shown in Fig. 8 and 9. If the user simulates two or more time slices, he will be given not only the results table for the entire simulation but also the time-slice based results tables. In each table, results are tabulated for each lane on each approach and for the total intersection.

The column labelled 'Vehicles Arrived' indicates the number of vehicles which arrived during the simulation (or time slice). These values correspond to the demands which were entered as input. The column labelled 'Vehicles Serviced' indicates how many vehicles crossed the stop line during the simulation. In the table representing the entire simulation, differences between the number of vehicles arrived and the number of vehicles serviced indicate the queue size at the end of the simulation. Small differences, especially when examining signal control, can usually be attributed to residual queues related to the cyclic operation of the signal. Substantial differences between the number of vehicles arrived and serviced indicate that the combination of geometric configuration, type of control, and, if signal timing is used, the phasing arrangement and timing, cannot adequately accommodate the demands.

Values for total delay, in vehicle-hours, are reported as well as
two values for average delay, in seconds per vehicle. For stop sign control, the number of stops is obviously equal to the number of arrivals. For signal control, total stops consist of primary stops and secondary stops (definitions refer to Section 3.7). The average number of stops per vehicle based on the total stops are also included in the tables. Two types of average values are included for each measure since it is debatable whether the average should be based on the number of vehicles arrived (Average 1) or on the number of vehicles actually serviced (Average 2). Finally, the maximum and average queue sizes encountered during the simulation are tabulated. The average queue size reported is a measure of the average queue size which would be observed in each lane if snapshots of the intersection were taken randomly during the simulation (or time slice).
Figure 8. Input Summary

**SUMMARY OF INPUT**
(08:00--09:00  December 6, 1988  Tuesday)

**CONFIGURATION: 4-APPROACH INTERSECTION**

**TYPE OF CONTROL: ACTUATED SIGNAL**

**RIGHT-TURN-ON-RED**
Northbound: Y  Southbound: Y  Eastbound: Y  Westbound: Y

**OPTIONS OF SHARED LANE**
Northbound: Y  Southbound: Y  Eastbound: Y  Westbound: Y

**NUMBER OF LANES**
Northbound: 2  Southbound: 2  Eastbound: 3  Westbound: 3

**SPEED PARAMETERS (mph)**
Northbound: 30  Southbound: 30  Eastbound: 30  Westbound: 30

**DISTANCE BETWEEN DETECTOR AND STOP LINE (feet)**
<table>
<thead>
<tr>
<th></th>
<th>Northbound</th>
<th>Southbound</th>
<th>Eastbound</th>
<th>Westbound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane 1</td>
<td>Lane 1: 120</td>
<td>Lane 1: 120</td>
<td>Lane 1: 120</td>
<td>Lane 1: 120</td>
</tr>
<tr>
<td>Lane 2</td>
<td>Lane 2: 120</td>
<td>Lane 2: 120</td>
<td>Lane 2: 120</td>
<td>Lane 2: 120</td>
</tr>
</tbody>
</table>

**THE PERFORMANCE OF DETECTORS AT STOP LINE**
( N)o detector; C)all only; E)x tend only; B)oth call and extend )

<table>
<thead>
<tr>
<th></th>
<th>Northbound</th>
<th>Southbound</th>
<th>Eastbound</th>
<th>Westbound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane 1</td>
<td>Lane 1: C</td>
<td>Lane 1: C</td>
<td>Lane 1: C</td>
<td>Lane 1: C</td>
</tr>
<tr>
<td>Lane 2</td>
<td>Lane 2: C</td>
<td>Lane 2: C</td>
<td>Lane 2: C</td>
<td>Lane 2: C</td>
</tr>
<tr>
<td>Lane 3</td>
<td>Lane 3: C</td>
<td>Lane 3: C</td>
<td>Lane 3: C</td>
<td>Lane 3: C</td>
</tr>
</tbody>
</table>

**THE PERFORMANCE OF DETECTORS AT UPSTREAM**
( N)o detector; C)all only; E)x tend only; B)oth call and extend )

<table>
<thead>
<tr>
<th></th>
<th>Northbound</th>
<th>Southbound</th>
<th>Eastbound</th>
<th>Westbound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane 1</td>
<td>Lane 1: E</td>
<td>Lane 1: E</td>
<td>Lane 1: E</td>
<td>Lane 1: E</td>
</tr>
<tr>
<td>Lane 2</td>
<td>Lane 2: E</td>
<td>Lane 2: E</td>
<td>Lane 2: E</td>
<td>Lane 2: E</td>
</tr>
<tr>
<td>Lane 3</td>
<td>Lane 3: E</td>
<td>Lane 3: E</td>
<td>Lane 3: E</td>
<td>Lane 3: E</td>
</tr>
</tbody>
</table>

**THE LENGTH OF DETECTORS AT STOP LINE**

<table>
<thead>
<tr>
<th></th>
<th>Northbound</th>
<th>Southbound</th>
<th>Eastbound</th>
<th>Westbound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane 1</td>
<td>Lane 1: 6</td>
<td>Lane 1: 6</td>
<td>Lane 1: 6</td>
<td>Lane 1: 6</td>
</tr>
<tr>
<td>Lane 2</td>
<td>Lane 2: 6</td>
<td>Lane 2: 6</td>
<td>Lane 2: 6</td>
<td>Lane 2: 6</td>
</tr>
<tr>
<td>Lane 3</td>
<td>Lane 3: 6</td>
<td>Lane 3: 6</td>
<td>Lane 3: 6</td>
<td>Lane 3: 6</td>
</tr>
</tbody>
</table>
Figure 8. Input Summary (cont.)

THE LENGTH OF DETECTORS AT UPSTREAM

<table>
<thead>
<tr>
<th></th>
<th>Lane 1</th>
<th>Lane 2</th>
<th>Lane 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northbound</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Southbound</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Eastbound</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Westbound</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

SIGNAL PHASING (using 8-phase NEMA scheme)

<table>
<thead>
<tr>
<th>Phase</th>
<th>Southbound L.T.</th>
<th>Southbound THRU</th>
<th>Southbound R.T.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 3</td>
<td>Eastbound L.T.</td>
<td>Eastbound THRU</td>
<td>Eastbound R.T.</td>
</tr>
<tr>
<td>Phase 4</td>
<td>Westbound L.T.</td>
<td>Westbound THRU</td>
<td>Westbound R.T.</td>
</tr>
<tr>
<td>Phase 6</td>
<td>Northbound L.T.</td>
<td>Northbound THRU</td>
<td>Northbound R.T.</td>
</tr>
</tbody>
</table>

SIGNAL TIMING (seconds)

<table>
<thead>
<tr>
<th>Phase</th>
<th>Min. Green</th>
<th>Yellow</th>
<th>All-Red</th>
<th>Max. Green</th>
<th>Extension</th>
<th>Recall</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>16.00</td>
<td>3.00</td>
<td>1.00</td>
<td>60.00</td>
<td>4.00</td>
<td>N</td>
</tr>
<tr>
<td>3</td>
<td>16.00</td>
<td>3.00</td>
<td>1.00</td>
<td>60.00</td>
<td>4.00</td>
<td>N</td>
</tr>
<tr>
<td>4</td>
<td>16.00</td>
<td>3.00</td>
<td>1.00</td>
<td>60.00</td>
<td>4.00</td>
<td>N</td>
</tr>
<tr>
<td>5</td>
<td>16.00</td>
<td>3.00</td>
<td>1.00</td>
<td>60.00</td>
<td>4.00</td>
<td>N</td>
</tr>
</tbody>
</table>

SATURATION FLOW RATES (vehicles per hour)
(lanes are numbered left to right)

<table>
<thead>
<tr>
<th></th>
<th>Lane 1</th>
<th>Lane 2</th>
<th>Lane 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northbound</td>
<td>1700</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southbound</td>
<td>1700</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eastbound</td>
<td>1700</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Westbound</td>
<td>1700</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MOVEMENT CLEARANCE TIMES (seconds)

<table>
<thead>
<tr>
<th></th>
<th>L.T.</th>
<th>THRU</th>
<th>R.T.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northbound</td>
<td>3.00</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Southbound</td>
<td>3.00</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Eastbound</td>
<td>3.00</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Westbound</td>
<td>3.00</td>
<td>2.00</td>
<td>2.00</td>
</tr>
</tbody>
</table>

LOST TIME (seconds)

1: 2.200, 2: 1.760, 3: 1.320, 4: 0.890, 5: 0.440

AVERAGE CRITICAL GAP (seconds)

Left-turning: 5.500, Right-turning: 5.500

TIME SLICES AND DEMANDS (vehicles)

<table>
<thead>
<tr>
<th>Time Slice 1 (08:00-09:00)</th>
<th>Northbound</th>
<th>Southbound</th>
<th>Eastbound</th>
<th>Westbound</th>
</tr>
</thead>
<tbody>
<tr>
<td>L.T.</td>
<td>43</td>
<td>43</td>
<td>43</td>
<td>250</td>
</tr>
<tr>
<td>THRU</td>
<td>643</td>
<td>643</td>
<td>499</td>
<td>499</td>
</tr>
<tr>
<td>R.T.</td>
<td>170</td>
<td>170</td>
<td>83</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td>VEHICLES ARRIVED SERVICED</td>
<td>TOTAL DELAY (veh-hrs)</td>
<td>AVERAGE-1 (sec/veh)</td>
<td>AVERAGE-2 (sec/veh)</td>
</tr>
<tr>
<td>---------------</td>
<td>---------------------------</td>
<td>-----------------------</td>
<td>---------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td><strong>Northbound</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane 1</td>
<td>420 213</td>
<td>6.07</td>
<td>52.06</td>
<td>102.64</td>
</tr>
<tr>
<td>Lane 2</td>
<td>432 628</td>
<td>6.11</td>
<td>50.93</td>
<td>35.03</td>
</tr>
<tr>
<td><strong>Southbound</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane 1</td>
<td>435 338</td>
<td>3.62</td>
<td>29.99</td>
<td>38.60</td>
</tr>
<tr>
<td>Lane 2</td>
<td>423 519</td>
<td>3.86</td>
<td>32.83</td>
<td>26.76</td>
</tr>
<tr>
<td><strong>Eastbound</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane 1</td>
<td>271 264</td>
<td>2.33</td>
<td>30.99</td>
<td>31.81</td>
</tr>
<tr>
<td>Lane 2</td>
<td>275 260</td>
<td>2.41</td>
<td>31.57</td>
<td>33.39</td>
</tr>
<tr>
<td>Lane 3</td>
<td>281 290</td>
<td>3.00</td>
<td>38.43</td>
<td>37.24</td>
</tr>
<tr>
<td><strong>Westbound</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane 1</td>
<td>271 269</td>
<td>2.32</td>
<td>30.83</td>
<td>31.05</td>
</tr>
<tr>
<td>Lane 2</td>
<td>277 261</td>
<td>2.56</td>
<td>33.31</td>
<td>35.35</td>
</tr>
<tr>
<td>Lane 3</td>
<td>271 283</td>
<td>2.93</td>
<td>38.93</td>
<td>37.28</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>3356 3325</td>
<td>35.22</td>
<td>37.78</td>
<td>38.14</td>
</tr>
</tbody>
</table>

AVERAGE-1 is per vehicle arrived
AVERAGE-2 is per vehicle serviced