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A GPSS/360 Computer Model for Simulation of Automobile Traffic at Road Intersections

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A GPSS/360 COMPUTER MODEL FOR SIMULATION OF AUTOMOBILE TRAFFIC AT ROAD INTERSECTIONS

BY

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RESEARCH REPORT

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I. INTRODUCTION

1. PROBLEM

The proper design of road intersections is crucial in the planning of highway and road networks. The capacity of a road network is as good (or bad) as the capacities of its individual intersections. "Since the operation of intersections may often be the critical factor in determining the overall capacity and performance of the highway network, traffic engineers are continually faced with the problem of controlling flows at intersections in order to improve total performance. This problem is complicated by the fact that each intersection has unique characteristics of physical layout, vehicle flow rates, turning movements, pedestrian movements, and so forth." [1]

The primary goal in intersection design is to reduce congestion. The traffic engineer should optimize the traffic flow by allowing cars to pass through as quickly as possible. Therefore, a criterion of a well designed intersection is minimum delay through the intersection. The traffic engineer may use travel time as a measure of the congestion or delay. [2] In addition, the average and maximum queue lengths are also important design factors, being measures of the congestion.

The problem is to forecast the vehicle travel times, the average queue lengths and the maximum queue lengths for any proposed design. The engineer requires competent methods of obtaining estimates for these parameters.

2. THE APPROACH

A method by which vehicle performance at a road junction can be predicted is computer simulation. This method has grown more attractive with the increased availability of digital computers and special simulation programming languages, and allows the engineer to construct and test the dynamics of a traffic system through the use of a computerized model of that system. The model is subjected to various inputs and operating situations to explore the nature of results which might be obtained from the real system if it were itself to experience the same kind of inputs and operating conditions. The model is designed to react to the various operating conditions in a manner quantitatively similar to the system itself, providing measurements which would usually be difficult to obtain in any other way.

The computer model presented in this report was written for a signalized intersection. It employs the GPSS/360 computer language.

3. BACKGROUND OF INTERSECTION SIMULATION

Historically, three general approaches have been used to determine performance at intersections; theoretical, empirical, and simulation.[3] The theoretical approach uses methods based on such theoretical considerations as follow-the-leader models,[4] queueing theory, fluid flow analogies, and kinetic theory.[5] The empirical approach employs previously made field observations to predict average performance characteristics for a proposed intersection design. The third, and newest, approach is computer simulation.

Simulation techniques are utilized when the system under consideration would be difficult to analyse using formal analytical methods or empirical formulas; when such solutions would be difficult to obtain within a reasonable period of time; or when a simulation study could offer a higher probability of being accurate. Simulation can also be used as an extension to the more traditional methods used by engineers in investigating traffic phenomena.

Various traffic simulation studies are reported in the literature. However, the author has found none that employed GPSS/360 (currently the most popular of the simulation languages).

The most extensive effort to simulate intersection traffic flow appears to be IBM's Vehicle Traffic Simulator (VTS), developed as a tactical tool for traffic system engineers.[6] This program was written in a special version of GPSS II and in the FAP assembly language. GPSS II is an early version of GPSS designed to run on the IBM 7090/94 systems. VTS relies on GPSS II for its structure, but a number of special assembly language subroutines were added to the program.

4. OBJECTIVES OF MODEL

The objective of this report is to provide a simulation model in terms of the GPSS/360 language. This is worthwhile for several reasons. VTS uses the GPSS language, but the program is owned by IBM. Secondly, since the IBM 7090/94's are older machines, most users of VTS would have to emulate the special version of GPSS II and the FAP language, and this would involve added cost and time. Thirdly, GPSS/360 is the most prominent computer simulation language today. It has received a substantial amount of exposure and is an excellent simulation tool. IBM has made it available to a large proportion of computer users and students.[7]

The model will simulate the movement of vehicles within a road intersection, and will determine and collect statistics on the average as well as total travel time and backup of vehicles in approach lanes.

It if furthermore the objective of this project to provide design personnel with a useful predictive tool for varieties of traffic situations. The goal is, therefore, to facilitate model and program modifications for changes in signal timing, vehicle flow rates, and percentage turning movements. A flexible model and program should enable these parameters to be varied without a complete recoding of the computer program. A major advantage of digital simulation is its speed in determining the effects of parameter changes on the measures of performance. If all the design parameters are varied, the combination of values producing the optimum measure of performance can be determined.

Since it is also desirable to keep the cost of computer runs reasonably low, a secondary consideration has been to restrict the central processor run time to an economically acceptable limit.

II. MODEL

1. DESIGN CONCEPT

Modeling can be thought of as being a representation of a system in a symbolic or physical form suitable for demonstrating the way the system behaves. A model is a substitute for some real equipment or system. "As an abstraction, simplification, or idealization of the system or event, the model helps to describe or in some sense duplicate it."[8] The model can be a basis for experimental investigations at lower cost and in less time than trying changes in the actual system.

Models are usually categorized as being either physical or symbolic. Symbolic models in turn can be thought of as analytical, numerical, or stochastic.[9] The present intersection model will fit into the last category. Stochastic models have the ability to represent random phenomena; stochastic simulation models require the generation of random numbers. The intersection model in this report will utilize a probabilistic description of incoming traffic flow using the GPSS/360 random number generators.

Although few physical systems are wholly continuous or discrete, most systems have one or the other type of change predominate. Systems in which changes are predominantly smooth are called continuous systems, while those in which changes are predominantly discontinuous are called discrete systems.[10] Since systems can thus usually be classified as being either continuous or discrete, there exist correspondingly two general categories of simulation languages: continuous and discrete.

Though the flow of vehicular traffic is a continuous process, a discrete type language was chosen here for its simulation. It was felt that the study of the continuous process could be simplified by considering the changes to occur as a series of discrete steps, and yet have the situation be accurately portrayed. The intersection problem with its emphasis on the interaction between vehicles does not necessarily require the computer to continuously simulate the activities of the vehicles. Instead, the simulation program can look ahead to each occurrence of a change of state in the system and then evaluate the situation.

Discrete event simulation programs such as GPSS/360 record the passage of time by a number referred to as clock time which indicates how many units of simulated time have passed since the start of the simulation. GPSS/360 updates the clock time by advancing it ahead to the time of the next most imminent event. That event is then executed; i.e., the affected transaction is moved to another block in the model.

The use of GPSS/360 will allow the intersection to be described naturally in the structure of the GPSS language. The situation described involves the flow of discrete items (vehicles) which are advancing through storage areas (traffic lanes) and processed in a set of facilities (decision points and collision points).

Figure 1, a general block diagram, shows the general concept of the model. GPSS/360 allows the use of block diagrams to describe systems.[11] The intersection is described as a block diagram in which the blocks represent activities, and lines joining the blocks indicate the sequence in which the activities are executed. The exact mechanism within each of these blocks will be described in later sections.

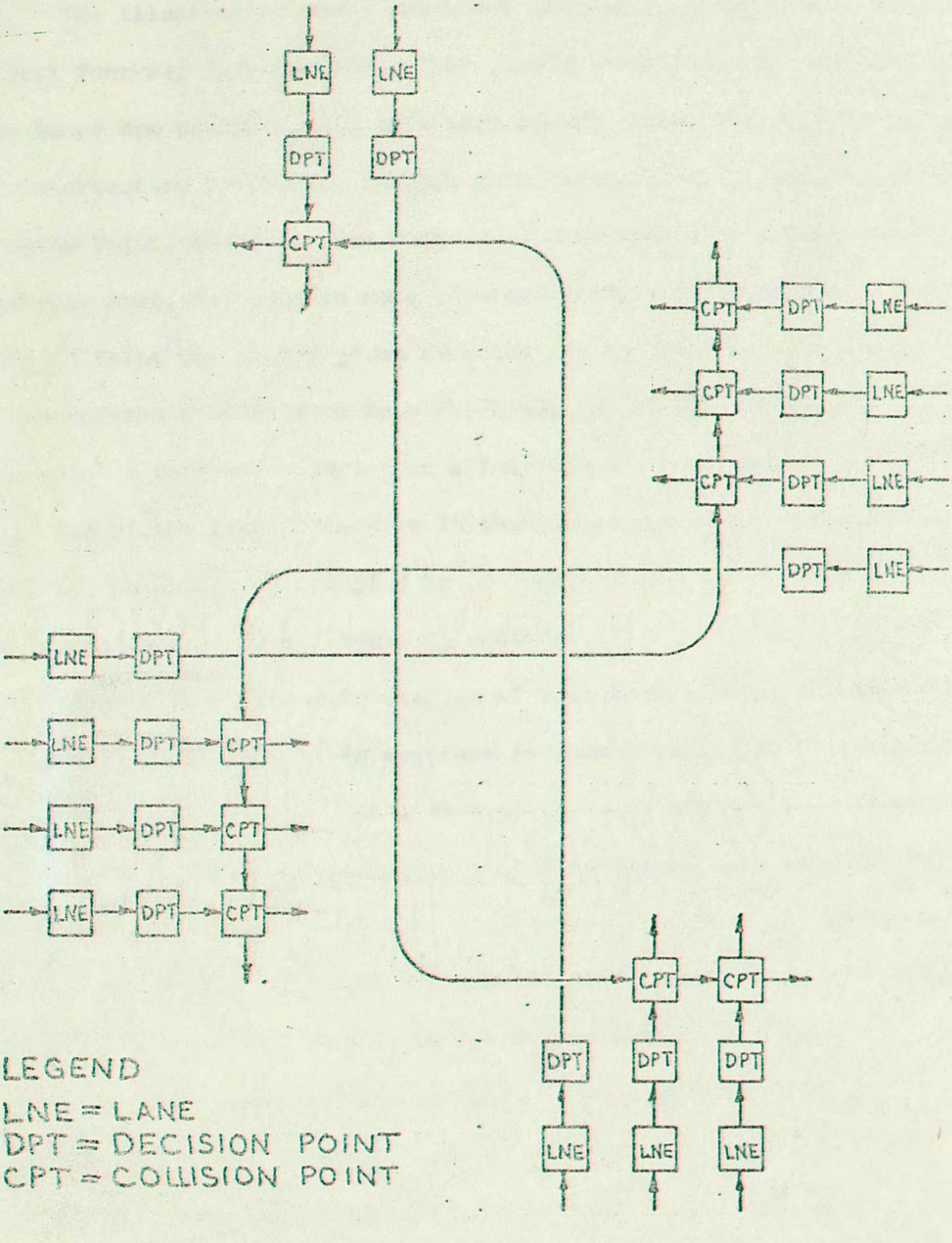


Fig. 1.--General Flow Diagram Showing Basic Concept of the Model.

The illustration shows the block diagram for traffic flow in a typical four-way intersection. There are several lanes in each direction. Some lanes are restricted to left-turn traffic only. Vehicles pass through the intersection by passing through three basic block types: Lane, Decision Point, and Collision Point - in that order. The Lane, being a storage area, may contain more than one vehicle (transaction). The Decision Point may at any given time contain only one vehicle and is used to control the traffic flow from the Lane. It allows vehicles to proceed at a rate which varies as a function of the state of the traffic light and of the traffic density in the opposing traffic stream. The collision point can be occupied by one vehicle only (at any given time) and may be entered from several directions.

Figure 2, a schematic diagram of vehicle-transaction flow in the GPSS model, illustrates this sequence in more detail. It is a diagram of the typical sequence of events, from start to finish. The vehicle-transaction is initially generated with a specified mean interarrival time. All transactions arriving from the same direction of approach (East, West, North, or South) are generated in this first block. Figure 2 shows the sequence for traffic in one of the four directions.

The transaction is next assigned several parameter values and queue designations. Parameter 1 is assigned a value which indicates whether the vehicle will turn left, right, or go straight ahead. This value is used in the decision block in which the transaction branches to an individual lane. Parameter 2 is assigned a value which indicates the direction from which the vehicle arrived (East, West, North or South). The value of Parameter 2 is used to determine in which direction the

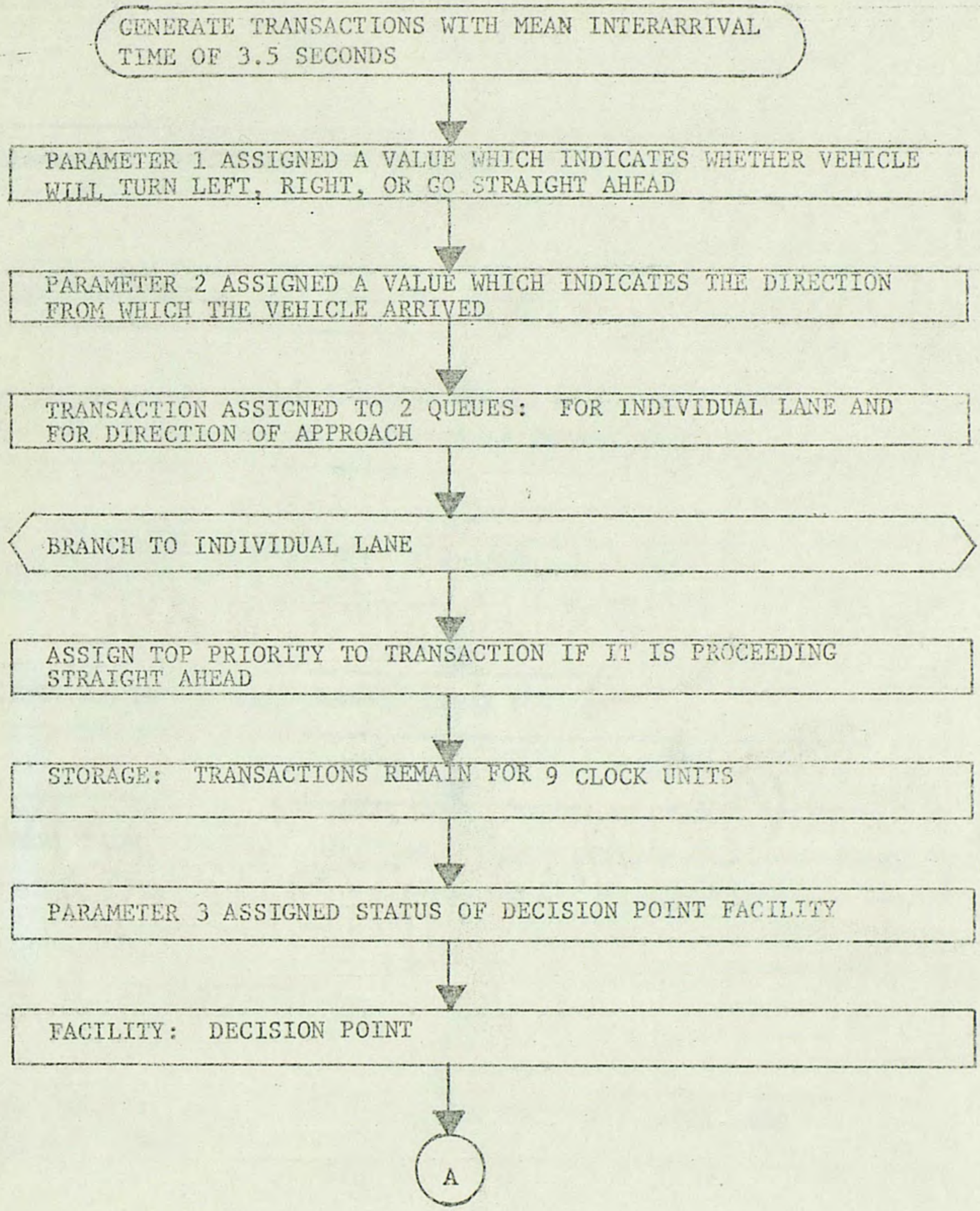


Fig. 2.—Schematic Diagram of Vehicle-Transaction Flow in GPSS Model.

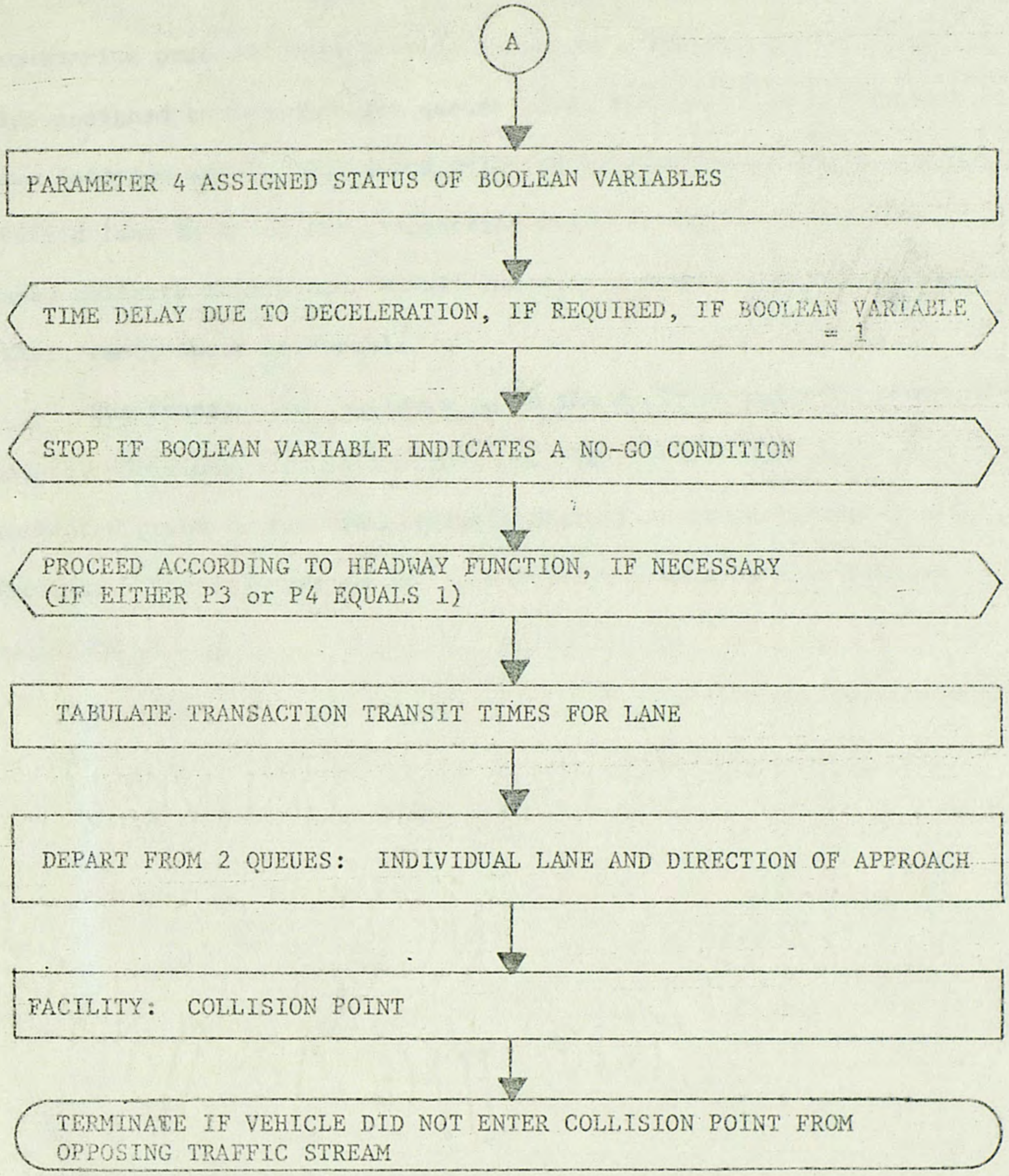


Fig.2.--(continued)

transaction proceeds when leaving a Collision Point. Each transaction is also assigned to two distinct queues after proceeding to its individual lane (storage area). One queue collects information on the single traffic lane in which the transaction will travel, while the second queue collects information on all lanes in a single direction of approach (East, West, North or South).

The transaction continues on to the decision point facility, where several decisions must be implemented. Statistical data will be collected prior to the transaction's entry into the collision point facility. The transaction is finally terminated after leaving the collision point.

2. FEATURES OF THE MODEL

The simulation model and program are general in structural characteristics to permit changes in the physical representation of the intersection. However, for the purpose of validating the model, a specific intersection was chosen as the physical model for which the program was designed. This intersection was selected because of its relatively complex traffic pattern, because it is in a well known section of the local area, and because it has been of interest to local traffic engineers.

2.1 Intersection Characteristics

The junction is situated in the city of Orlando, Florida, and includes the following characteristics:

(a) Signalized traffic control

(b) Pretimed signals

(c) Multiphase operation of signals, including separate left turn phases.

Figure 3 shows a simplified layout of the selected area, the crossing of Bumby Avenue with Colonial Drive (State Highway 50). The site is located at the busy northwest corner of a shopping center. There are altogether 13 approach lanes, four of which are restricted to left turn traffic. As indicated, the left turn lanes are limited with respect to the maximum number of vehicles in them.

Figure 4 shows the time apportionments for the various signal lights, measured with a stop watch. Total cycle time was measured to be 70.0 seconds.

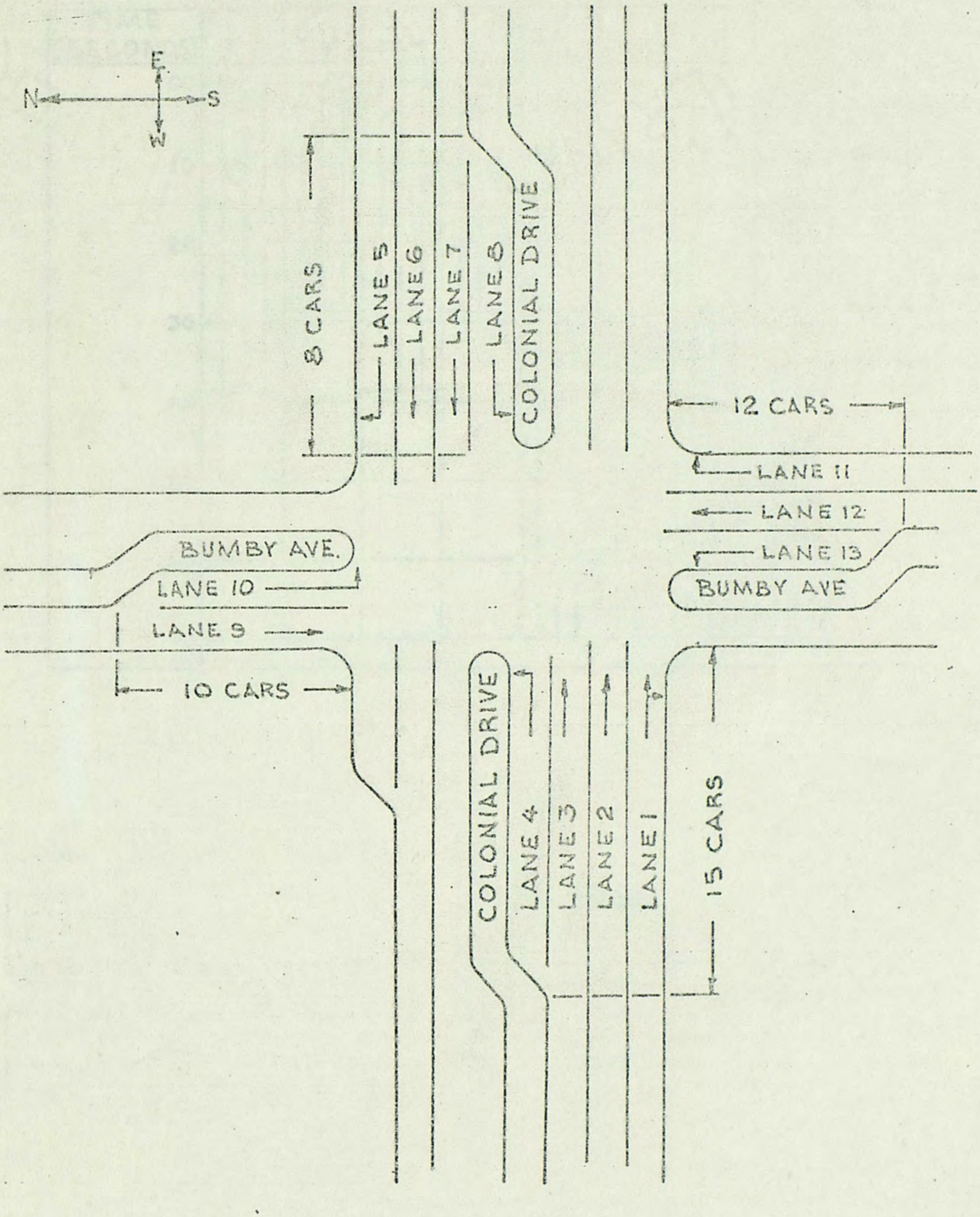
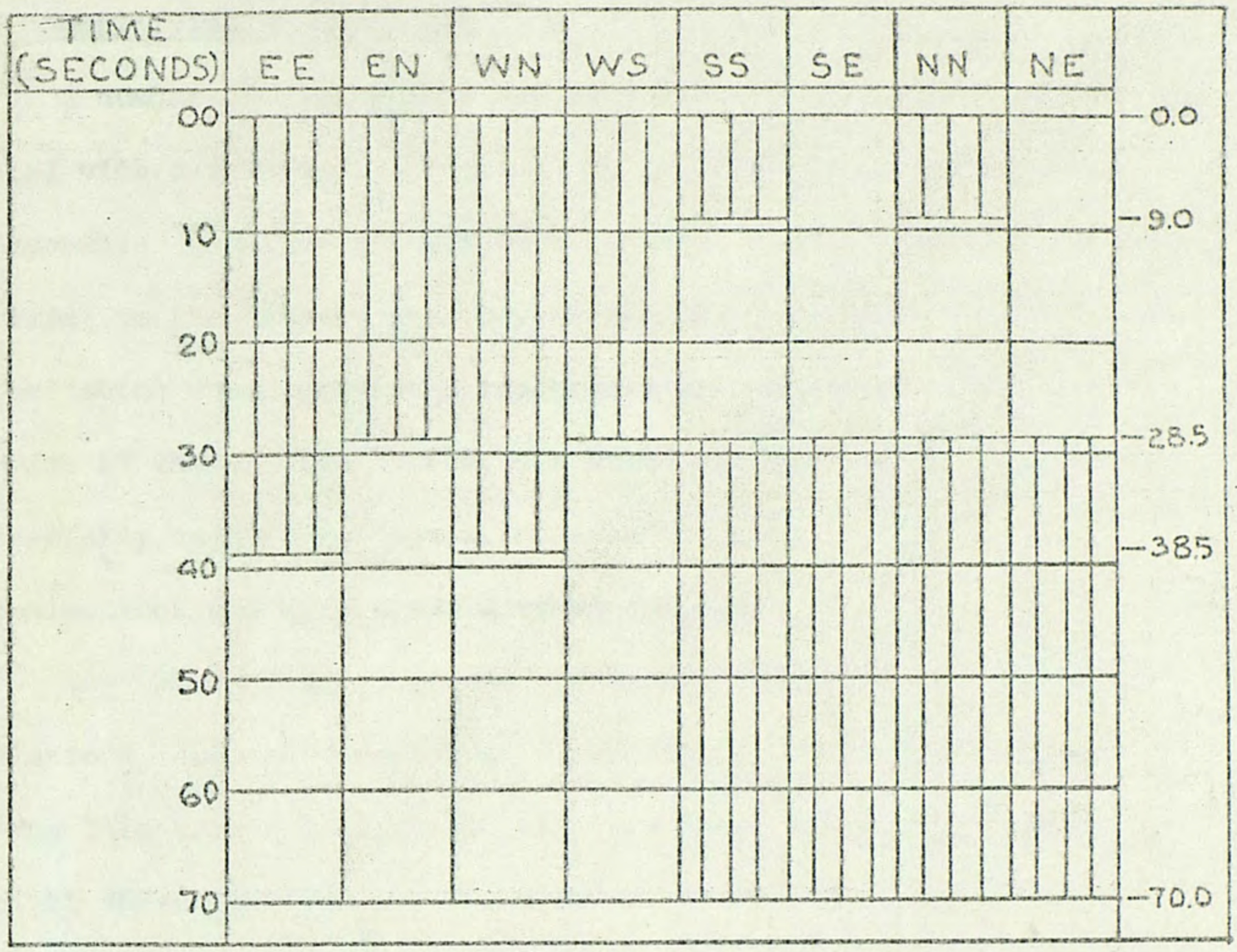


Fig. 3.--Intersection Layout of Colonial Drive and Bumby Avenue.



LEGEND:

RED LIGHT

GREEN & YELLOW LIGHTS

Traffic Lights

EE - East to East
EN - East to North
WW - West to West
WS - West to South
SS - South to South
SE - South to East
NN - North to North
NW - North to West

Fig. 4.—Signal Light Timing at Colonial Drive and Bumby Avenue.

2.2 Simplifying Assumptions

A number of assumptions and approximations were required in order to deal with a manageable program. By avoiding excessive details, unreasonable computing efforts were avoided, with a hopefully negligible detriment to the desired accuracy of results. The goal was to formulate a model which would provide a reasonably accurate prediction of the behavior of the traffic system, yet would not penalize the user with unreasonably excessive computational and programming times. The approximations and hypotheses were as follows:

(a) Without any exception, drivers are obeying the traffic regulations, such as stopping at a red light, proceeding on green, turning left from a designated left turn lane, and giving priority to straight ahead traffic.

(b) Vehicles are of equal size. In a waiting line, the spacing between vehicles is uniform.

(c) Vehicles do not experience malfunctions. Emergency situations never arise.

(d) Uniform acceleration and decelerations rates for all vehicles.

(e) The time period assigned to the yellow warning light is considered as part of the green (go) cycle.

(f) Left turning vehicles will require the same amount of time to clear the intersection as straight-through movements.

(g) Intersection treated as an isolated area, although this is not completely realistic due to the proximate locality of neighboring intersections.

(h) Data on entrance and headway times similar to those reported by Greenshields et. al.[12] This concerns the time required for the first vehicle to enter the intersection after the light turns green, and the headway between successive vehicles in line as they enter the intersection. See section 2.10 of this report for further discussion of the subject.

(i) No weaving of vehicles between lanes.

(j) Exponential arrival rates. See section 2.6 of this report.

(k) No pedestrians.

2.3 Measures of Performance

The engineer that wants to improve an existing traffic intersection, or to construct a new one, should select well-defined quantitative yardsticks on which to base the design. Definitions are needed for the exact meaning of "congestion" and "delay". It would not be adequate merely to state that "congestion is reduced"; one or more explicit numerical measures of performance are needed to give a quantitative expression of "how much" the congestion is reduced. Three such measures were selected for this study:

(a) The average travel time for a vehicle in the intersection area.

(b) The average backup (queue length).

(c) The maximum backup.

Travel time is the total elapsed time of travel, including stops and delay, necessary for a vehicle to travel from one point to another over a specified route and under existing traffic conditions. Congestion and delay may be evaluated by means of travel time data.[13] The travel time data includes stopped time delay, time losses due to deceleration and acceleration, as well as the normal travel time (without delays).

Each of the three measures can be obtained for individual lanes, for individual directions of approach containing several lanes, and also for the entire system. When stated for the entire system, they provide a measure of the combined, overall effectiveness. The measures are represented by numerical values. These will allow intersection performance to be stated in quantitative terms and will serve to provide the factual data needed to evaluate the operation of the intersection.

2.4 Model Segments

The model is composed of the following major segments:

A. Movement of vehicles through the intersection.

1. Arrivals from West.
2. Arrivals from East.
3. Arrivals from North.
4. Arrivals from South.

B. Control light timing.

C. Headway function clocks.

1. East to East function.
2. East to North function.
3. West to West function.
4. West to South function.
5. South to South function.
6. South to East function.
7. North to North function.
8. North to West function.

D. Specification of simulation run lengths.

Details on these model segments will be provided throughout the remainder of the report.

2.5 System Boundaries

A fundamental concept in formulating the model is the specification of a boundary for the system. The system's interactions occur within the boundary. This boundary is defined in such a way that its interior elements and interactions do not have a relevant effect on components outside the boundary.[14] For the traffic intersection problem, boundaries have been chosen as follows:

(a) Vehicles enter the system upon "arrival" at the intersection area or region. Arrival constitutes (1) entry to within a specified distance from the curb line, or (2) joining a waiting line, - whichever occurs first. For example, a car approaching from the West will pass the system boundary at 15 car lengths[15] from the curb line, the defined area of approach, unless 15 or more cars are already backed up in line, in which case the vehicle will pass through the boundary wherever it joins the queue.

(b) Vehicles depart the system on departure from the last collision point along their route. Collision points are those points in the intersection area where vehicles would collide if both arrived at the same time.

2.6 Arrival Rates

Analysis has shown that the Poisson distribution can, assuming that arrivals are randomly distributed over time, be used to predict vehicle arrival rates, and that the exponential distribution can, in turn, be used to describe headways.[16] However, the assumption of randomly distributed arrivals is not valid for heavy traffic, since experimental work has demonstrated that traffic can be considered random only at light flows. It was decided that the Poisson distribution should be an adequate approximation for this study for the case of light to medium traffic flows of less than 500 vehicles per hour per lane. The exponential function has the advantage of being a single distribution function. For simulation of higher vehicle flow rates, a suggested modification to the exponential gap-distribution function would require the use of multiple distribution functions. The use of the gamma probability function has also been suggested.

2.7 Conflict Points

In the vicinity of an intersection, road users must adjust their speed to avoid collision with each other. In the intersection area, the road user may want to transfer from his original route to another route of differing direction, or he may need to cross the paths of extraneous traffic streams which flow between himself and his destination. The road user may therefore find it necessary to (a) diverge from, (b) merge with, or (c) cross the paths of other road users. When such diverging, merging, or crossing occurs, there exists potential conflict between two or more road users.

In the intersection model of this report, diverging traffic occurs at the entrance into the special left lanes (see Figure 5). At these points a car may proceed in either of two directions: straight ahead, or into the left lane. If either of these lanes contained vehicles which were completely backed up to the diverging point, that point would be a source of conflict, since the vehicle at that point would block all traffic which had not as yet passed through it. In order to represent

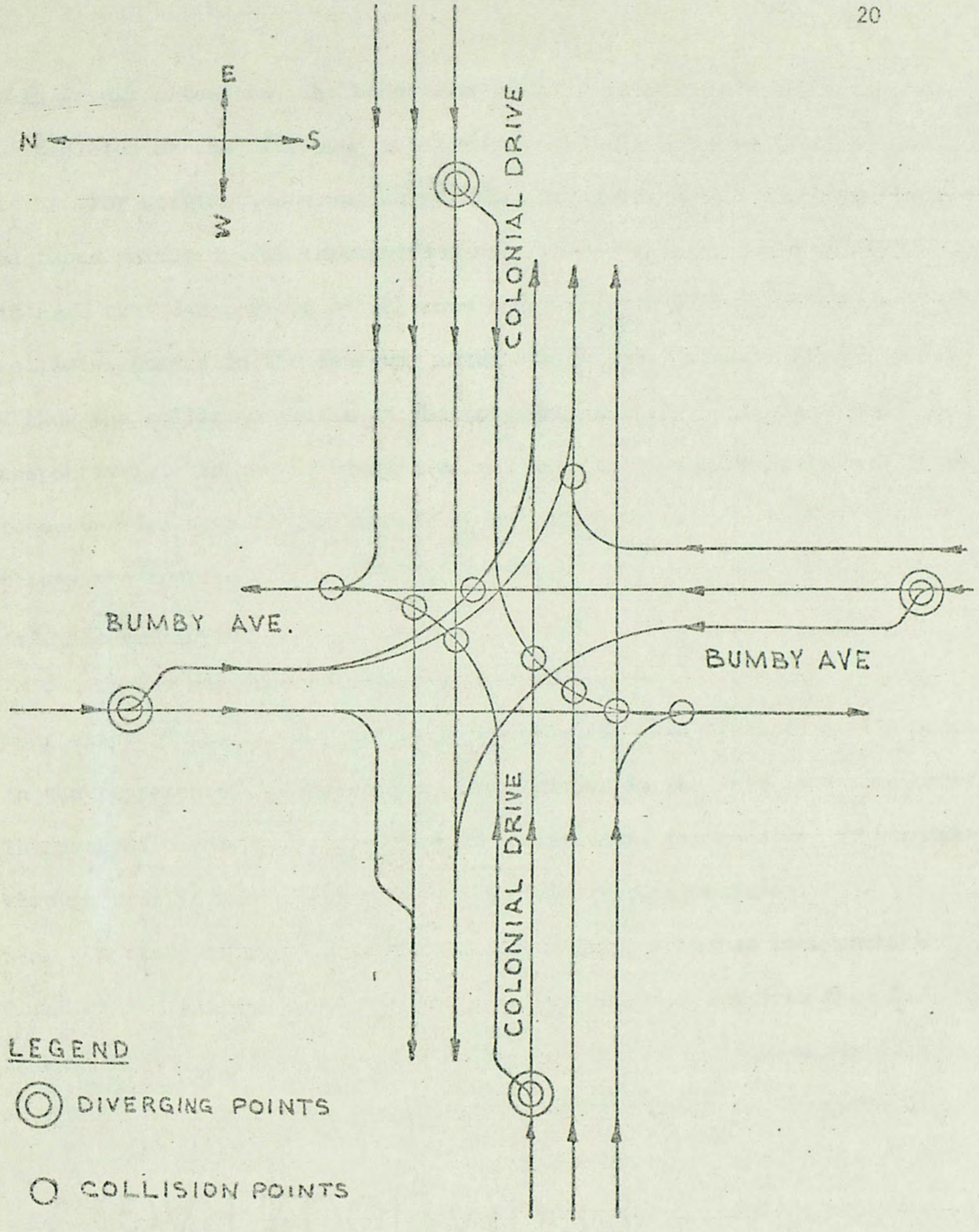


Fig. 5—Conflict Points

this actual situation, the simulation model will therefore block the flow of vehicles at the diverging point when a vehicle occupies that point.

For merging and crossing traffic, collision points can be defined as those points in the intersection area where vehicles would collide if more than one arrived at the same time. Figure 5 shows the ten collision points in the four-way intersection under study. Figures 6 and 7 show the collision points in the East-West and the North-South axis, respectively. In the simulation model, each collision point is restricted to occupation by a single vehicle at any given time. The collision points are represented by GPSS facilities.

2.8 Critical Gaps

It has been observed that in a crossing maneuver, a gap or lag must exist in the traffic stream being crossed. Two situations will occur in the represented intersection: (a) vehicles in the left lane must cross the path of oncoming traffic, and in consequence, (b) oncoming or straight through traffic must cross the path of left turning vehicles.

A study of opposed left turn crossings at an urban intersection found that delayed left turning drivers refused all gaps less than 3.75 seconds and accepted all gaps of 4.75 or greater. The median was 4.25 seconds.[17] The study did not show the delay resulting to the opposing (straight-ahead) traffic.

The model in this report permits the analyst to select critical acceptance gaps for each of the above situations. He may, if he desires, select a unique value for each individual traffic lane. Vehicles will not be allowed to proceed until acceptable gaps appear in the opposing flow of traffic. The vehicle transactions will be blocked at their

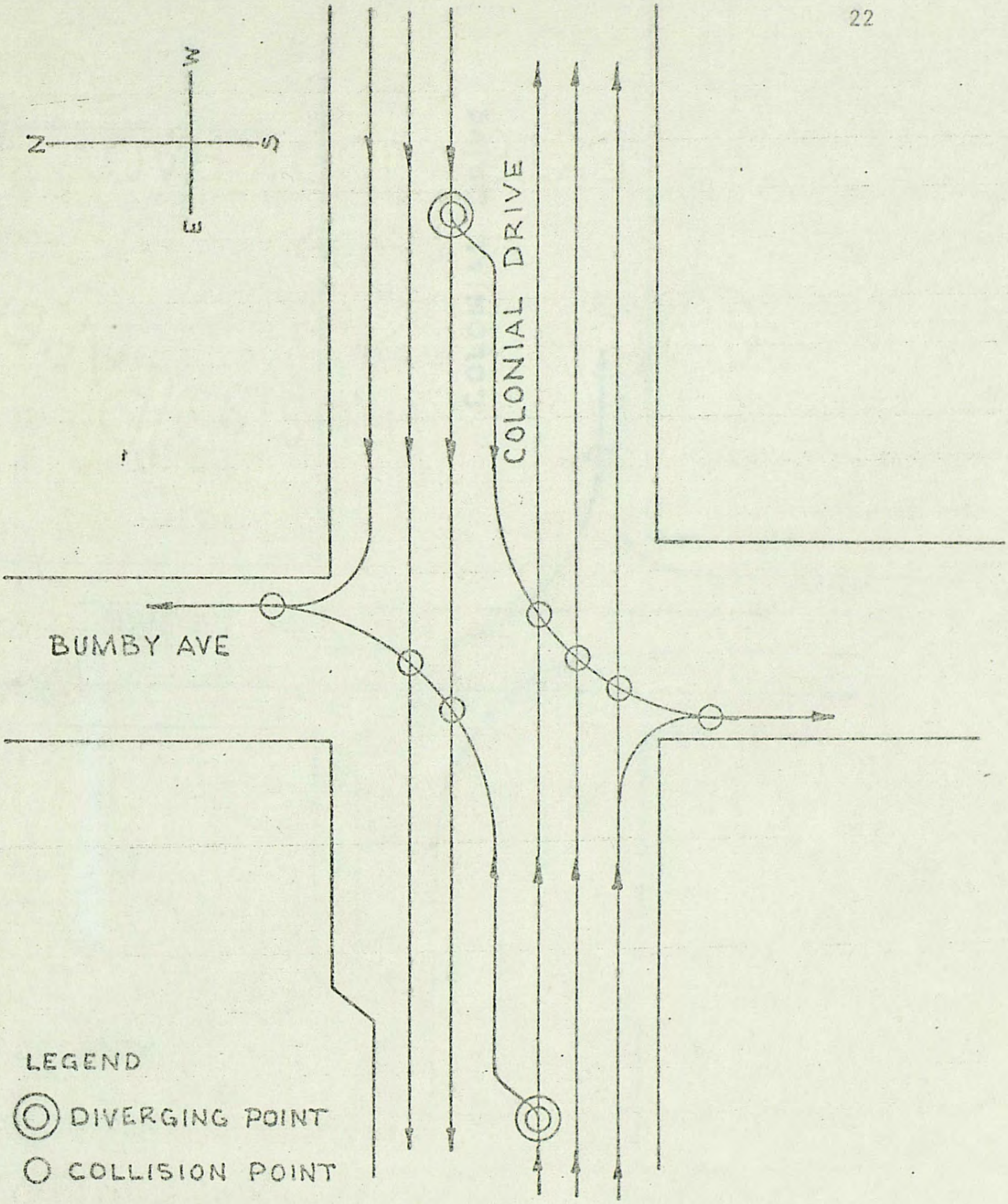


Fig. 6.--Conflict Points, East-West Axis.

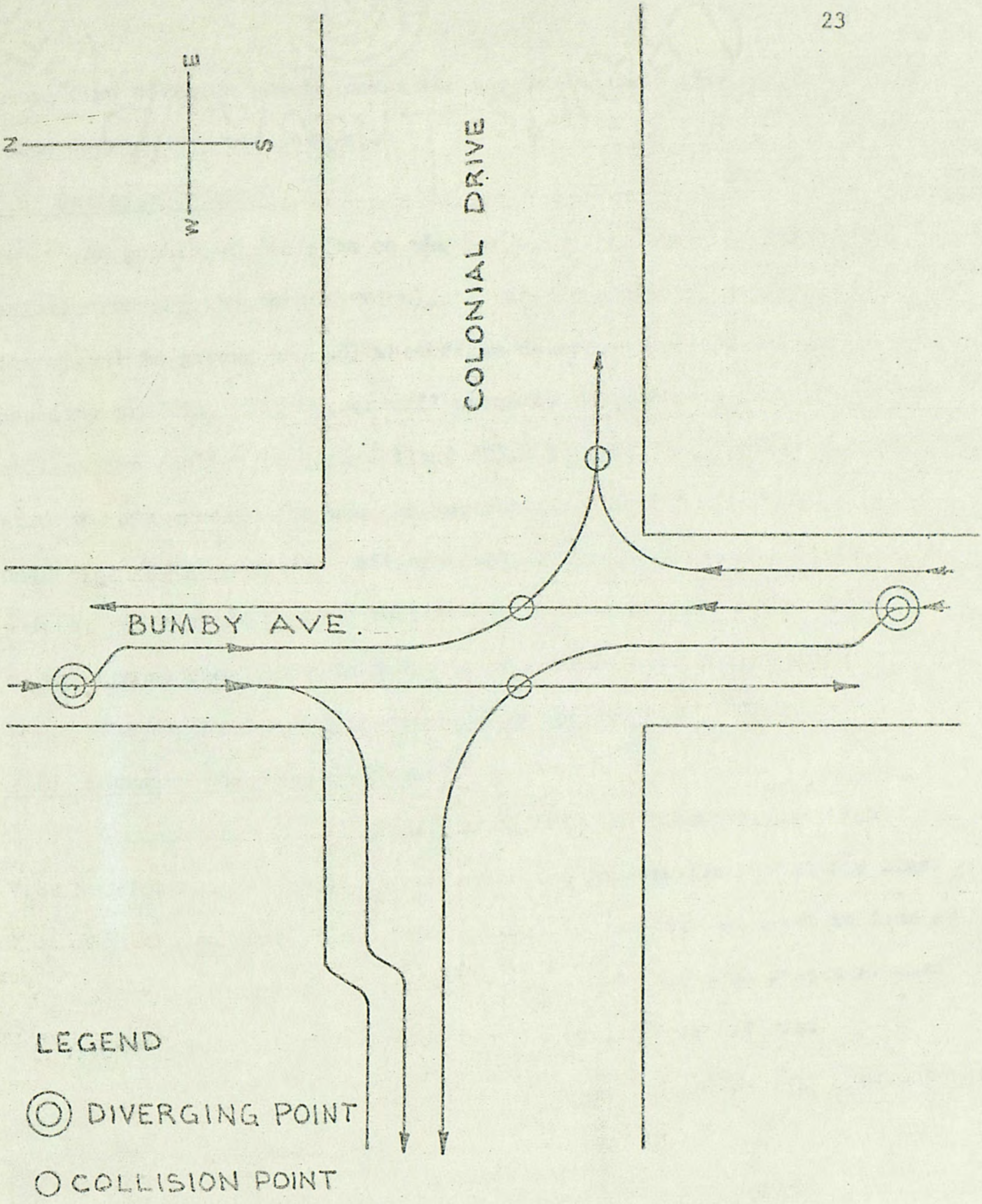


Fig. 7.—Conflict Points, North-South Axis.

respective decision points until the gap is equal to or greater than the value selected by the analyst.

2.9 Decision Points

At points of decision on whether or not to proceed (immediately before crossing the intersection), the driver needs to determine (A) if the signal is green, and (B) whether he detects an acceptable gap in opposing traffic. The driver will normally proceed only with concurrent affirmative replies to both (A) and (B). In addition, he must decelerate prior to his passage through the intersection if either condition is negative, though positive (affirmative) shortly thereafter. At decision points, represented by GPSS facilities, a constant time factor is added to the transaction delay in order to account for the deceleration time loss. The computer model is detailed in Section 3.1.

2.10 Entrance and Headway Times

Greenshields et. al[18] were concerned with measuring the time required for the first vehicle to enter the intersection after the light turned green, and with the headway between successive vehicles in line as they entered the intersection. The results obtained from passenger cars from an intersection in Hartford, Connecticut, are as follows:

First car:	3.8 sec. to enter after light turns green;
Second car:	3.1 sec after first car;
Third car:	2.7 sec after second car;
Fourth car:	2.4 sec after third car;
Fifth car:	2.2 sec after fourth car;
Sixth car:	2.1 sec after fifth car.

The last headway value applies also to any additional vehicles in the queue when the signal turns green.

The above study was conducted in 1944. In a later study, 1960, the entrance times of the first vehicle and the successive headways of the following vehicles were less than in the earlier study, but the minimum value to which headways converged (approximately 2.1 seconds) was the same in both studies.[19]

The driver and vehicle performance data as measured by these studies appear important in determining the maximum rate at which cars may move through an intersection. The computer model accounts for these observations by allowing vehicles to depart the decision point blocks at rates similar to those found in the studies. A special headway function assigns a delay time to each vehicle at a decision point, such that vehicles advance through the decision point in accordance with that headway function. Figure 8 illustrates the headway function used in the model.

The function uses a counter for its independent variable. The counter's value is incremented by one at each basic time interval, but is reset to zero when both conditions for proceeding become GO (green traffic light, and acceptable gap detected in the opposing traffic), at which time the first vehicle in line is free to proceed. It is the changing of states from NO-GO to GO that triggers the resetting of the counter. Each traffic lane is assigned its own headway function with associated counter, and these operate independently of those assigned to other lanes.

The entrance and headway times are the maximum allowable rates, and apply to successive vehicles in line. In a real situation, however,

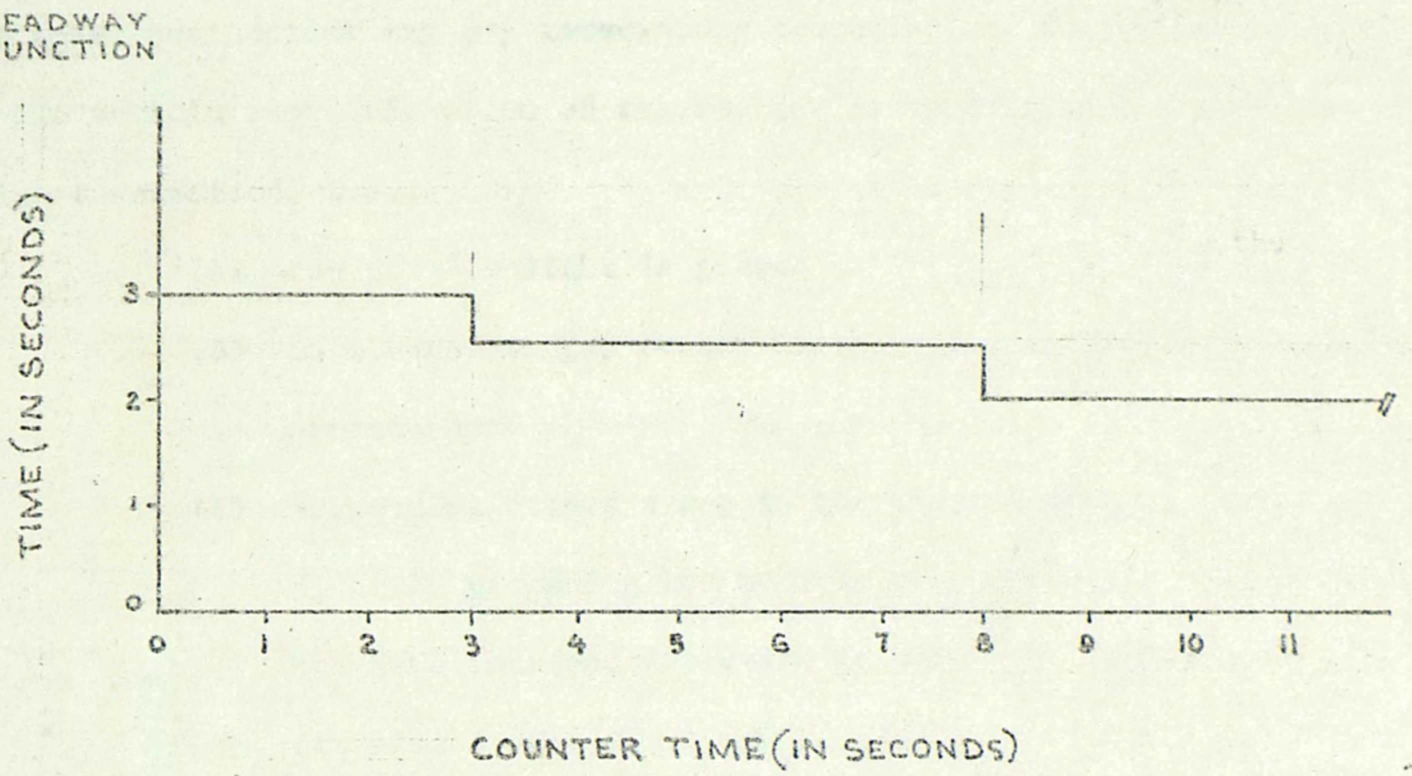


Fig. 8.--Headway Function in Computer Model.

there may frequently appear gaps in the traffic stream and the waiting line, and the queue may periodically empty. In that event, the foregoing headway analysis does not apply, and a different treatment is needed. The model must detect any gap immediately preceding any individual vehicle in the vehicle's own direction of travel, and if conditions (A), (B), and (C) are satisfied, i.e.,

(A) the traffic light is green;

(B) an acceptable gap occurs in the opposing traffic stream; and

(C) there also occurs a gap in the traffic steam directly preceding the vehicle of interest in the same lane and direction in which the vehicle travels;

-- then the vehicle will not be delayed in accordance with the headway function, but will instead be free to proceed to the next facility, the collision point.

The details of how this is implemented can be found in Section 3.1.

3.0 COMPUTER PROGRAM

The program consists of four segments:

A. Flow of Vehicles

B. Control of Traffic Lights

C. Control of Headway Function Counters

D. Control of Simulation Run Lengths

In each segment, transactions are created and destroyed independently of those in other segments. The basic unit of simulation time is 0.5 seconds. The selection of 0.5 seconds is consistent with the goal of minimizing the computer cost yet permitting an adequate dynamic representation of the vehicle flow interactions.

The present version of the source program resides on 632 punched cards (including comment cards). The CPU run time for simulating 7.0 minutes of traffic flow under steady state conditions was less than 60 seconds. The program utilizes 400 GPSS blocks, 15 Functions, 9 Boolean Variables, 8 Variables, 13 Storage Areas, 17 Tables, 22 Facilities, 8 Savevalues, 12 Logic Switches and 17 Queues. For a table of program symbol definitions, see Appendix A. Appendix B has the program listings.

3.1 Program Segment A

Figure 9 shows a flow diagram of Program Segment A. In this segment, each transaction represents a vehicle. Transactions are generated at specified rates, which are modified by exponential functions. Generation is initiated separately for each of the four directions of approach - West, East, North, and South. Diverging points are represented by gate blocks, lanes by storage areas, decision points and collision points by facilities. After a transaction leaves a collision point, it is of no further interest to the user, and is at that point removed from the model.

Each transaction will utilize parameters 1 through 4 as follows:

PARAMETER NUMBER	VALUE ASSIGNED ACCORDING TO
1	type of traffic (straight ahead, left or right turn)
2	direction of approach (West, East, North or South)
3	status of decision point facility (used/not used)
4	status of Boolean Variable NGO (go/no go)

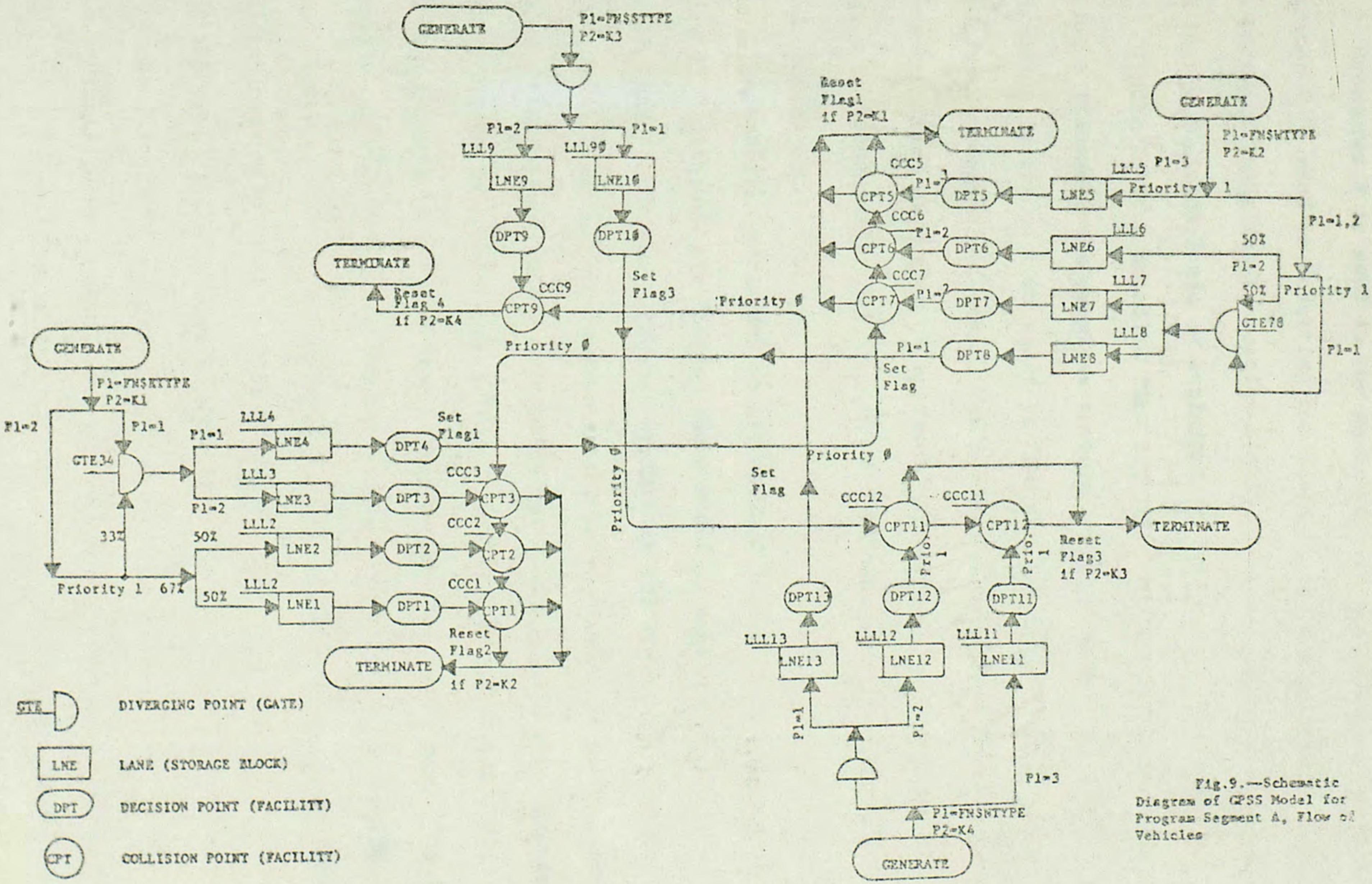


Fig.9.—Schematic Diagram of GPSS Model for Program Segment A, Flow of Vehicles

Parameter 1 is used in the assignment of vehicles to various lanes. Parameter 2 is used in resetting the flags in the decision point logic (see Decision Point Model, section 3.1.2). Parameters 3 and 4 are also used in the decision logic as explained in section 3.1.2.

Figure 10 is a detailed flow diagram from Program Segment A showing a transaction's progress through a single lane. The flow of the transaction is traced from start to finish. The diagram is representative of the usual sequence of events for a vehicle-transaction which arrives from a specified direction of approach, proceeds through a lane storage area, a decision point facility, and a collision point facility.

3.1.1 Traffic Lane Model

The traffic lane model is illustrated in the block diagram of Figure 11. Although the diagram shows the flow sequence specifically through Lane 3, the same sequence applies to all lanes. If the storage is not full, a transaction may enter the ENTER block. It then proceeds to the ADVANCE block, where it remains for 9 clock units (4.5 seconds). The delay time is set to 9 clock units because of a requirement for Decision Point 8 to block a transaction until Lane 3 is empty. The 4.5 second value corresponds to the acceptable gap described in Section 2.8.

Next, on leaving the ADVANCE block, the present status of Facility DPT3 is assigned to Parameter 3. This value is zero when the facility is available; otherwise it is one. The value of Parameter 3 will be used in the decision point logic.

Finally, the transaction is seized by Facility DPT3 before leaving LNE3. This is to insure that it will not be held up <u>between</u> LNE3 and DPT3.

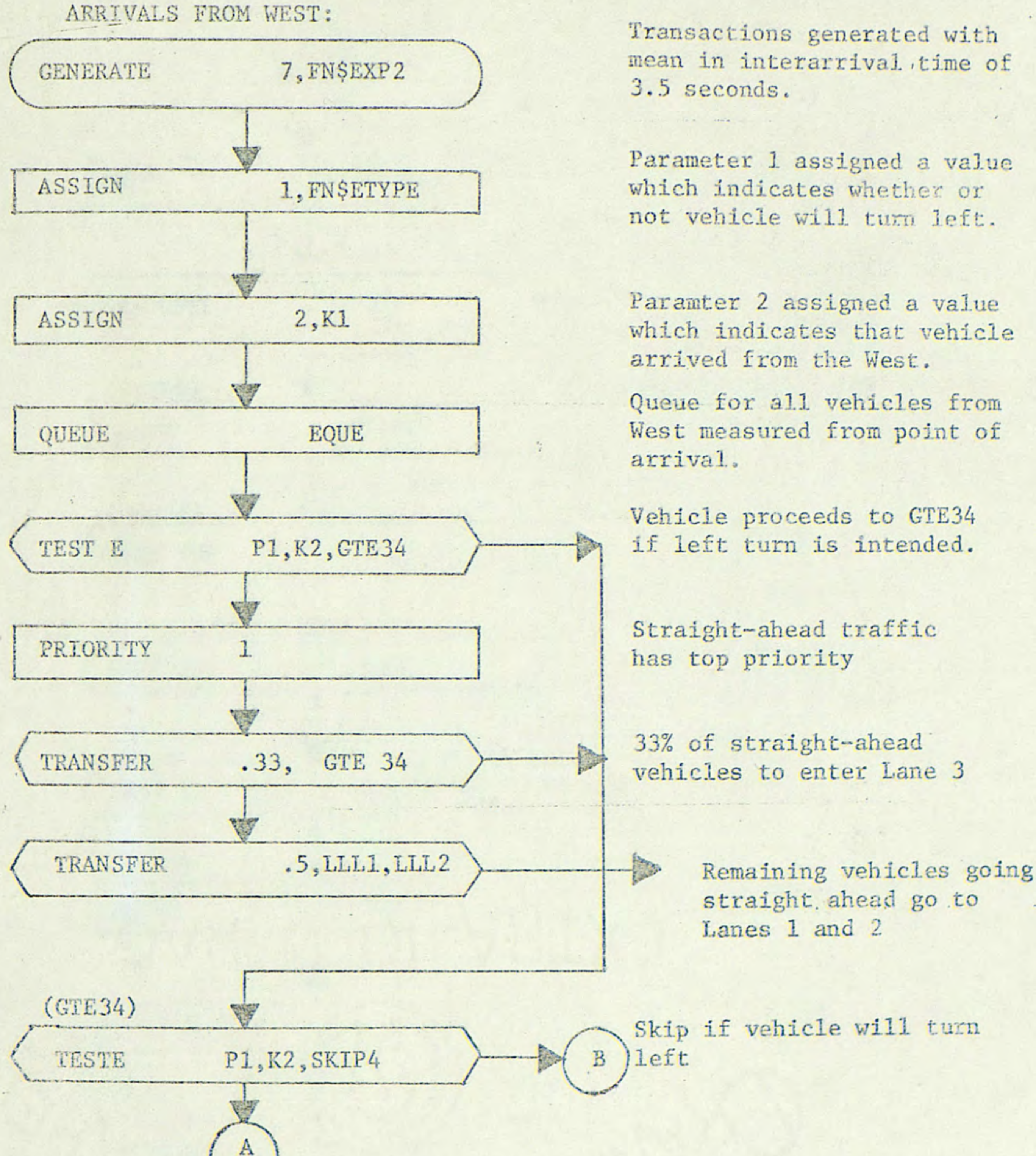


Fig.10.—Detailed Flow Diagram for a Single Lane.

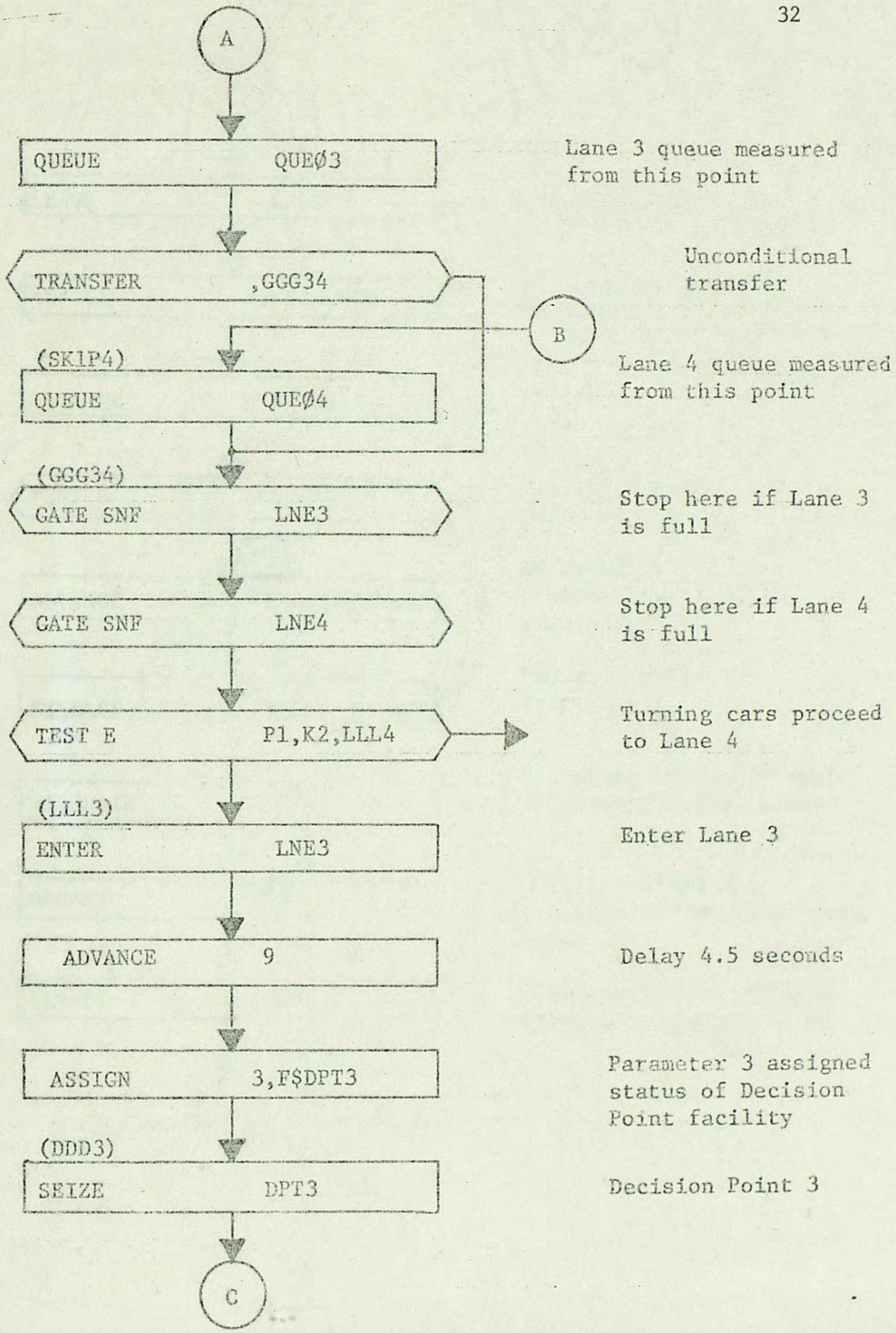
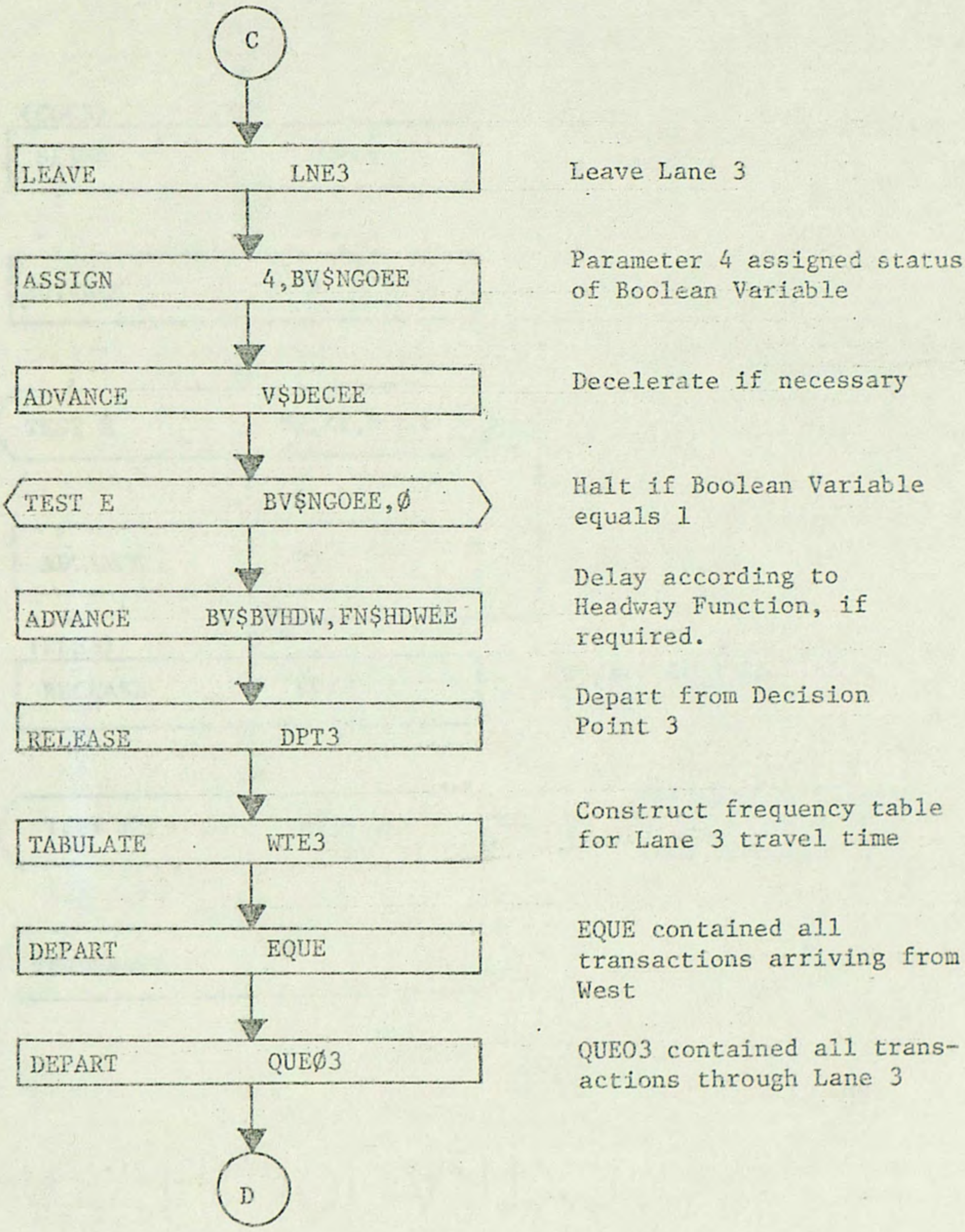


Fig.10.--(continued)



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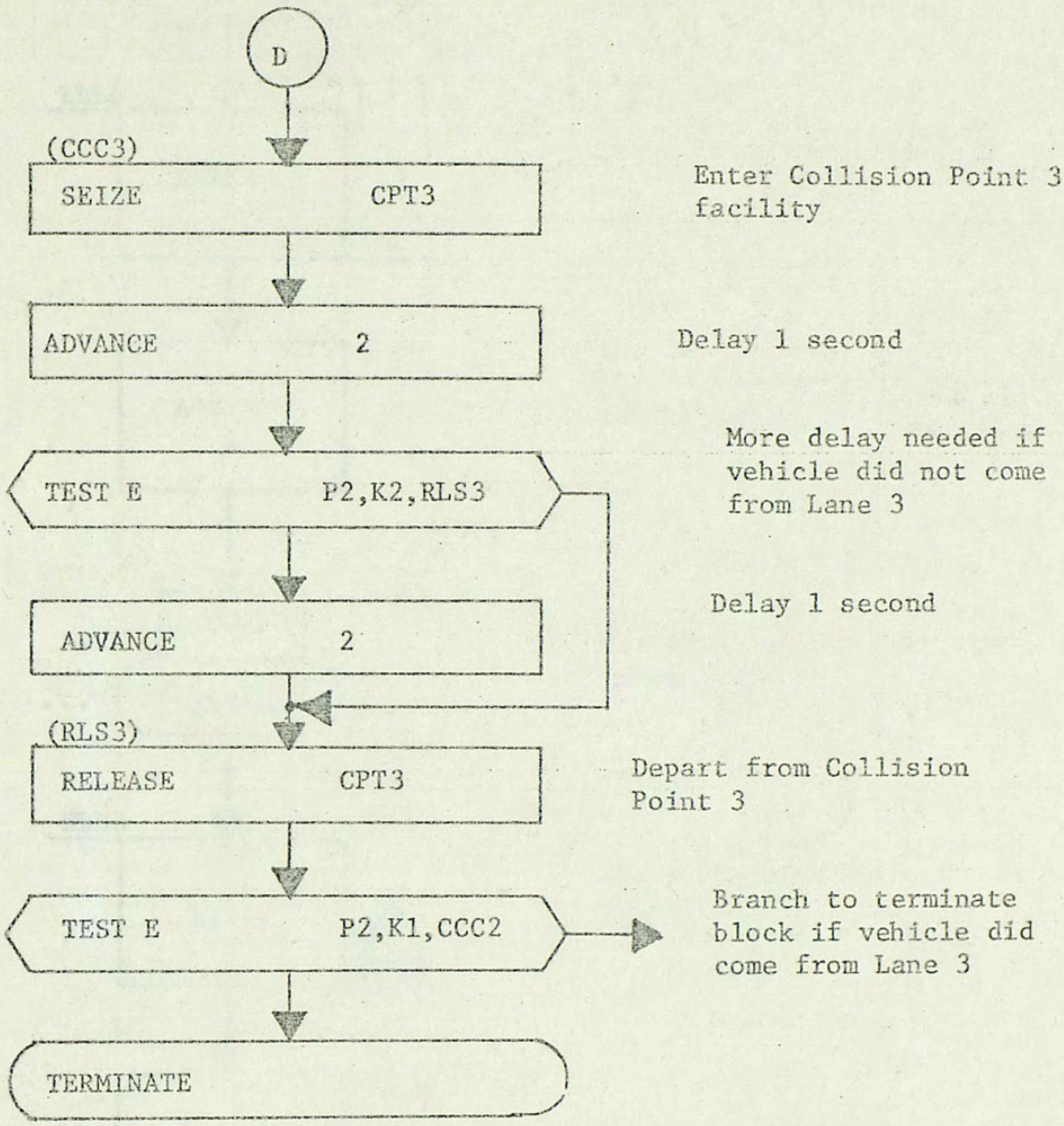


Fig.10--(continued)

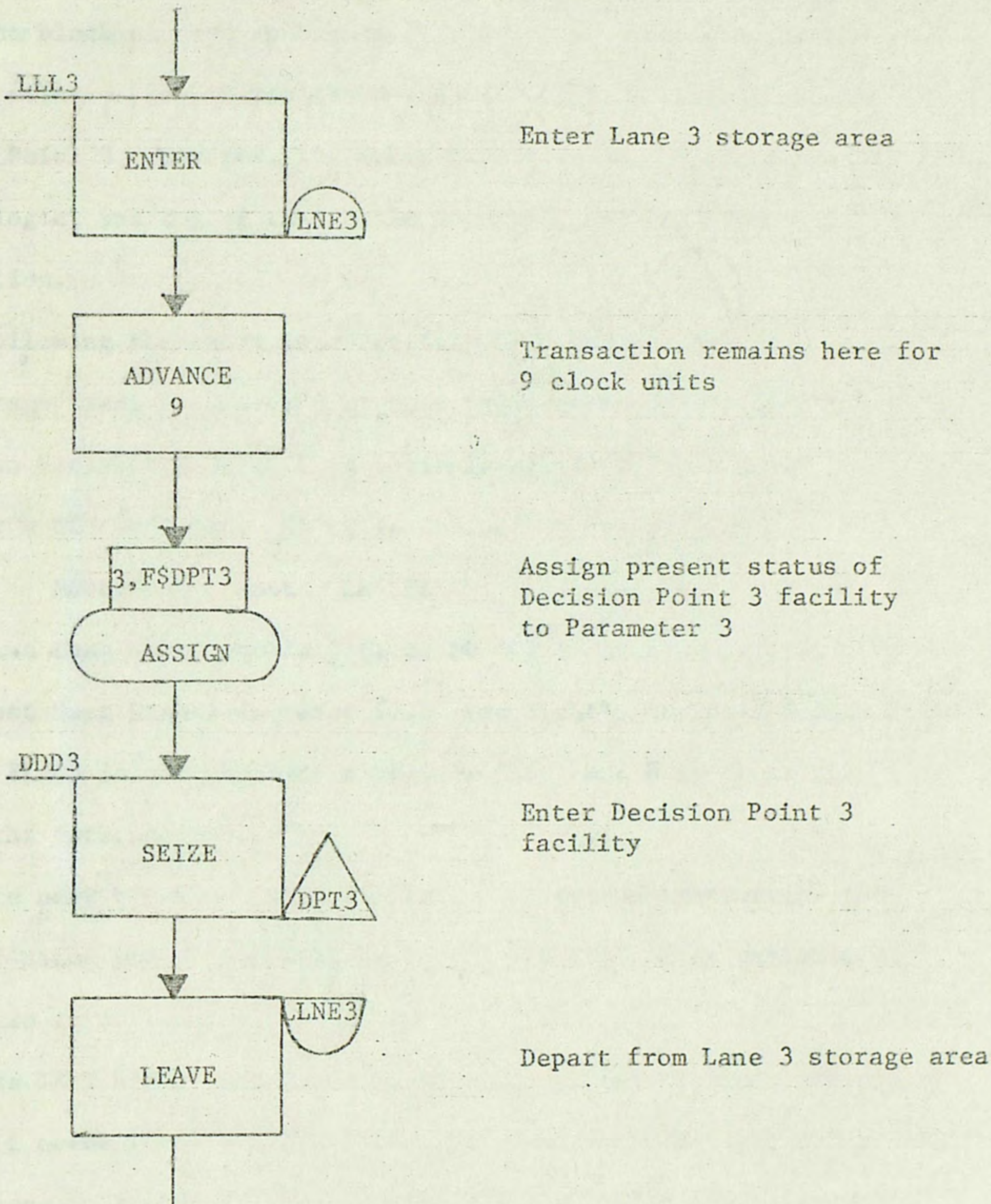


Fig.11.--Traffic Lane Model

3.1.2 Decision Point Model

The block diagram in Figure 12 illustrates the GPSS model of the decision point. The diagram shows the flow of transactions through Decision Point 3. However, the other twelve decision points use the same type of logic, and any of them could have been selected for this illustration.

Following the entry into Facility DPT3 and the departure from the LNE3 storage area, Parameter 4 of each transaction is assigned the value of Boolean Variable NGOEE. This variable equals 1 for a NO-GO condition, and 0 for a GO condition. NGOEE is defined in the program as

```
NGOEE  BVARIABLE  LR$EELTE + LS$FLAG2
```

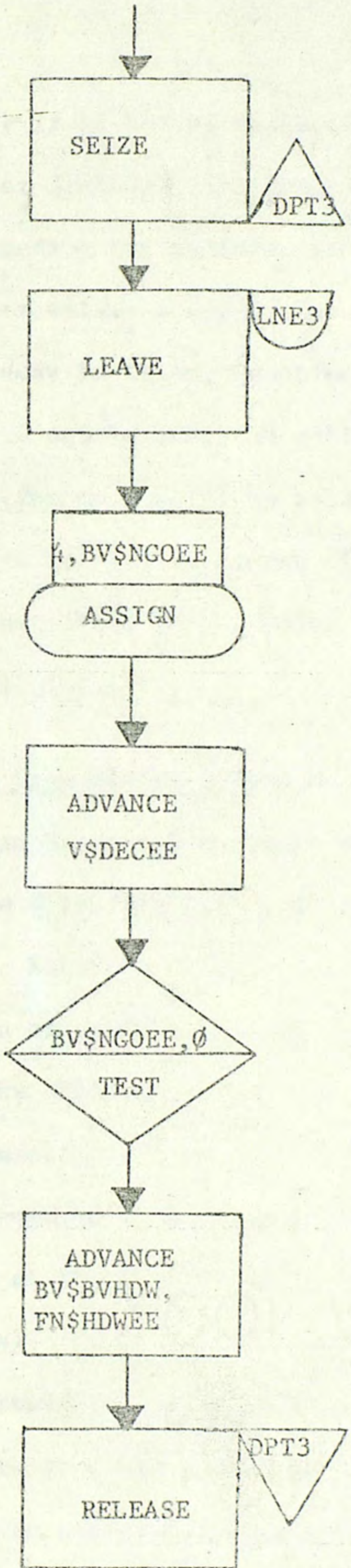
which means that NGOEE equals 1 (i.e. NO-GO) if either Logic Switch EELTE (East-East Light) is reset (i.e. red light), or Logic Switch FLAG2 is set. FLAG2 is set whenever a vehicle from Lane 8 is crossing through the intersection.

The next block, an ADVANCE block, delays the transaction the amount of clock units indicated by variable DECEE. This variable equals zero if no deceleration is required.

The TEST block determines whether the transcation can proceed or whether it needs to be blocked either because of a red light or because of an unacceptable gap in the opposing traffic. If Boolean Variable NGOEE equals zero, the transaction continues to the next block.

The next block, another ADVANCE block, may or may not delay the transaction, depending on whether the Boolean Variable BVHDW equals 1 or 0. BVHDW is defined as

```
BVHDW  BVARIABLE  P3'E'1 + P4'E'1
```



Enter Decision Point 3 facility

Depart from Lane 3 storage area

Assign to Parameter 4 the value of the Boolean variable

Delay the transaction if deceleration required.

Halt the transaction if the Boolean Variable equals one

Delay the transaction according to the Headway Function if the Boolean Variable equals one

Depart from Decision Point 3 facility

Fig.12.--Decision Point Model

It equals one if either of Parameters 3 or 4 equals one. The condition that Parameter 3 equals zero indicates a gap in the traffic stream directly preceding the vehicle, in the same lane and direction in which the vehicle travels. A gap in the vehicle's own direction of travel means that the Headway Function, Function HDWEE, will not be used in the logic. If Parameter 4 equals one, the vehicle has had to decelerate, and the Headway Function must still be used. In any case, if BVHDW equals one, the vehicle is delayed an amount of time equal to FN$HDWEE.

The last block in the model releases the transaction from the decision point facility.

3.2 Program Segments B, C, and D

Program Segment B controls the timing of the 8 logic switches that represent the 8 traffic lights in the system. The switches are named EELTE, ENLTE, NNLTE, NWLTE, SELTE, SSLTE, WSLTE, and WWLTE according to the direction of traffic that they control. Figure 13 shows a schematic diagram of the GPSS model for this segment.

A transaction is generated at each basic clock unit. Savevalue 1 is then incremented by one. This savevalue is used to count the time from start to end of the traffic cycle. The cycle ends at 140 clock units (70.0 seconds).

The savevalue equals 18 at 9.0 seconds into the cycle. At this time the South-to-South and North-to-North lights must turn green. See Figure 2 for an overall view of the signal light timing.

Lights must also change at 28.5, 38.5 and 70.0 seconds into the cycle. At 70.0 seconds the cycle is restarted, and the savevalue is reset to zero.

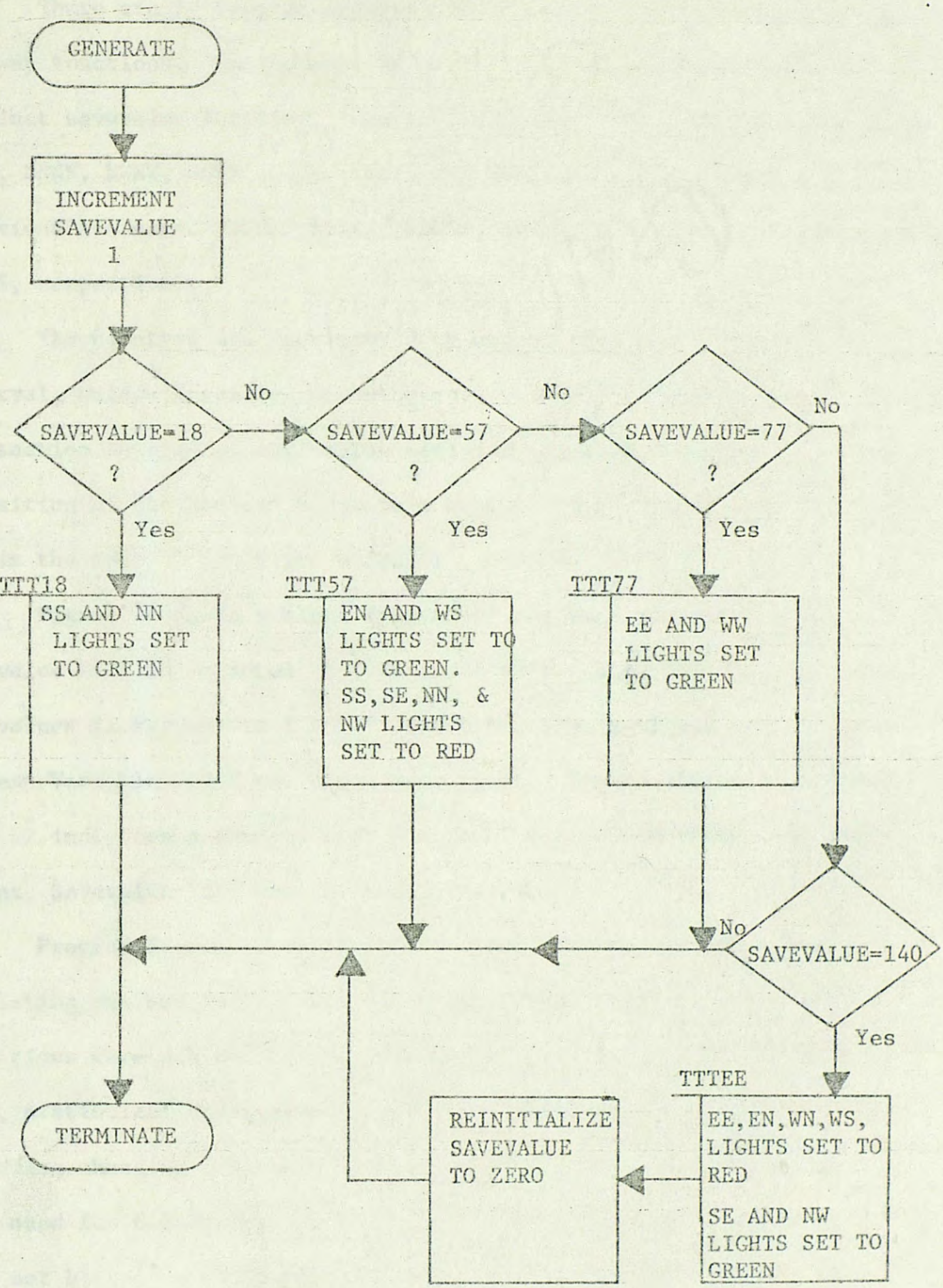


Fig.13.--Schematic Flow Diagram
of Program Segment B, Traffic Light Control

There are in Program Segment C eight counters associated with 8 Headway Functions. The current value of each counter is stored in a distinct savevalue location. The savevalue locations are named EEEE, ENEN, NNNN, NWNW, SSSS, SESE, WWWW, and WSWS. The corresponding headway functions are named HDWEE, HDWEN, HDWNN, HDWNW, HDWSS, HDWSE, HDWWW, and HDWWS, respectively.

The counters are incremented by one at each new simulation time interval, unless a special moment occurs when all conditions for the transaction to proceed out of the decision point block become GO. The transition of the Boolean Variable's state from NO-GO to GO is detected, and is the special condition which triggers the resetting of a counter.

Figure 14 shows a block diagram of one such counter. The value in Savevalue EEEE is incremented each clock unit. The TEST block compares the values in Parameters 1 and 2, which had been assigned the values of Boolean Variable NGOEE one clock unit apart. The condition P1 greater than P2 indicates a changed state in NGOEE from NO-GO to GO. At that moment, Savevalue EEEE must be reset to zero.

Program Segment D controls the simulation run length. The simulation was run for 2.0 traffic cycles, until typical operating conditions were achieved (i.e., steady state). Using a RESET control card, statistical observations up to that point were tossed out, without otherwise changing the state of the model. The simulation was then continued for 6.0 cycles, or 420 seconds, with statistics gathered which were not biased by the atypical observations initially accumulated.

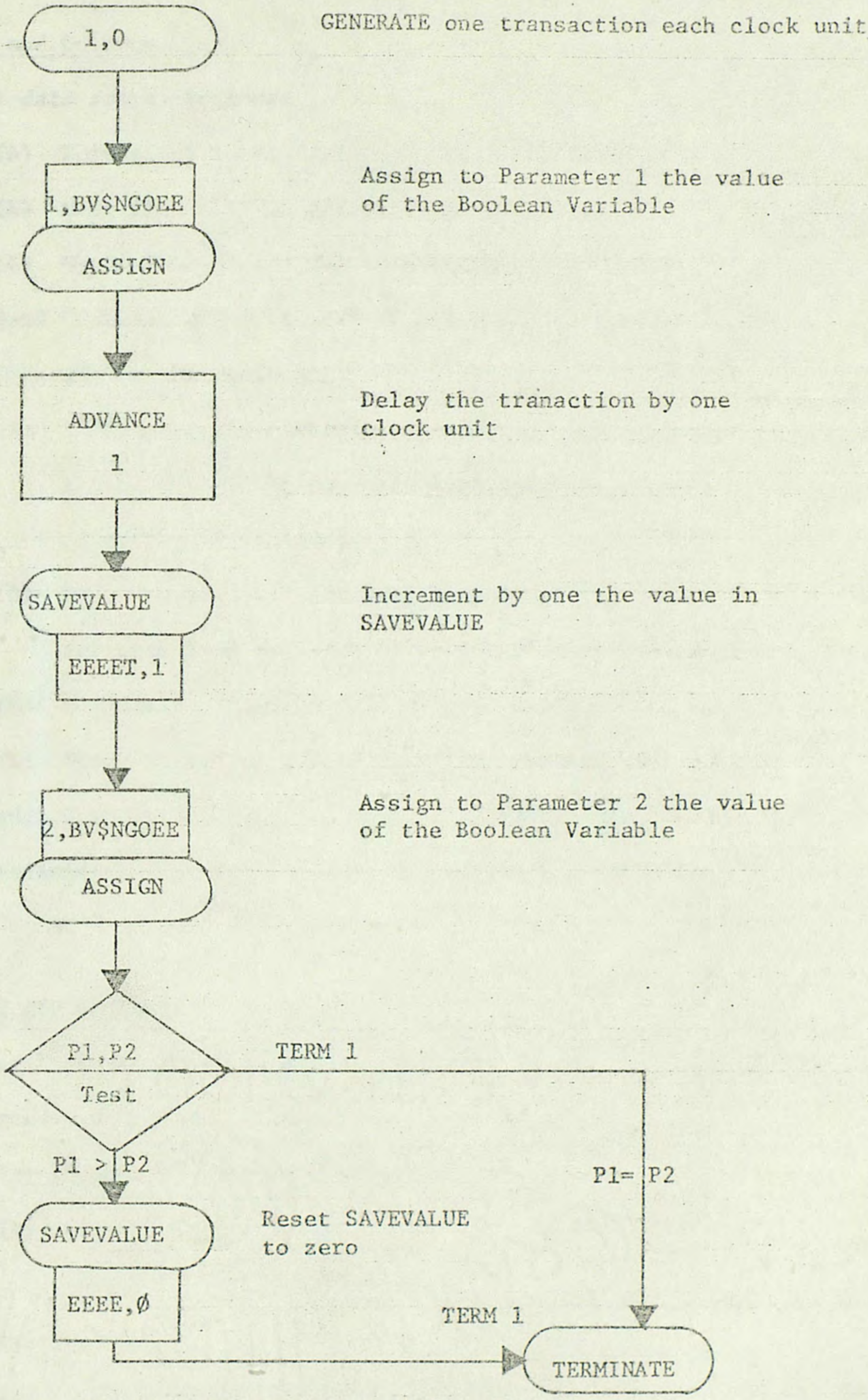


Fig.14.—Flow Diagram of Counting Mechanism in Program Segment C, Control of Headway Function Counters.

3.3 Inputs and Outputs

Input data are as follows:

(A) Percent of total traffic making left/right turns.

(B) Mean time between arriving vehicles.

(C) Cycle lengths for signal settings.

Standard GPSS/360 printouts, which are detailed tabular listings, provide information on the following:

(A) Distribution of vehicle travel times (time spent in the intersection) for each lane and for each direction of approach.

(B) Distribution of queue lengths (average, maximum, etc.) for each lane and each direction of approach.

(C) Average utilization of lane capacities.

(D) Total number of vehicles passing through each lane.

Appendix C shows the output from the program in Appendix B. The output is the same as the one used in the validation process under Section III of this report.

4. SUMMARY AND COMMENTS

Summarizing the results, a computer model of a traffic intersection was constructed. The model includes:

(a) Poisson distributed arrival rates.

(b) Multi-phase operation of traffic signals, including separate left-turn phases.

(c) Diverging points and collision points.

(d) Decision point logic

(e) Time loss computed for deceleration at decision points, when required.

(f) Entrance and headway time functions used, similar to those reported by Greenshields, et al.

(g) Detection of gaps in each vehicle's own traffic stream.

(h) Detection of gaps in the opposing traffic stream.

By replacing a few punched program cards, it is relatively easy to modify the following input parameters:

(A) Percent of total traffic making left/right turns. This parameter is regulated by the functions ETYPE, WTYPE, STYPE and NTYPE which specify the percentage of left turns, right turns and straight-ahead traffic for each of the four directions of approach. Changing all four would require the replacement of four punched cards.

(B) Mean time between arriving vehicles. Regulated by the four GENERATE blocks in Program Segment A which create the vehicle-transactions that enter into the system. Mean time is specified in Field A of the GENERATE block. Four punched cards would be changed.

(C) Cycle lengths for signal settings. This parameter is controlled in Program Segment B by four TEST blocks. A change would involve the replacement of four cards.

(D) Critical acceptance gaps. This parameter is specified by the ADVANCE block in each Lane. The total of 13 Lanes would require a change in 13 punched cards.

The CPU processing time for each simulation run was less than one minute, which, in the author's opinion, is reasonably low and economically acceptable.

Thr next section of the report presents the results of a validation test to determine how well the model predicts the degree of congestion.

III. RESULTS OF TEST AND VALIDATION

Validation is the process of testing the agreement between the behavior of the simulation model and the real system process.[20] How well does the simulation approximate reality? Most tests of validity of simulation models compare the output of the simulation to historical data under similar operating conditions. If the output of the simulation model is close to the historical data, the simulation is accepted as a realistic representation of the system.

Validation of the intersection model requires historical data from the intersection. Such data should provide factual information concerning the amount of delay at the specific intersection of interest, as well as information on the number of vehicles delayed. Several methods for field measurements are suggested in the Traffic Engineering Handbook.[21] They include travel time studies, which measure the travel time from a point in advance of the intersection to a point in or beyond the intersection. It is legitimate to evaluate congestion and delay by means of travel time data.[22] Methods to obtain the travel time data include:

(a) Observers stationed at a vantage point, tracing vehicles through an intersection, and recording stop watch times between critical points.

(b) Test cars operated between the same two points.

(c) License plate numbers and times recorded at two points.

(d) Twenty-pen recorders, with road tubes at critical points and/or observers operating keys to aid in identifying vehicles passing through the test section.

(e) Spaced serial photos, taken from a vantage point, to permit the timing of each vehicle shown on the film.

These methods require extensive personnel and time in the collection and analysis of the data. An alternate, less time consuming method, is also suggested, however. It involves the counting of all vehicles in a defined area of the approach at periodic time intervals. A sampling procedure requiring an observer, a stop watch, and a recording form for each traffic lane is developed. The observer counts and records all vehicles in the approach lane at periodic intervals (such as every 15 seconds). This sampling, along with volume count, permits estimation of the vehicle-seconds of travel time with considerable accuracy. Vehicle-seconds of travel time are obtained by multiplying the total number of vehicles recorded by the sampling interval.

Using this latter method as a basis, the author obtained historical data of the Colonial-Bumby intersection with a movie camera that had a special time lapse attachment. The attachment enabled photography at a fixed speed of one frame every 2.0 seconds. The roof of the building occupied by the Orlando Federal Savings & Loan Association (Colonial Branch) provided a vantage point from which to record the traffic in each of the four directions of approach.

Results were tabulated for 7.0 minute periods in each direction of approach. This corresponds to 6.0 cycles. The resulting travel time was obtained by multiplying the total number of vehicles recorded in the defined area of approach by the sample interval of 2.0 seconds. Other data which were obtained from the film included the average queues, the maximum queues, and the traffic volumes in each lane. Appendix D has the data from the film.

Next, the computer model was run with input data corresponding to the historical data from the film, i.e., the timing of traffic signals, percent of left and right turns, and mean times between arrivals. Figure 15 compares the results. Comparisons were not possible for arrivals from West and North because the camera did not have a full view of the defined area of approach from those directions, although it did record the traffic volumes in those lanes.

The comparison in Figure 15 shows the differences found between the historical and the simulation data. In view of the various simplifying assumptions and the sampling procedure to approximate the historical information, these differences do not seem unreasonable.

The summary shows a tendency by the model to underestimate the values in the historical data. Excepting one category, the model results are lower than those obtained from the film.

In evaluating these results, the fact that the validation run tabulated was the only one made should be taken into consideration. No prior tuning of the program was done. The model could, prior to a second validation run, be adjusted for closer agreement with the historical data. In actual practice, using this model as an evaluation

	OBSERVED ON FILM	PREDICTED BY SIMULATION
A. ARRIVALS FROM EAST		
1. Average Travel Time	21.2	18.7
2. Average Queue	5.5	4.97
3. Maximum Queue	14	17
B. ARRIVALS FROM SOUTH		
1. Average Travel Time	34.9	28.56
2. Average Queue	5.06	4.86
3. Maximum Queue	13	12

Fig.15.--Summary of Results

tool, it would be expected that such tuning to existing conditions would take place.

Since no rigorous statistical tests were possible on the comparisons in Figure 15, no conclusive deductions can be drawn for the model's validity, other than to say that these preliminary results do suggest a valid simulation model. Further testing would obviously be required for a complete check of the validity.

IV. CONCLUSION

As the number of vehicles on the road continues to grow, traffic problems constitute a continuing challenge. Traffic congestions are especially frequent in urban areas. The amount of funds devoted to their solution is increasing.

Solutions require the analysis and evaluation of alternative traffic designs. In recent years, traffic engineers have turned to more intensive use of computers for reducing the time and cost of analysis and design. Modeling and simulation with the aid of computers permit the study of a traffic system, such as an intersection, without having to construct the actual system itself, and is cheaper and quicker than experimenting on the actual system, which in any case would not normally be possible.

The computer model in this report simulates automobile traffic at a road intersection. Its intended use is in highway intersection design. The parameters of the simulation (approach volumes, proportion of turning vehicles, cycle and phase lengths) can be varied and the effects of changes can be measured. Changes such as prohibition of turning movements, change in right of way controls, and additional lanes are feasible. The model is general in structural characteristics and could be adapted to various intersection designs with differing physical layouts.

This report will not only be useful in the analysis and design of road intersections, but can also serve as a basis for further investigations using the techniques which have been presented.

APPENDIX A

TABLE OF PROGRAM SYMBOL DEFINITIONS

APPENDIX A.

TABLE OF PROGRAM SYMBOL DEFINITIONS

GPSS Entity	Interpretation
A. Transactions:	
Model Segment A	A vehicle
Model Segment B	A timer
Model Segment C	A timer
Model Segment D	A timer
B. Functions:	
EXP2	Exponential Function 2
EXP3	Exponential Function 3
EXP4	Exponential Function 4
HDWEE	Headway Function, East to East
HDWEN	Headway Function, East to North
HDWWW	Headway Function, West to West
HDWWS	Headway Function, West to South
HDWSS	Headway Function, South to South
HDWSE	Headway Function, South to East
HDWNN	Headway Function, North to North
HDWNW	Headway Function, North to West
ETYPE	Types or categories of East-bound traffic (arrivals from the West)
WTYPE	Types of West-bound traffic
STYPE	Types of South-bound traffic
NTYPE	Types of North-bound traffic
C. Boolean Variables:	
BVHDW	Boolean Variable, Headway
NGOEE	NO-GO, East to East

NGOEN	NO-GO, East to North
NGOWW	NO-GO, West to West
NGOWS	NO-GO, West to South
NGOSS	NO-GO, South to South
NGOSE	NO-GO, South to East
NGONN	NO-GO, North to North
NGONW	NO-GO, North to West

D. Variables:

DECEE	Decelerate, East to East
DECEN	Decelerate, East to North
DECWW	Decelerate, West to West
DECWS	Decelerate, West to South
DECSS	Decelerate, South to South
DECSE	Decelerate, South to East
DECNN	Decelerate, North to North
DECNW	Decelerate, North to West

E. Storages:

LNE1	Lane 1
LNE2	Lane 2
LNE3	Lane 3
.	.
.	.
.	.
LNE13	Lane 13

F. Tables:

EQUE	East Queue (arrivals from West)
WQUE	West Queue
SQUE	South Queue
NQUE	North Queue
WTE1	Wait Times, Lane 1
WTE2	Wait Times, Lane 2
WTE3	Wait Times, Lane 3

GPSS Entity	Interpretation
WTE4	Wait Times, Lane 4
.	.
.	.
.	.
WTE13	Wait Times, Lane 13

G. Facilities:

CPT1	Collision Point No. 1
CPT2	Collision Point No. 2
CPT3	Collision Point No. 3
CPT5	Collision Point No. 5
CPT6	Collision Point No. 6
CPT7	Collision Point No. 7
CPT9	Collision Point No. 9
CPT11	Collision Point No. 11
CPT12	Collision Point No. 12
DPT1	Decision Point 1
DPT2	Decision Point 2
DPT3	Decision Point 3
.	.
.	.
.	.
DPT13	Decision Point 13

H. Savevalues:

EEEE	E to E flow of traffic
ENEN	E to N flow of traffic
NNNN	N to N flow of traffic
NWNW	N to W flow of traffic
SSSS	S to S flow of traffic
SESE	S to E flow of traffic
WWWW	W to W flow of traffic
WSWS	W to S flow of traffic

GPSS Entity	Interpretation
I. Logic Switches:	
EELTE	Traffic Light, E to E
ENLTE	Traffic Light, E to N
NNLTE	Traffic Light, N to N
NWLTE	Traffic Light, N to W
SELTE	Traffic Light, S to E
SSLTE	Traffic Light, S to S
WSLTE	Traffic Light, W to S
WWLTE	Traffic Light, W to W
FLAG1	Set with E to N car is in intersection
FLAG2	Set when W to S car is in intersection
FLAG3	Set when S to E car is in intersection
FLAG4	Set when N to W car is in intersection
J. Queues:	
EQUE	East-bound (arriving from West)
WQUE	West-bound
NQUE	North-bound
SQUE	South-bound
QUE01	Lane 1
QUE02	Lane 2
QUE03	Lane 3
.	.
.	.
.	.
QUE13	Lane 13

APPENDIX B

PROGRAM LISTING

```
                    *** IBM PROGRAM PRODUCT 5734-XS2 (V1M3) ***
                                                                                STATEMENT
                                                                                 NUMBER
      REALLOCATE FUN,15,BVR,24,VAR,8,STO,26
      REALLOCATE TAB,19,LOG,12,QUE,19,FAC,26
      REALLOCATE FSV,9,HSV,0,FMS,0,MMS,0,CMA,0
***LTOP***

BLOCK                                                                           STATEMENT
NUMBER  *LOC   OPERATION  A,B,C,D,E,F,G,H,I          COMMENTS                   NUMBER
        *
        *
        *
        *
        *
        *                   GPSS/360 COMPUTER MODEL FOR SIMULATION OF
        *                   AUTOMOBILE TRAFFIC AT ROAD INTERSECTION
        *
        *                   --   IEMS 698 RESEARCH REPORT
        *                        I.GOLOVCSENKO
        *
        *
        *
        *
           SIMULATE
        *
        *    INITIALIZE LOGIC SWITCHES
           INITIAL     LS$SELTE/LS$NWLTE
        *
        *    FUNCTION DEFINITIONS
        EXP2  FUNCTION    RN2,C24
        0,0/.1,.104/.2,.222/.3,.355/.4,.509/.5,.69
        .6,.915/.7,1.2/.75,1.38/.8,1.6/.84,1.83/.88,2.12
        .9,2.3/.92,2.52/.94,2.81/.95,2.99/.96,3.2/.97,3.5
        .98,3.9/.99,4.6/.995,5.3/.998,6.2/.999,7/.9997,8
        EXP3  FUNCTION    RN3,C24
        0,0/.1,.104/.2,.222/.3,.355/.4,.509/.5,.69
        .6,.915/.7,1.2/.75,1.38/.8,1.6/.84,1.83/.88,2.12
        .9,2.3/.92,2.52/.94,2.81/.95,2.99/.96,3.2/.97,3.5
        .98,3.9/.99,4.6/.995,5.3/.998,6.2/.999,7/.9997,8
        EXP4  FUNCTION    RN4,C24
        0,0/.1,.104/.2,.222/.3,.355/.4,.509/.5,.69
        .6,.915/.7,1.2/.75,1.38/.8,1.6/.84,1.83/.88,2.12
        .9,2.3/.92,2.52/.94,2.81/.95,2.99/.96,3.2/.97,3.5
        .98,3.9/.99,4.6/.995,5.3/.998,6.2/.999,7/.9997,8
```

```
 HDWEE FUNCTION   X$EEEE,D3
6,6/16,5/20,4
 HDWEN FUNCTION   X$ENEN,D3
6,6/16,5/20,4
 HDWWW FUNCTION   X$WWWW,D3
6,6/16,5/20,4
 HDWWS FUNCTION   X$WSWS,D3
6,6/16,5/20,4
 HDWSS FUNCTION   X$SSSS,D3
6,6/16,5/20,4
 HDWSE FUNCTION   X$SESE,D3
6,6/16,5/20,4
 HDWNN FUNCTION   X$NNNN,D3
6,6/16,5/20,4
 HDWNW FUNCTION   X$NWNW,D3
6,6/16,5/20,4
 ETYPE FUNCTION   RN5,D2
,055,1/1,0,2
 WTYPE FUNCTION   RN6,D3
***LTOP***

,072,1/,891,2/1,0,3
 STYPE FUNCTION   RN7,D2
,125,1/1,0,2
 NTYPE FUNCTION   RN8,D3
,279,1/,721,2/1,0,3
*
*     BOOLEAN VARIABLES DEFINED
 BVHDW BVARIABLE  P3'E'1+P4'E'1
 NGOEE BVARIABLE  LR$EELTE+LS$FLAG2
 NGOEN BVARIABLE  LR$ENLTE+(LS$ENLTE*LS$EELTE*BV$NGEN1'E'1)
 NGEN1 BVARIABLE  SNE$LNE5+SNE$LNE6+SNE$LNE7
 NGOWW BVARIABLE  LR$WWLTE+LS$FLAG1
 NGOWS BVARIABLE  LR$WSLTE+(LS$WSLTE*LS$WWLTE*BV$NGWS1'E'1)
 NGWS1 BVARIABLE  SNE$LNE1A+SNE$LNE2A+SNE$LNE3A
 NGOSS BVARIABLE  LR$SSLTE+LS$FLAG4
 NGOSE BVARIABLE  LR$SELTE+(LS$SELTE*LS$SSLTE*BV$NGSE1'E'1)
 NGSE1 BVARIABLE  SNE$LNE11+SNE$LNE12
 NGONN BVARIABLE  LR$NNLTE+LS$FLAG3
 NGONW BVARIABLE  LR$NWLTE+(LS$NWLTE*LS$NNLTE*SNE$LNE9)
*
```

```
*     VARIABLE DEFINITIONS
 DECEE VARIABLE    8*BV$NGOEE
 DECEN VARIABLE    8*BV$NGOEN
 DECWW VARIABLE    8*BV$NGOWW
 DECWS VARIABLE    8*BV$NGOWS
 DECSS VARIABLE    8*BV$NGOSS
 DECSE VARIABLE    8*BV$NGOSE
 DECNN VARIABLE    8*BV$NGONN
 DECNW VARIABLE    8*BV$NGONW
*
*     STORAGE DEFINITIONS
 LNE1  STORAGE     15
 LNE2  STORAGE     15
 LNE3  STORAGE     15
 LNE4  STORAGE     15
 LNE5  STORAGE     8
 LNE6  STORAGE     8
 LNE7  STORAGE     8
 LNE8  STORAGE     8
 LNE9  STORAGE     10
 LNE10 STORAGE     10
 LNE11 STORAGE     12
 LNE12 STORAGE     12
 LNE13 STORAGE     12
*
*     TABLE DEFINITIONS
 EQUE  QTABLE     EQUE,0,20,30
 WQUE  QTABLE     WQUE,0,20,30
 SQUE  QTABLE     SQUE,0,20,30
 NQUE  QTABLE     NQUE,0,20,30
 TEST2 QTABLE     TEST2,0,1,7
 TEST4 QTABLE     TEST4,0,1,7
 WTE1  TABLE      M1,0,20,30
 WTE2  TABLE      M1,0,20,30
 WTE3  TABLE      M1,0,20,30
 WTE4  TABLE      M1,0,20,30
 WTE5  TABLE      M1,0,20,30
***LTOP***

 WTE6  TABLE      M1,0,20,30
 WTE7  TABLE      M1,0,20,30
 WTE8  TABLE      M1,0,20,30
 WTE9  TABLE      M1,0,20,30
 WTE10 TABLE      M1,0,20,30
 WTE11 TABLE      M1,0,20,30
 WTE12 TABLE      M1,0,20,30
 WTE13 TABLE      M1,0,20,30
*
*
*
```

```
          *
          *
          *
          *
          *
          *
          *
          *         SECTION -   ARRIVALS FROM WEST
          *         ********
1                   GENERATE    7,FN$EXP2          FROM WEST
2                   ASSIGN      1,FN$ETYPE         P1=FN$ETYPE
3                   ASSIGN      2,K1               P2=K1: ARRIVALS FROM WEST
4                   QUEUE       EQUE               Q FORMED AT PT OF ARRIVAL
5                   TEST E      P1,K2,GTE34
6                   PRIORITY    1                  ASSIGNED TO NO-TURN TRAFFIC
7                   TRANSFER    .33,,GTE34         ALL XACTS IN THIS BLOCK, P1=K2
8                   TRANSFER    .5,LLL1,LLL2       SPLIT REMAINING XACTS
9             GTE34 TEST E      P1,K2,SKIP4
10                  QUEUE       QUE03
11                  TRANSFER    ,GGG34
12            SKIP4 QUEUE       QUE04
13            GGG34 GATE SNF    LNE3
14                  GATE SNF    LNE4
15                  TEST E      P1,K2,LLL4         TURNING CARS PROCEED TO LANE 4
16            LLL3  ENTER       LNE3               LANE 3 (P1=K2)
17                  ADVANCE     9                  4.5 SECONDS IS ACCEPTABLE GAP
18                  ASSIGN      3,F$DPT3
19            DDD3  SEIZE       DPT3               DECISION POINT 3
20                  LEAVE       LNE3
21                  ASSIGN      *,BV$NGOEE
22                  ADVANCE     V$DECEE            DECELERATE
23                  TEST E      BV$NGOEE,0         GO IF BOOL VAR = 0
24                  ADVANCE     BV$BVHDW,FN$HDWEE
25                  RELEASE     DPT3
26                  TABULATE    WTE3
27                  DEPART      EQUE
28                  DEPART      QUE03
29            CCC3  SEIZE       CPT3
30                  ADVANCE     2
31                  TEST E      P2,K1,RLS3
32                  ADVANCE     2
33            RLS3  RELEASE     CPT3
34                  TEST E      P2,K1,CCC2
35                  TERMINATE                        OF NO MORE INTEREST IF EAST BOUND
          *
          *
***LTOP***
```

```
*
36   LLL4  ENTER      LNE4
37         ADVANCE    9
38         ASSIGN     3,F$DPT4
39         SEIZE      DPT4
40         LEAVE      LNE4
41         ASSIGN     6,BV$NGOEN
42         ADVANCE    V$DECEN
43         TEST E     BV$NGOEN,0
44         QUEUE      TEST4
45         ADVANCE    BV$RVHDW,FN$HDWEN
46         DEPART     TEST4
47         RELEASE    DPT4
48         TABULATE   WTE4
49         DEPART     EQUE
50         DEPART     QUE04
51         LOGICS     FLAG1
52         TRANSFER   ,CCC7
*
*
*
53   LLL1  QUEUE      QUE01
54         ENTER      LNE1                LANE 1
55         ADVANCE    9
56         ASSIGN     3,F$DPT1
57         SEIZE      DPT1
58         LEAVE      LNE1
59         ASSIGN     4,BV$NGOEE
60         ADVANCE    V$DECEE
61         TEST E     BV$NGOEE,0
62         ADVANCE    BV$RVHDW,FN$HDWEE
63         RELEASE    DPT1
64         TABULATE   WTE1
65         DEPART     EQUE
66         DEPART     QUE01
67   CCC1  SEIZE      CPT1
68         ADVANCE    2
69         TEST E     P2,K1,RLS1
70         ADVANCE    2
71   RLS1  RELEASE    CPT1
72         TEST E     P2,K2,TTT2
73         LOGICR     FLAG2
74   TTT2  TERMINATE
*
*
```

```
               *
75        LLL2  QUEUE       QUE02
76              ENTER       LNE2            LANE 2
77              ADVANCE     9
78              ASSIGN      3,F$DPT2
79              SEIZE       DPT2
80              LEAVE       LNE2
81              ASSIGN      4,BV$NGOEE
82              ADVANCE     V$DECEE
83              TEST E      BV$NGOEE,0
84              QUEUE       TEST2
85              ADVANCE     BV$RVHDW,FN$HDWEE
***LTOP***

86              DEPART      TEST2
87              RELEASE     DPT2
88              TABULATE    WTE2
89              DEPART      EQUE
90              DEPART      QUE02
91        CCC2  SEIZE       CPT2
92              ADVANCE     2
93              TEST E      P2,K1,RLS2
94              ADVANCE     2
95        RLS2  RELEASE     CPT2
96              TEST E      P2,K1,CCC1
97              TERMINATE
          *
          *
          *
          *
          *
          *     SECTION -   ARRIVALS FROM EAST
          *     *******
98              GENERATE    8,FN$EXP3       FROM EAST
99              ASSIGN      1,FN$KTYPE
100             ASSIGN      2,K2
101             QUEUE       EQUE
102             TEST NE     P1,K3,LLL5
103             TEST E      P1,K2,GTE78
104             PRIORITY    1
105             TRANSFER    .5,GTE78,LLL6
106       GTE78 TEST E      P1,K2,SKIP8
107             QUEUE       QUE07
108             TRANSFER    ,GGG78
109       SKIP8 QUEUE       QUE08
110       GGG78 GATE SNF    LNE7
111             GATE SNF    LNE8
```

```
112          TEST E      P1,K1,LLL7
113   LLL8   ENTER       LNE8
114          ADVANCE     9
115          ASSIGN      3,FSDPT8
116          SEIZE       DPT8
117          LEAVE       LNE8
118          ASSIGN      4,BVSNGOWS
119          ADVANCE     VSDECWS
120          TEST E      BVSNGOWS,0
121          ADVANCE     BVSBVHDW,FNSMDWWS
122          RELEASE     DPT8
123          TABULATE    WTE8
124          DEPART      WQUE
125          DEPART      QUE08
126          LOGICS      FLAG2
127          TRANSFER    ,CCC3
       .
       .
       .
128   LLL7   ENTER       LNE7
129          ADVANCE     9
130          ASSIGN      3,FSDPT7
131          SEIZE       DPT7
132          LEAVE       LNE7
***LTOP***

133          ASSIGN      4,BVSNGOWW
134          ADVANCE     VSDECWW
135          TEST E      BVSNGOWW,0
136          ADVANCE     BVSBVHDW,FNSMDWWW
137          RELEASE     DPT7
138          TABULATE    WTE7
139          DEPART      WQUE
140          DEPART      QUE07
141   CCC7   SEIZE       CPT7
142          ADVANCE     2
143          TEST E      P2,K2,RLS7
144          ADVANCE     2
145   RLS7   RELEASE     CPT7
146          TEST E      P2,K2,CCC6
147          TERMINATE
       .
       .
       .
```

```
148    LLL6   QUEUE      QUE06
149           ENTER      LNE6
150           ADVANCE    9
151           ASSIGN     3,FN$DPT6
152           SEIZE      DPT6
153           LEAVE      LNE6
154           ASSIGN     4,BV$NGOWW
155           ADVANCE    V$DECWW
156           TEST E     BV$NGOWW,0
157           ADVANCE    BV$BVHDW,FN$HDWWW
158           RELEASE    DPT6
159           TABULATE   WTE6
160           DEPART     WQUE
161           DEPART     QUE06
162    CCC6   SEIZE      CPT6
163           ADVANCE    2
164           TEST E     P2,K2,RLS6
165           ADVANCE    2
166    RLS6   RELEASE    CPT6
167           TEST E     P2,K2,CCC5
168           TERMINATE
       .
       .
       .
169    LLL5   QUEUE      QUE05
170           ENTER      LNE5
171           PRIORITY   1
172           ADVANCE    9
173           ASSIGN     3,FN$DPT5
174           SEIZE      DPT5
175           LEAVE      LNE5
176           ASSIGN     4,BV$NGOWW
177           ADVANCE    V$DECWW
178           TEST E     BV$NGOWW,0
179           ADVANCE    BV$BVHDW,FN$HDWWW
180           RELEASE    DPT5
181           TABULATE   WTE5
182           DEPART     WQUE
183           DEPART     QUE05
***LTOP***

184    CCC5   SEIZE      CPT5
185           ADVANCE    2
186           TEST E     P2,K2,RLS5
187           ADVANCE    2
188    RLS5   RELEASE    CPT5
189           TEST E     P2,K1,TTT1
190           LOGICR     FLAG1
191    TTT1   TERMINATE
       .
```

```
       *
       *
       *
       *
       *        SECTION  --  ARRIVALS FROM NORTH
       *        *******
192             GENERATE   15,FN$EXP4        FROM NORTH
193             ASSIGN     1,FN$STYPE
194             ASSIGN     2,K3
195             QUEUE      SQUE
196       STE91 TEST E     P1,K2,SKP91
197             QUEUE      QUE09
198             TRANSFER   ,GGG91
199       SKP91 QUEUE      QUE10
200       GGG91 GATE SNF   LNE10
201             GATE SNF   LNE9
202             TEST E     P1,K2,LLL10
203             PRIORITY   1
204       LLL9  ENTER      LNE9
205             ADVANCE    9
206             ASSIGN     3,F$DPT9
207             SEIZE      DPT9
208             LEAVE      LNE9
209             ASSIGN     4,BV$NGOSS
210             ADVANCE    V$DECSS
211             TEST E     BV$NGOSS,0
212             ADVANCE    BV$BVHDW,FN$HDWSS
213             RELEASE    DPT9
214             TABULATE   WTE9
215             DEPART     SQUE
216             DEPART     QUE09
217       CCC9  SEIZE      CPT9
218             ADVANCE    4
219             RELEASE    CPT9
220             TEST E     P2,K4,TTT4
221             LOGICR     FLAG4
222       TTT4  TERMINATE
       *
       *
       *
223       LLL10 ENTER      LNE10
224             ADVANCE    9
225             ASSIGN     3,F$DPT10
226             SEIZE      DPT10
227             LEAVE      LNE10
228             ASSIGN     4,BV$NGOSE
229             ADVANCE    V$DECSE
230             TEST E     BV$NGOSE,0
```

```
231              ADVANCE    BVSBYHDW,FNSHDWSE
232              RELEASØ    DPT10
233              TABULATE   WTE10
234              DEPART     SQUE
235              DEPART     QUE10
236              LOGICS     FLAG3
237              TRANSFØR   ,CCC12
         *
         *
         *
         *
         *
         *       SECTION  --  ARRIVALS FROM SOUTH
         *       *******
238              GENERATE   14,FNSEXP4        FROM SOUTH
239              ASSIGN     1,FNSNTYPE
240              ASSIGN     2,K4
241              QUEUE      NQUE
242              TEST NE    P1,K3,LLL11
243        GTE13 TEST E     P1,K2,SKP13
244              QUEUE      QUE12
245              TRANSFØR   ,GGG13
246        SKP13 QUEUE      QUE13
247        GGG13 GATE SNF   LNE12
248              GATE SNF   LNE13
249              TEST E     P1,K1,LLL12
250        LLL13 ENTER      LNE13
251              ADVANCE    9
252              ASSIGN     3,FSDPT13
253              SEIZE      DPT13
254              LEAVE      LNE13
255              ASSIGN     4,BVSNGONW
256              ADVANCE    VSDECNW
257              TEST E     BVSNGONW,0
258              ADVANCØ    BVSBVHDW,FNSHDWNW
259              RELEASØ    DPT13
260              TABULATE   WTE13
261              DEPART     NQUE
262              DEPART     QUE13
263              LOGICS     FLAG4
264              TRANSFER   ,CCC9
265        LLL12 ENTER      LNE12
266              ADVANCØ    9
267              ASSIGN     3,FSDPT12
268              SEIZE      DPT12
269              LEAVE      LNE12
270              ASSIGN     4,BVSNGONN
```

```
271            PRIORITY   1
272            ADVANCE    VSDECNN
273            TEST E     BVSNGONN,0
274            ADVANCE    BVSBVHDW,FNSHDWNN
275            RELEASE    DPT12
276            TABULATE   WTE12
277            DEPART     NQUE
278            DEPART     QUE12
279      CCC12 SEIZE      CPT12
280            ADVANCE    4
***LTOP***

281            RELEASE    CPT12
282            TEST E     P2,K4,CCC11
283            TERMINATE
         *
         *
         *
284      LLL11 QUEUE      QUE11
285            ENTER      LNE11
286            ADVANCE    9
287            ASSIGN     3,FSDPT11
288            SEIZE      DPT11
289            LEAVE      LNE11
290            ASSIGN     4,BVSNGONN
291            PRIORITY   1
292            ADVANCE    VSDECNN
293            TEST E     BVSNGONN,K0
294            ADVANCE    BVSBVHDW,FNSHDWNN
295            RELEASE    DPT11
296            TABULATE   WTE11
297            DEPART     NQUE
298            DEPART     QUE11
299      CCC11 SEIZE      CPT11
300            ADVANCE    2
301            TEST E     P2,K4,RLS11
302            ADVANCE    2
303      RLS11 RELEASE    CPT11
304            TEST E     P2,K3,TTT3
305            LOGICR     FLAG3
306      TTT3  TERMINATE
         *
         *
         *
         *
         *
         *
         *
         *
         *
```

```
              *
              *        SECTION -    CONTROL LIGHT TIMING
              *        *******
307                    GENERATE     1,0
308                    SAVEVALUE    1+,1
309                    TEST NE      X1,K16,TTT18
310                    TEST NE      X1,K57,TTT57
311                    TEST NE      X1,K77,TTT77
312                    TEST NE      X1,K140,TTTFF
313                    TERMINATE
314             TTT18  LOGIC S      SSLTE
315                    LOGICS       NNLTE
316                    TERMINATE
317             TTT57  LOGIC S      ENLTE
318                    LOGICS       WSLTE
319                    LOGICR       SSLTE
320                    LOGICR       SELTE
321                    LOGICR       NNLTE
322                    LOGICR       NWLTE
***LTOP***

323                    TERMINATE
324             TTT77  LOGIC S      EELTE
325                    LOGICS       WWLTE
326                    TERMINATE
327             TTTFF  LOGIC R      EELTE
328                    LOGICR       ENLTE
329                    LOGICR       WWLTE
330                    LOGICR       WSLTE
331                    LOGICS       SELTE
332                    LOGICS       NWLTE
333                    SAVEVALUE    1,0                   REINITIALIZE TO ZERO
334                    TERMINATE
              *
              *
              *
              *        SECTION  --  SAVEVALUE EEEE USED AS CLOCK
              *        *******
335                    GENERATE     1,0
336                    ASSIGN       1,BV$NGOEE
337                    ADVANCE      1
338                    SAVEVALUE    EEEE+,1               INCREMENT X$EEEE
339                    ASSIGN       2,BV$NGOEE
340                    TEST L       P1,P2,TERM1
341                    SAVEVALUE    EEEE,0                INITIALIZE X$EEEE
342             TERM1  TERMINATE
```

```
        *
        *       SECTION  --  SAVEVALUE ENEN USED AS CLOCK
        *       *******
343             GENERATE    1,0
344             ASSIGN      1,BV$NGOEN
345             ADVANCE     1
346             SAVEVALUE   ENEN+,1
347             ASSIGN      2,BV$NGOEN
348             TEST L      P1,P2,TERM2
349             SAVEVALUE   ENEN,0
350       TERM2 TERMINATE
        *
        *       SECTION  --  SAVEVALUE WWWW USED AS CLOCK
        *       *******
351             GENERATE    1,0
352             ASSIGN      1,BV$NGOWW
353             ADVANCE     1
354             SAVEVALUE   WWWW+,1
355             ASSIGN      2,BV$NGOWW
356             TEST L      P1,P2,TERM3
357             SAVEVALUE   WWWW,0
358       TERM3 TERMINATE
        *
        *       SECTION  --  SAVEVALUE WSWS USED AS CLOCK
        *       *******
359             GENERATE    1,0
360             ASSIGN      1,BV$NGOWS
361             ADVANCE     1
362             SAVEVALUE   WSWS+,1
363             ASSIGN      2,BV$NGOWS
364             TEST L      P1,P2,TERM4
365             SAVEVALUE   WSWS,0
***LTOP***

366       TERM4 TERMINATE
        *
        *       SECTION  --  SAVEVALUE SSSS USED AS CLOCK
        *       *******
367             GENERATE    1,0
368             ASSIGN      1,BV$NGOSS
369             ADVANCE     1
370             SAVEVALUE   SSSS+,1
371             ASSIGN      2,BV$NGOSS
372             TEST L      P1,P2,TERM5
373             SAVEVALUE   SSSS,0
374       TERM5 TERMINATE
        *
```

```
          *         SECTION  --  SAVEVALUE SESE USED AS CLOCK
          *         *******
375                 GENERATE    1,0
376                 ASSIGN      1,BV$NGOSE
377                 ADVANCE     1
378                 SAVEVALUE   SESE+,1
379                 ASSIGN      2,BV$NGOSE
380                 TEST L      P1,P2,TERM6
381                 SAVEVALUE   SESE,0
382         TERM6   TERMINATE
          *
          *         SECTION  --  SAVEVALUE NNNN USED AS CLOCK
          *         *******
383                 GENERATE    1,0
384                 ASSIGN      1,BV$NGONN
385                 ADVANCE     1
386                 SAVEVALUE   NNNN+,1
387                 ASSIGN      2,BV$NGONN
388                 TEST L      P1,P2,TERM7
389                 SAVEVALUE   NNNN,0
390         TERM7   TERMINATE
          *
          *         SECTION  --  SAVEVALUE NWNW USED AS CLOCK
          *         *******
391                 GENERATE    1,0
392                 ASSIGN      1,BV$NGONW
393                 ADVANCE     1
394                 SAVEVALUE   NWNW+,1
395                 ASSIGN      2,BV$NGONW
396                 TEST L      P1,P2,TERM8
397                 SAVEVALUE   NWNW,0
398         TERM8   TERMINATE
          *
          *
          *
          *
          *
          *         SECTION  --  SPECIFY RUN LENGTHS
          *                     *********
399                 GENERATE    140                ONE XACT EA 70 SECONDS (EA CYCLE)
400                 TERMINATE   1                  TERMINATE COUNT
                    START       2,NP               RUN 2 CYCLES WITHOUT PRINT OUT
          *THIS WAS DONE TO ACHIEVE STEADY STATE CONDITIONS
                    RESET                            INITIALIZE VARIOUS COUNTS
***LTOP***

                    START       6                  RUN 6 CYCLES
          *
          *
          *
                    END
```

APPENDIX C

OUTPUT FROM RUN

STORAGES

					-AVERAGE UTILIZATION DURING-						
STORAGE	CAPACITY	AVERAGE CONTENTS	ENTRIES	AVERAGE TIME/UNIT	TOTAL TIME	AVAIL. TIME	UNAVAIL. TIME	CURRENT STATUS	PERCENT AVAILABILITY	CURRENT CONTENTS	MAXIMUM CONTENTS
LNE5	8	.213	10	17.900	.026				100.0	1	2
LNE6	8	1.944	50	32.660	.243				100.0		8
LNE7	8	1.224	45	22.844	.152				100.0		6
LNE11	12	.619	20	26.000	.051				100.0		3
LNE12	12	1.620	39	34.897	.135				100.0	1	7
LNE9	10	3.626	60	50.767	.362				100.0	10	10
LNE1	15	1.235	42	24.690	.082				100.0		6
LNE2	15	1.613	39	34.744	.107				100.0		7
LNE3	15	1.946	46	35.543	.129				100.0		7
LNE4	15	.120	7	14.429	.008				100.0		2
LNE8	8	.086	8	9.000	.010				100.0		2
LNE10	10	.088	6	12.333	.008				100.0	1	1
LNE13	12	.686	18	32.000	.057				100.0	1	3

LTOP

QUEUES

QUEUE	MAXIMUM CONTENTS	AVERAGE CONTENTS	TOTAL ENTRIES	ZERO ENTRIES	PERCENT ZEROS	AVERAGE TIME/TRANS	$AVERAGE TIME/TRANS	TABLE NUMBER	CURRENT CONTENTS
EQUE	19	6.989	135		.0	43.488	43.488	1	
WQUE	17	4.970	113		.0	36.946	36.946	2	1
SQUE	13	4.651	67		.0	58.313	58.313	3	13
NQUE	12	4.863	80		.0	51.062	51.062	4	5
TEST2	1	.154	39	7	17.9	3.333	4.062	5	
TEST4	1	.034	8	1	12.5	3.625	4.142	6	
QUE03	8	2.596	46		.0	47.413	47.413		
QUE04	2	.388	8		.0	40.750	40.750		
QUE01	7	1.795	42		.0	35.904	35.904		
QUE02	8	2.209	39		.0	47.589	47.589		
QUE07	7	1.772	45		.0	33.088	33.088		
QUE08	2	.141	8		.0	14.875	14.875		
QUE06	10	2.563	50		.0	43.059	43.059		
QUE05	3	.492	10		.0	41.399	41.399		1
QUE09	11	4.649	61		.0	61.278	61.278		11
QUE10	2	.201	6		.0	28.166	28.166		2
QUE12	8	2.383	40		.0	50.049	50.049		2
QUE13	4	1.314	19		.0	58.105	58.105		2
QUE11	4	1.165	21		.0	46.619	46.619		1

$AVERAGE TIME/TRANS = AVERAGE TIME/TRANS EXCLUDING ZERO ENTRIES

LTOP

FACILITIES

FACILITY	NUMBER ENTRIES	AVERAGE TIME/TRAN	-AVERAGE UTILIZATION DURING- TOTAL TIME	AVAIL. TIME	UNAVAIL. TIME	CURRENT STATUS	PERCENT AVAILABILITY	TRANSACTION NUMBER SEIZING	PREEMPTING
DPT3	46	11.870	.690				100.0		
CPT3	54	3.685	.236				100.0	60	
DPT4	8	28.125	.287				100.0		
DPT1	42	11.214	.560				100.0		
CPT1	50	3.680	.219				100.0		
DPT2	39	12.846	.596				100.0		
CPT2	47	3.660	.204				100.0		
DPT8	8	5.875	.055				100.0		
DPT7	45	10.244	.548				100.0		
CPT7	53	3.698	.233				100.0		
DPT6	50	10.020	.596				100.0		
CPT6	58	3.724	.257				100.0		
DPT5	9	26.111	.279				100.0		
CPT5	17	3.059	.081				100.0		
DPT9	51	13.569	.823				100.0	34	
CPT9	67	4.000	.319				100.0		
DPT10	5	19.000	.113				100.0	7	
DPT13	18	29.333	.628				100.0	53	
DPT12	39	16.436	.763				100.0	6	
CPT12	42	4.000	.200				100.0		
DPT11	21	21.857	.546				100.0	45	
CPT11	24	3.667	.194				100.0		

LTOP

TABLES

TABLE EQUE

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
135	43.674	29.250	5896.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	-.000	-1.493
20	38	28.14	28.1	71.8	.457	-.809
40	32	23.70	51.8	48.1	.915	-.125
60	20	14.81	66.6	33.3	1.373	.558
80	24	17.77	84.4	15.5	1.831	1.241
100	20	14.81	99.2	.7	2.289	1.925
120	1	.74	100.0	.0	2.747	2.609

REMAINING FREQUENCIES ARE ALL ZERO
LTOP

TABLE MQUE

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
112	37.357	28.187	4184.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	-.000	-1.325
20	46	41.07	41.0	58.9	.535	-.615
40	17	15.17	56.2	43.7	1.070	.093
60	18	16.07	72.3	27.6	1.606	.803
80	20	17.85	90.1	9.8	2.141	1.512
100	11	9.82	100.0	.0	2.676	2.222

REMAINING FREQUENCIES ARE ALL ZERO
LTOP

TABLE SQUE

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
54	65.425	30.437	3533.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	-.000	-2.149
20	1	1.85	1.8	98.1	.305	-1.492
40	8	14.81	16.6	83.3	.611	-.835
60	19	35.18	51.8	48.1	.917	-.178
80	8	14.81	66.6	33.3	1.222	.478
100	10	18.51	85.1	14.8	1.528	1.135
120	6	11.11	96.2	3.7	1.834	1.792
140	2	3.70	100.0	.0	2.139	2.450

REMAINING FREQUENCIES ARE ALL ZERO
LTOP

TABLE NOUE

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
75	57.119	33.125	4284.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	-.000	-1.724
20	15	19.99	19.9	80.0	.350	-1.120
40	13	17.33	37.3	62.6	.700	-.516
60	10	13.33	50.6	49.3	1.050	.086
80	14	18.66	69.3	30.6	1.400	.690
100	14	18.66	87.9	12.0	1.750	1.294
120	8	10.66	98.6	1.3	2.100	1.898
140	1	1.33	100.0	.0	2.450	2.502

REMAINING FREQUENCIES ARE ALL ZERO
LTOP

TABLE TEST2

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
39	3.333	1.593	130.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	7	17.94	17.9	82.0	-.000	-2.091
1	0	.00	17.9	82.0	.300	-1.464
2	0	.00	17.9	82.0	.600	-.836
3	0	.00	17.9	82.0	.900	-.209
4	30	76.92	94.8	5.1	1.199	.418
5	2	5.12	100.0	.0	1.500	1.045

REMAINING FREQUENCIES ARE ALL ZERO
LTOP

TABLE TEST4

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
8	3.625	1.503	29.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	1	12.50	12.5	87.5	-.000	-2.410
1	0	.00	12.5	87.5	.275	-1.745
2	0	.00	12.5	87.5	.551	-1.080
3	0	.00	12.5	87.5	.827	-.415
4	6	75.00	87.5	12.5	1.103	.249
5	1	12.50	100.0	.0	1.319	.914

REMAINING FREQUENCIES ARE ALL ZERO
LTOP

TABLE WTE1

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
42	35.904	25.500	1508.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	-.000	-1.408
20	15	35.71	35.7	64.2	.557	-.623
40	9	21.42	57.1	42.8	1.114	.160
60	10	23.80	80.9	19.0	1.671	.944
80	6	14.28	95.2	4.7	2.228	1.729
100	2	4.76	100.0	.0	2.785	2.513

REMAINING FREQUENCIES ARE ALL ZERO
LTOP

TABLE WTE2

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
39	47.589	27.812	1856.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	-.000	-1.711
20	8	20.51	20.5	79.4	.420	-.991
40	10	25.64	46.1	53.8	.840	-.272
60	7	17.94	64.1	35.8	1.260	.446
80	7	17.94	82.0	17.9	1.681	1.165
100	7	17.94	100.0	.0	2.101	1.884

REMAINING FREQUENCIES ARE ALL ZERO
LTOP

TABLE WTE3

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
46	47.500	33.437	2185.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	-.000	-1.420
20	14	30.43	30.4	69.5	.421	-.822
40	10	21.73	52.1	47.8	.842	-.224
60	2	4.34	56.5	43.4	1.263	.373
80	9	19.56	76.0	23.9	1.684	.971
100	10	21.73	97.8	2.1	2.105	1.570
120	1	2.17	100.0	.0	2.526	2.168

REMAINING FREQUENCIES ARE ALL ZERO
LTOP

TABLE WTE4

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
8	43.375	25.500	347.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	-.000	-1.700
20	1	12.50	12.5	87.5	.461	-.916
40	3	37.50	50.0	50.0	.922	-.132
60	1	12.50	62.5	37.5	1.383	.651
80	2	25.00	87.5	12.5	1.844	1.436
100	1	12.50	100.0	.0	2.305	2.220

REMAINING FREQUENCIES ARE ALL ZERO
LTOP

TABLE WTE5

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
9	45.111	29.437	406.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	-.000	-1.532
20	3	33.33	33.3	66.6	.443	-.853
40	0	.00	33.3	66.6	.886	-.173
60	3	33.33	66.6	33.3	1.330	.505
80	2	22.22	88.8	11.1	1.773	1.185
100	1	11.11	100.0	.0	2.216	1.864

REMAINING FREQUENCIES ARE ALL ZERO
LTOP

TABLE WTE6

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
50	43.379	29.375	2169.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	-.000	-1.476
20	17	33.99	33.9	66.0	.461	-.795
40	6	11.99	45.9	54.0	.922	-.115
60	10	19.99	65.9	34.0	1.383	.565
80	10	19.99	85.9	14.0	1.844	1.246
100	7	13.99	100.0	.0	2.305	1.927

REMAINING FREQUENCIES ARE ALL ZERO
LTOP

TABLE WTE7

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
45	33.111	26.500	1490.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	-.000	-1.249
20	20	44.44	44.4	55.5	.604	-.494
40	10	22.22	66.6	33.3	1.208	.259
60	4	8.88	75.5	24.4	1.812	1.014
80	8	17.77	93.3	6.6	2.416	1.769
100	3	6.66	100.0	.0	3.020	2.524

REMAINING FREQUENCIES ARE ALL ZERO
LTOP

TABLE WTE8

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
8	14.875	12.492	119.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	-.000	-1.190
20	6	75.00	75.0	25.0	1.344	.410
40	1	12.50	87.5	12.5	2.689	2.011
60	1	12.50	100.0	.0	4.033	3.612

REMAINING FREQUENCIES ARE ALL ZERO
LTOP

TABLE WTE9

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
50	68.719	29.062	3436.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	-.000	-2.364
20	0	.00	.0	100.0	.291	-1.676
40	5	9.99	9.9	90.0	.582	-.988
60	19	37.99	47.9	52.0	.873	-.300
80	8	15.99	63.9	36.0	1.164	.388
100	10	19.99	83.9	16.0	1.455	1.076
120	6	11.99	95.9	4.0	1.746	1.764
140	2	3.99	100.0	.0	2.037	2.452

REMAINING FREQUENCIES ARE ALL ZERO
LTOP

TABLE WTE10

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
4	24.250	11.898	97.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	-.000	-2.038
20	1	25.00	25.0	75.0	.824	-.357
40	3	75.00	100.0	.0	1.649	1.323

REMAINING FREQUENCIES ARE ALL ZERO
LTOP

TABLE WTE11

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
20	47.899	33.500	958.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	-.000	-1.429
20	5	25.00	25.0	75.0	.417	-.832
40	5	25.00	50.0	50.0	.835	-.235
60	3	14.99	64.9	35.0	1.252	.361
80	3	14.99	79.9	20.0	1.670	.958
100	1	4.99	84.9	15.0	2.087	1.555
120	3	14.99	100.0	.0	2.505	2.152

REMAINING FREQUENCIES ARE ALL ZERO
LTOP

TABLE WTE12

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
38	59.315	32.687	2254.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	-.000	-1.814
20	7	18.42	18.4	81.5	.337	-1.202
40	7	18.42	36.8	63.1	.674	-.590
60	5	13.15	49.9	50.0	1.011	.020
80	6	15.78	65.7	34.2	1.348	.632
100	8	21.05	86.8	13.1	1.685	1.244
120	5	13.15	100.0	.0	2.023	1.856

REMAINING FREQUENCIES ARE ALL ZERO
LTOP

TABLE WTE13

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
17	63.058	33.437	1072.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	-.000	-1.885
20	3	17.64	17.6	82.3	.317	-1.287
40	1	5.88	23.5	76.4	.634	-.689
60	2	11.76	35.2	64.7	.951	-.091
80	5	29.41	64.7	35.2	1.268	.506
100	5	29.41	94.1	5.8	1.585	1.104
120	0	.00	94.1	5.8	1.902	1.702
140	1	5.88	100.0	.0	2.220	2.301

REMAINING FREQUENCIES ARE ALL ZERO
LTOP

****
*   *
*   FULLWORD SAVEVALUES   *
*   *
****

NUMBER - CONTENTS		NUMBER - CONTENTS		NUMBER - CONTENTS		NUMBER - CONTENTS		NUMBER - CONTENTS		NUMBER - CONTENTS	
1	139	EEEE	43	ENEN	7	WWWW	139	WSWS	139	SSSS	82
SESE	82	NNNN	82	NWNW	121						

LTOP

****
*   *
*   LOGIC SWITCHES   *
*   *
****

LOGIC SWITCH - SET (ON) STATUS

NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER
EELTE	ENLTE	WWLTE	WSLTE											

LTOP

*
*
*

END

***** TOTAL RUN TIME (INCLUDING ASSEMBLY) = .86 MINUTES *****

APPENDIX D

TIME LAPSE FILM DATA

APPENDIX D

TABULATION OF TIME LAPSE FILM DATA

Location: Intersection of Bumby Ave & Colonial Drive

Date: Thursday, January 24, 1974

Time: 1400 - 1500 hours (afternoon)

The four directions of approach were recorded separately, each over a period of 420 seconds. The camera recorded one frame each 2.0 seconds.

APPENDIX D

ARRIVALS FROM EAST

LANE	5	6	7	8	ALL
Vehicle-Seconds Travel Time	180	1122	760	274	2336
No. of Vehicles	8	51	39	12	110
Percent of Vehicles	7.2	46.4	35.5	10.9	100.0
Average Travel Time Per Vehicle (seconds)	22.5	22.0	19.5	22.8	21.2
Average Queue	0.43	2.7	1.8	0.65	5.5
Maximum Queue	2	5	8	3	14
Arrival Rate (Seconds/vehicle)					3.81

APPENDIX D

ARRIVALS FROM SOUTH

LANE	11	12	13	ALL
Vehicle-Seconds Travel Time	644	800	682	2126
No. of Vehicles	17	27	17	61
Percent of Vehicles	27.9	44.2	27.9	100.0
Average Travel Time Per Vehicle (seconds)	37.9	29.6	40.1	34.9
Average Queue	1.53	1.9	1.62	5.06
Maximum Queue	4	6	6	13
Arrival Rate (Seconds/vehicle)				6.9

APPENDIX D

ARRIVALS FROM WEST

LANE	4	3	2	1	ALL
No. of Vehicles	7	51	53	17	128
Percent of Vehicles	5.5	39.8	41.4	13.3	100.0
Arrival Rate					3.28

ARRIVALS FROM NORTH

LANE	10	9	ALL		
No. of Vehicles	7	49	56		
Percent of Vehicles	12.5	87.5	100.0		
Arrival Rate			7.5		

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