CHAPTER III

METHOD OF RESEARCH

The Study of Basic Intersection Model

Starting from basic intersection, Poisson distribution is fed into the N-S-E bounds for generating input arrivals of vehicles. The probability ratio of the arrivals distribued in the individual lanes of turn-left, turn-right and go straightforward as well as the probability of servicing time for vehicles crossing an intersection are given. Assume that the peak-hour period occurs within 2 hours or 7200 seconds. The divisions of the unit of time into such small interval as seconds will enable us to investigate the behavior of the simulated configuration about queues step by step.

At zero clock time and zero waited queues, generation of the arrivals and services for the flow of vehicles in N-S-E bounds are started, by using a ratio of red phase per green phase in a certain cycle of timing. Then the number of queues and services are recorded in the data files. The generation of the arrivals and services at each clock time is repeated and the number of queues and services are again recorded through the given period of time. At the end of the process, the maximum queue-length for each lane of N-S-E bounds is obtained. At the same time, in W-bound, one detector is placed in a certain point to count the number of vehicles coming from the other bounds passing into this bound. By counting the numbers of vehicles in an equal interval of time, the frequency distribution of input vehicles for W-bound is found. This frequency distribution form is very useful for applying to find the optimal queue-length between intersections. This will be discussed later. The basic model is shown in Fig. 3-1.

Application of the Model for Intersections

It can be seen in Fig. 3-2 that the basic intersection model is applied reversibly for both intersections A and B. The N-S bound of intersection A is pointed downward and N-S bound of intersection B is pointed upward, so that the W-bound of both intersections are the same link. Then the queue to be optimized is in this link. Assume that the model is fed by an equal probability ratio of turn-left, turn-right and go straight-forward as well as the probability of services. ? From the assumptions stated before, the outer inputs flow into the intersections can be any kind of distribution forms. To be more facile to analyze and make simply the model, Poisson distribution is used for generating the arriving of vehicles. According to the fact that, the time interval between the arriving vehicles is Exponential distribution, so in the computer programming, the generation of Exponential distribution is replaced. The mean or expected value using for generating the distribution is close to the real-world data taken from the AIT's Transportation Research Lab. some part of Bangkok. The determination is shown in the next section.

At intersection A, the timing signal is fixed for a specific proportion of phasing, called phase ratio, and intersection B's timing signal is varied. Starting with one phase ratio at B, the arriving vehicles are generated with Exponential distribution for every bound except W-bound of both intersections. Assume that no vehicles appear in the link between that intersections at the beginning. According to the generation of vehicles for a basic intessection, the detectors at W-bound of both intersections A and B will detect the vehicles passing into the link AB, and form the frequency patterns of the flow. From assumptions stated previously in Chapter I, it is assumed that the vehicles' speed is constant when moving from A to B and from B to A. Then the frequency pattern from A to B would have the same pattern along that link. Therefore the input arrivals for W-bound of intersection B can be generated by this frequency distribution pattern, with the use of Empirical Discrete Distribution generation. In the computer programming, the subprogram called DISCR is used for this purpose. Similarly, the input vehicles for W-bound of intersection A, can be also generated by the frequency distribution pattern coming from B to A. It means that for every clock time of simulation starting from zero to 7200 seconds the arrivals and services for every bound of both intersections can be generated, and the queue-length between intersections from A to B and from B to A are obtained. After that the second set of different proportion of phasing is tried, by repeating the same process which has been done to obtain the new solution of queue-length. For various phase ratio, the various queue-length between A and B are obtained. Tabulating all of these results and plotting the graph between phase ratio and masium queue length, the optimal phase ratio for optimal queue-length can be found.

Data Consideration

Data to be considered here is the mean value of Exponential distribution. The approximated value is determined from the collected data of Transportation division, Asian Institute of Technology, Bangkok. The data is taken from ground station counts with volumes, veh / 5 min, on Wednesday, 3rd March 1971, at the following locations:

Site : Eastbound and Westbound traffic along Rama I Road, Bangkok

East section : Henri Dunant Street to Phya Thai Road

West section : Phya Thai Road to Charoenpol Market Lane

The data is shown in Table 3-1 below:

Table 3-1

Time	EB	EB	WB	WB	Time	EB	EB	WB	WB
	East	West	East	West		East	West	East	West
0820					0925				
	165	147	176	165		163	133	176	144
0825					0930				
	177	133	148	140		166	157	154	157
0830					0935				
	169	115	173	149		150	122	146	129
0835					0940				
	159	132	182	153		183	149	138	126
0840					0945				
	157	145	178	167		167	145	168	125
0845					0950				
	183	122	140	130		142	125	166	125
0850					0955				
	185	128	161	135		175	130	114	114
0855					1000				
	118	105	170	158		136	126	181	120
0900					1005				
	171	144	161	138		177	153	191	168
0905					1010				
	174	131	193	155		188	147	201	138
0910					1015				
	181	141	172	131		155	144	156	122
0915					1020				
	139	110	148	128		170	154	165	114
0920					1025				
	153	119	121	121		201	161	171	126
0925					1030				

From Table 3-1, the average headway of vehicles may be determined as follow:

For EB East column :

Total vehicles from clock time 0820 to 1030 is 4304

For the number of counts is 26

Then mean value = 4304 / 26 = 165.5 veh / 5-mins.

or Average headway = 60 X 5 / 165.5 = 1.81 sec / veh.

For EB West column :

Total vehicles in the same period of time as EB East is 3518

with the same number of counts

Then mean value = 3518 / 26 = 135.3 veh / 5-mins.

or Average headway = 60 X 5 / 135.3 = 2.21 sec / veh.

For WB East column :

Total vehicles is 4250

Hence, the mean value = 4250 / 26 = 163.4 veh / 5-mins.

Then, Average headway = 60 X 5 / 163.4 = 1.84 sec / veh.

For WB West column :

Total vehicles is 3578

The mean value = 3578 / 26 = 137.6 veh / 5-mins.

or Average headway = 60 X 5 / 137.6 = 2.19 sec / veh.

Then the final average headway per bound is

(1.81 + 2.21 + 1.84 + 2.19) / 4 = 2.01 sec / veh.

or about 2 sec/veh.

This is the expected value that will be used in the generation of the distribution for the model.

Computer Programming

The computer programming used for the model is developed by using FORTRAN IV programming language with IBM 1130 system, 8K - core storage and one disk system. Since the program is too large and the computer system has to use overlay system which will make the program takes too long time in computation, it is advisable that the program divided into three main programs. The CALL LINK statements are then used to link those three programs. With this technique the computing time is reduced appreciably. The disk system is used to store all data generated in the computer programs, because the computer core storage of this computer is too small to carry such big scale of dimensions in memorizing those generated data. It needs the user area about 560 sectors in the disk to store all data.

The main programs are name TRAF1, TRAF2, and TRAF3. They contain 12 subprograms called ARRIV, DEARV, DISCR, GPROB, MAXVQ, PARTQ, QLANE, QUEUE, RANDU, TEXPA, TNORS and UNFRM. The programs are shown in APPENDIX C, and the logical flow chart is shown in APPENDIX D. All variables used in the computer programming are described in APPENDIX E. The following section will explain the details of the functions of each programs and its application.

<u>Main Program TRAF1</u> This program contains the informations about the generation of queues and services of one intersection for N-S-E bounds. It takes about 45 mins. of computing time for doing this section. All necessary data input is read by this program, the arrangement of the input data will be described before the last section of this chapter. The flow chart in APPENDIX D will explain clearly about the logical function of

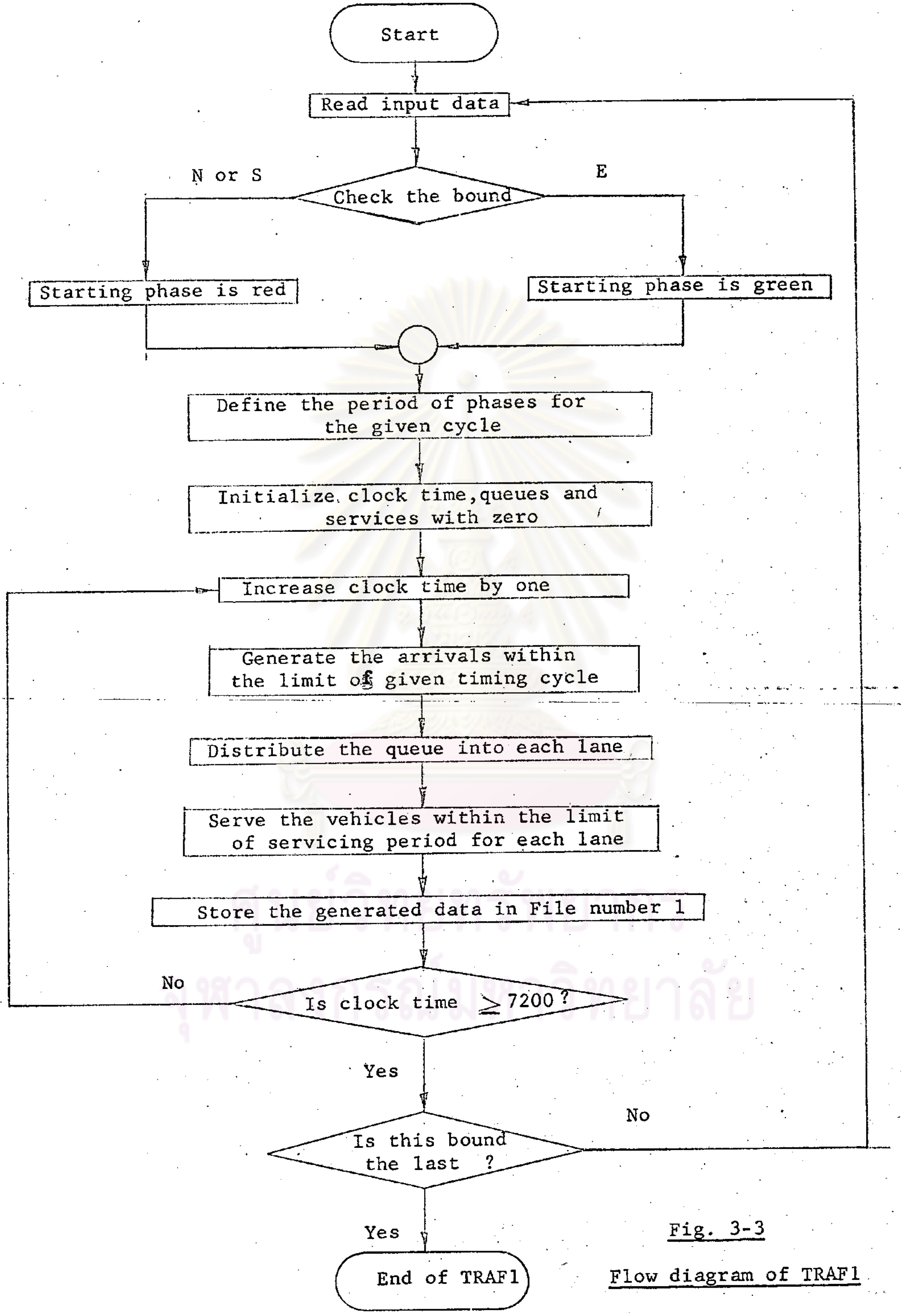

Fig. 3-3

Flow diagram of TRAF1

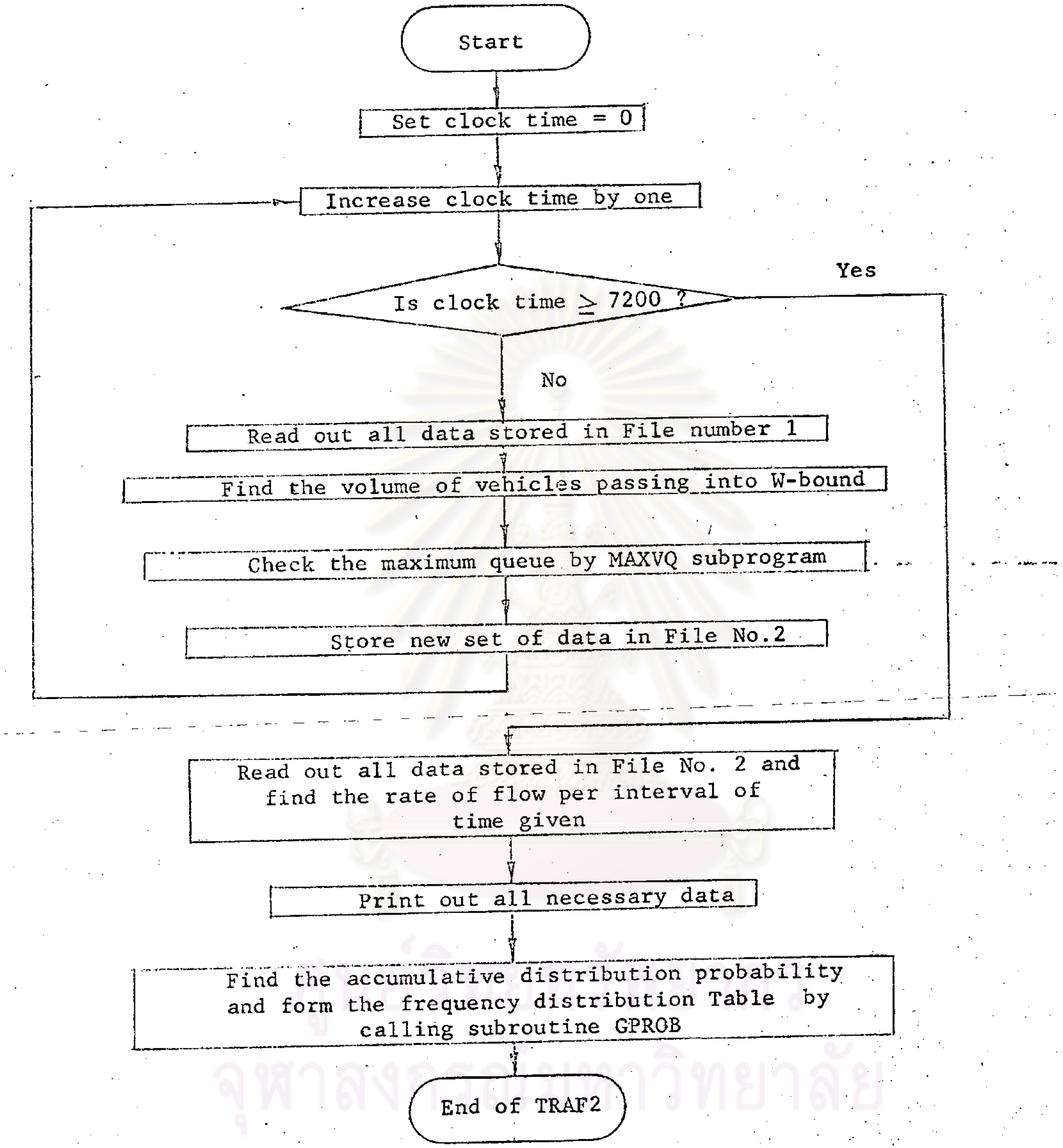

Fig. 3-4 Flow diagram of TRAF2

this computer programming. The necessary subroutines called in this program are RANDU, QUEUE, TEXPA, TNORS and ARRIV. The generation of the queues and services for each bound is independently computed, however they are stored in the same number of data file as shown in the program (see APPENDIX C). The outline shown in Fig. 3-3, shows briefly the function of the program.

Main Program TRAF2. This program is used for computing the number of vehicles passing into W-bound, finding the maximum queues for each lane of N-S-E bounds and also the maximum volume of vehicles the clock time indicated the maximum queue and maximum volume for each of the bound. It is denoted that a vehicle moving from the stop sign of any bound to the detector placed in W-bound must take time. This can be specified by the reasonable value like this, assumed that vehicle takes 2 second of time to move from the stop sign of turn-left lane of Southbound to the detector position, and 4 seconds of time from the stop sign of turn-right lane of Northbound and straightforward lanes of Eastbound to the detector. If it is applied to the actural intersection, these value of time can be changed to the suitable ones. Therefore, the detector will count the number of vehicles passing into this bound with the delay time, with vespect to the clock time at stop sign positions. The straightforward lane, may be the multiple lanes if the number of lane of the input data is more than 3. In this case the number of vehicles will be distributed according to the number of lanes defined. The program includes 3 subprograms called MAXVQ, QLANE and GPROB. The function of this program is first starting to read out all data stored in file number 1 and counting the number of vehicles passing into W-bound with the assumed delay time as well as the volume of vehicles for N-S-E bounds and store all data in file number 2 in every unit of clock time. At the same time the MAXVQ subprogram is called to check the maximum queue for each lane of the bound and maximum volume for each bound. After that GPROB is called to form the frequency distribution pattern of the flow of detector which is useful for generating the arrivals between intersections for the program TRAF3. This program's computing time is about 5 mins. The outline of flow diagram is shown in Fig. 3-4.

Main Program TRAF3 This program is the application program for two intersections which is used to find the optimal queue-length between intersections. As shown in Fig. 3-2. The frequency distributions for both intersections A and B have been generated from TRAF1 and TRAF2. For TRAF3, the queues and services to be generated are in the ways along the link, one is from intersection A to B and another is from B to A. The process of generating the data is the same as TRAF1, accept the input distribution form is not the Poisson distribution or in the other word the Exponential distribution, but it is the Empirical discrete distribution which is formed by the detector in TRAF2. After running program TRAF1 and TRAF2 all necessary data will be stored in file number 200 and 300, therefore coming to this program the data stored in file numbers can be destroyed and replaced the new set of data which is generated by program TRAF3. Doing like this is to safe the area in the disk and make compactly the programs. Some data will be read by this program. The subroutine called in this program are RANDU, PARTQ, DISCR, DEARV, TNORS, MAXVQ and QLANE. It takes about 30 mins. per one set of NVEHC in computation. After running this program the maximum queue for each lane and maximum volume of vehicles moving from A to B and from B to A can be found. Also the clock time indicated the maximum queue and volume are obtained.

The following section will explain the use of each subprogram.

Subprogram RANDU This subprogram has been obviously explained in APPENDIX B about its usage and function. There is no need to explain anymore.

Subprogram TEXPA This subprogram is used to generate the headway of vehicles by the Exponential distribution generation as mentioned in chapter II, but in this subprogram there are some differences from that one for some specifications have been changed. From the program shown in APPENDIX C, there are 3 parameters to be considered, IX, TMEAN and TARV. IX is the random input integer for generating the random output from the calling subroutine RANDU, this will result R the random number which is the number in the limit between zero and one. Meanwhile, the new IX is generated by setting IX = IY, which IY is the new input random number for the next generation from the same subroutine RANDU. Then the random headway for Exponential distribution is generated by the following equation:

$$X = - TMEAN * ALOG(R) + 1.$$

Where TMEAN is the average headway given by input data.
Due to the assumption stated in chapter I, 1. is added for limitting the minimum headway of vehicles. Actually X and be any floating point, number but in this record only the integer number of headway is needed in computation so that the value of X has to be changed into integer number by setting it equal to the integer variable TARV. This program is used in TRAF1 only.

Subroutine TNORS This program is used for serving the vehicles in crossing an intersection. IX, PROB1, PROB2 and TSERV are the parameters of the program. RANDU is also used for being the generator of random number, with IX is an input random number, and also the output for the next generation of random number similarly to TEXPA subprogram. It is assumed that the headway for vehicles to be served is about 2 seconds, this assumption is taken from the Table 5.2a page 104 of Traffic flow Theory by D.R. Drew. This assumed to be a normal service, but actually the even may be change that means, some accidents may occur at any interval of time which will make the vehicles move faster or slower than the normal level. To gid rid of this problem, it can be assumed that for vehicles moving faster than normal level, let the time to be served (TSERV) is 3 seconds and if the vehicles moving slower than the normal level, let TSERV = 1. Assume that the probability for the vehicles can be served within 2 seconds occur in the traffic situation a %, and the probability of vehicles can be served within 3 seconds occur b % so the less (100 - a - b) % is for TSERV = 1. Using accumulative probability, say total probability ocurred is one, then the limit of vehicles can be served by TSERV = 2 is assumed to be in the limit from 0 to a/100 unit, and for vehicles to be served by TSERV = 3 is in the limit from $a/100^+$ to (a+b)/100, all the less from $(a+b)/100^+$ to 1.0 is for TSERV = 1. After arranging the limit for the events occur, then the random number R is generated by RANDU, R's limit is also started from 0 to 1.0, therefore, if R is the number falls within the limit of 0 to a/100 the serving time would be 2 seconds, if R is in the limit of $a/100^+$ to (a+b)/100 the serving time would be 3 seconds and the less limit would be 1 second. This is the idea of how the servicing time can be generated. For the atual event this servicing time may be change to the suitable ones, for it may occur more than 3 intervals of time. According to the parameters of the program PROB1 is equal to a/100, and PROB2 is equal to (a+b)/100. Clarifying that, TSERV is the integer output for the servicing time, similarly to the generation of input arrivals TARV. This program is used in main program TRAF1 and TRAF3.

Subprogram QUEUE This is the subprogram called in TRAF1. Its' function is only checking the time, whether that clock time there is a vehicle coming into the lane or not, if there is, increasing the queue indicator variable ITQ by one. This program uses no trick in programming, just simple one so skip to the next one.

Subprogram ARRIV This program is used for distributing the vehicles into each specific lane according to the probabilistic values for how many percentages of vehicle to run into turn-left lane, how many percentages of vehicles to run into straightforward lane and how manu percentages for turn-right lane. The method used is similare to subprogram TNORS. The accumulative probability and generated random number from subprogram RANDU, the difference is only that the previous program is wanted the time, but this program is wanted the number of vehicles distributed in the specific lane. Subroutine TEXPA is also needed in this program. The variable, PB1 and PB2 are the accumulative probability given. Within the limit of 0 to 1.0. The range from 0 to PB1 is the limit of vehicles go into turn-left lane, the range from $PB1^+$ to PB2 is the limit of vehicles go into the straighforward lane and the less from $PB2^+$ to 1.0 is the limit of vehicles go into turn-right lane. Other variables descriptions will be defined in APPENDIX E. This program is called in TRAF1.

Subprogram MAXVQ This subprogram is used to find the maximum queue and volume of the flow, also the clock time indicated the maximum occur. It is the simple one without any trick in programming. It is called in TRAF1 and TRAF3.

<u>Subprogram UNFRM</u> This subprogram is used for generating the uniform distribution of the headway of vehicles generated by the Empirical discrete distribution method. This subroutine is called by subroutine DISCR. There is some difference from the theoretical FORTRAN programming as mentioned in chapter II, the equation shown below is added into the subprogram.

KTARV = 300 . * FLOAT(NVEHC) / TARV + 0.50 (see APPENDIX C)

Where KTARV is the result of the required headway in an integer number. NVEHC is the number of vehicles to be generated each time. This is an important point for this program, for the parameters A and B in the program has the dimension of number of vehicles per 5 mins. After generating by uniform distribution method, it results TARV which has the same unit as A and B. Since the purpose of the program is to generateethe headway of vehicles, no number of vehicles per interval of time so it has to be converted the former unit into the unit of seconds per vehicle. Suppose, that in 5 mins. there are TARV vehicles coming into the given point, therefore the headway of each vehicle should be 5 X 60 ./ TARV seconds. From the Table of frequency distribution of vehicles passing into W-bound, which is the result from TRAF2, seeing that the class interval of number of vehicles per 5 mins. is quite high and effect the accuracy of time to be generated. Because if the number 300 is divided by TARV and gets a floating point number, but the integer number is needed in final result, so this number has to be rounded off, then this will lead to occurring of an error, for example if the resultant number of 300./TARV is about 1.5, after rounding off it becomes 1. The percentage of an error is about 33% that is very high. To get rid of this problem, instead of generating one vehicle at one time, the more vehicles would be tried. The results in the

Table 4-1 will show the effect of various number of NVEHC and the way of how to choose the optimal value of NVEHC will be discussed later. Note that, the number 0.50 is added into the equation shown in this section is to round off the number which its' decimal value is higher than 0.5 to become 1.

Subprogram PARTQ This program is almost the same as the subprogram QUEUE. The difference is only the generation of vehicles at the same clock time may be more than one. This is the approximation method, due to the fact it can not be generated at the same time but for such small internal of time it may be assumed possibly. The accuracy of this program depend on the value NVEHC. The result will be discussed later.

Subprogram DISCR This program is used to generate the arrivals of Empirical discrete distribution. The empirical data is taken from the frequency distribution generated by main program TRAF1 and TRAF2 and getting the accumulative probability named PROB which is one parameter in this subroutine. The process of generation is the same as subroutine TEXPA and TNORS the only thing that distincguishs from those programs is more probability value is put into account. The subroutine to be called in this program is UNFRM.

Subprogram DEARV This program is used to generate the arrivals and distribute the flow in each lane, due to the probability ratio of turn-left, turn-right and go straightforward. The method of the generation is similar to the subprogram ARRIV, e accept the variable NVEHC is to be considered to make the program be more effective for empirical discrete condition. The subroutine called in this subprogram is DISCR and RANDU.

Subprogram GPROB This program is used for finding the accumulative probability distribution, which is obtained from the accumulative frequency distribution table the results from main program TRAF1 and TRAF2. The method of this program is to classify the class interval for vehicles per 5 mins. into the form of frequency distribution. This Table is shown in the sample program in APPENDIX F. The interval is classified by ten vehicles per interval or may be 5 vehicles per interval. This depends on the range between the lower limit and uper limit of the class intervals, if the range is too big or big enough it is assumed to be classified the interval into 10 vehicles per class interval, if it is too small it is assumed to be classified the interval into 5 vehicles per class interval. This is enough for the research, for it has been observed during testing the program before making the decision, the results give the reasonable value which will be discussed in later chapter. It is assumed that if the range of uper limit and lower limit is greater than 60 vehicles, let the class interval be 10 vehicles per interval, and if the range is less than 60 vehicles let the class interval be 5 vehicles per interval, this can be seen in the computer program and How chart in APPENDIX C and D. The frequency distribution table is formed and printed in this program. No any subroutine is needed in this program.

<u>Subprogram QLANE</u> This subprogram is used for finding the queue per lane of the straightforward lanes. The variables IFWQ and LANE are the parameters used in this program. IFWQ is both input and output parameter, for the input condition it is the total maximum volume of vehicles occurred in the straightforward lanes and for the output condition it is the maximum queue per straightforward lane. LANE is the number of straightforward lanes. If there is the fraction after dividing the total volumes by number of lanes,

one vehicle will be added for at least one lane would have the maximum queue, for example if IFWQ = 10 vehicles per 3 lanes, then the maximum queue per lane is 10/3 + 1 = 4 vehicles, this is the fact that if would occur in one of the lanes, the distributed queue should be in this form, 3-3-4 or 3-4-3 or other combinations. But if the IFWQ is equal to 9 that will have no problem, it must be 3-3-3, so if there is no fraction one vehicle is not necessary to be as the previous condition. This subprogram is called in TRAF2 and TRAF3.

The Arrangement of Input Data for Computer Programming

For TRAF1, the arrangement of the data is in the following order; and the Format has been shown in the program listed in APPENDIX C.

The 1st data card

The input variables are

M, (MM(I),I = 1,M),IX,LANE

Where M is the number of period for counting the volume of vehicles passing the detector, here using M = 3

MM is the periods of time for counting the volume of vehicles passing the detector. MM = 60, 300 and 900 is used in this research.

IX is the first entry input random integer number for RANDU, it is described in APPENDIX B.

LANE is the number of straightforward lanes.

The 2nd data card

The input variables are

TMEAN, PBL1, PBL2, PBF1, PBF2, PBR1, PBR2

where TMEAN is the average headway for the Exponential distribution used in subprogram TEXPA.

PBL1 and PBL2 is the turn-left service-accumulative probability used in subprogram INORS.

PBF1 and PBF2 is the straightforward service-accumulative probability used in subprogram TNORS

PBR1 and PBR2 is the turn-right service-accumulative probability used in subprogram TNORS.

The 3rd data card

The input variables are

NPHAS, N, K4

where NPHAS is the number of phases to be used as the controlled signal, here using NPHAS = 2 or 4.

N is the number of bounds for the input distribution at intersection, here using N = 3 (for S-N-E bounds only)

K4 is the logical-control variable for the program in linking the main programs. If K4 is 1 after executing TRAF1, it will link program 2 (TRAF2) and then back to program one again, if K4 is 2 after executing program 2 it will link the 3rd program (TRAF3).

The 4th data card

The input variables are

(IPHAS(I), I = L, NPHAS), NOCYL

Where IPHAS is the period of phases for controlling the signal. The number of phases depend on the variable NPHAS.

NOCYL is the period of time for a complete cycle of timing in seconds.

The 5th data card

The input variables are

IBOUN, (IPROB(JN, J1), J1 - 1,3)

Where IBOUN is the indicator for indicating the bound to be generated the queue. IBOUN - 1 for Northbound and Southbound, the will cause the starting phase is red phase according to the assumption stated in chapter I. IBOUN - 2 for Eastbound, it is started with green phase.

IPROB is the probability percentages of turn-left, go straight-forward and turn-right vehicles.

JN is the number of loop, according to the number of bounds.

The 6th data card

The input variables are

AA, PB1, PB2

Where AA is the name of the bound.

PB1 and PB2 are the accumulative probability for distributing the vehicles into each apecific lane. They are used in subprogram ARRIV and DEARV.

For TRAF 2 only data card is to be read, the variable is shown below:

QNOTE

Where QNOTE is the comment card for indicating the order of data used. It is printed out in the result sheet.

For TRAF3 There are two data cards to be read.

The 1st one

The input variables are

(IPROB(IS, IR), IR = 1,3)

Where IPROB is the percentages of probability of turn-left, go straightforward and turn-right conditions.

IS is the number of data for each set, there are two set of data because this is used for the link between intersections which has two ways for vehicles to move along.

The 2nd one

The input variables are

PB1, PB2, PBL1, PBL2, PBF1, PBF2, PBR1, PBR2

All of these variables are to be used for the same purpose as the 2nd data card and the 6th data card in TRAF1.

Cases of Study

The cases of study of this model can be arranged as the following items:

Case 1 From the model shown in Fig. 3-2, the timing signal at intersection A is fixed at one phase ratio, and phase ratio at intersection B, is varied, the input data of both intersections are the same except input IX of A and B should be different. The optimal queue-length can be obtained by this section, but for each phase ratio, the most effective value for NVEHC is to be found first, this is given to the 2nd case.

Case 2 For it is very difficult to adjust the most effective value of NVEHC which make the generated distribution form of the random discrete distribution close to the orginal distribution. This can be studied by giving the various values of NVEHC for each phase ratio then the result should give one unique value that has the same distribution form as the input and the number of input arrivals generated by subroutine DISCR is close to the number of total vehicles input at the detector.

Case 3 For an intersection, if the other data parameters are fixed, except phase ratio is varied, the variations of queue length for each lane of Southbound, Northbound and Eastbound, and the variations of volume of vehicles for the bounds can be atudied. The volume passing into Westbound and the frequency distribution variations can be also studied.

Case 4 The total input - output of vehicles for an intersection and the link between intersections are considered.

Case 5 The study of clock time which the maximum queue-length occur with the variation of NVEHC.

Case 6 The study of the queues for difference number of phases.

Case 7 The study of a variation of queue length for the various value of timing cycles.

Case 8 For the case of input IX of RANDU subroutine, by theoretically the output result should have same value, even if IX has the different value. To see whether it will happen like this or not, the different value of IX are used for checking.

Case 9 The various probability ratios for vehicles to distribute vehicles into the specific lane are studied, due to the fact, it should have an effect to the queue-length certainly.

All of the cases will be resulted and discussed in the next chapter, and they are sufficient to accomplish the study of research.