TRAFFIC SYSTEM SIMULATION

NIPON SRIYEN

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Thesis
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TRAFFIC SYSTEM SIMULATION

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The traffic problem in Bangkok effects a massive population. The aim of this thesis was to develop a computer program simulating traffic conditions in Bangkok, using statistics of traffic conditions between 1996 - 1998. The program was developed by software development methodology. First, the details of roads and junctions in central Bangkok were transformed into a network node-link system. Then the vehicles in the node-link system were defined and separated into two groups. Personnel vehicles can move randomly in the node-link system and mass transit vehicles use fixed node-link paths in the system.

Generation methods were described in terms of the mathematical methodology of probability and distribution including random methods.

At the end of study, the node-link system and queue were represented by a graphic program. This program contains variable parameters of the mathematical model. These parameters can be altered interactively.

The deliverable item from this thesis is a traffic simulation program that can be used to study and improve traffic conditions in Bangkok, by using a what-if analysis that changes parameters in the simulation program. The basic idea is that traffic conditions and problems in Bangkok are different from other cities. It is recommended a Thai researcher use Software Development Methodology to study and improve the local traffic problem in Bangkok.

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เนื่องจากปัญหาการจราจรในกรุงเทพมหานคร เป็นปัญหาสำคัญและมีผลต่อประชาชนโดยรวม จึงเป็นปัญหาที่มีความจำเป็นจะต้องดำเนินการศึกษาวิจัย เพื่อหาทางแก้ไขปัญหาดังกล่าว วัตถุประสงค์หลักในการทำวิทยานิพนธ์ฉบับนี้คือ การพัฒนาโปรแกรมระบบคอมพิวเตอร์ เพื่อจำลองระบบการจราจรในเขตกรุงเทพมหานคร โดยใช้ข้อมูลทางสถิติ ซึ่งเกี่ยวข้องกับเงื่อนไขการจัดการและควบคุมระบบการจราจร ของกรุงเทพมหานครในช่วงปี พ.ศ. 2539 ถึง 2541 โดยใช้วิธีการออกแบบระบบและพัฒนาโปรแกรม เป็นพื้นฐานในการศึกษา และพัฒนา, ในขั้นตอนแรก ทำการศึกษารายละเอียดถนนและแยกสัญญาณไฟจราจร ในบริเวณกรุงเทพมหานคร จากนั้นจึงนำมาแปลงเป็นแบบจำลองระบบเครือข่ายจราจร, ในการศึกษานี้ พาหนะในการเดินทางจะศึกษาจากกลุ่มหลัก 2 กลุ่ม คือ รถยนต์ส่วนบุคคล ซึ่งมีเส้นทางการเดินทางได้ทั่วทั้งระบบ และพาหนะ ที่ใช้ในระบบขนส่งมวลชน ซึ่งมีเส้นทางการเดินทางที่แน่นอน

การสร้างและกำหนดรูปแบบพาหนะที่เข้าสู่ระบบการจำลองระบบการจราจร จะอธิบายในรูปแบบวิธีการทางคณิตศาสตร์ เช่นการแจกแจง, ความน่าจะเป็น รวมทั้งวิธีการสร้างตัวเลขสุ่ม

ในขั้นตอนสุดท้ายของการศึกษา โปรแกรมการจำลองระบบการจราจรที่พัฒนาขึ้นจะสามารถแสดง ระบบเครือข่ายการจราจรและคิวของพาหนะ ที่เกิดขึ้นในบริเวณที่ศึกษาในโหมดกราฟฟิก โดยโปรแกรมดังกล่าว สามารถทำการปรับปรุง เปลี่ยนแปลง พารามิเตอร์ต่างๆ ซึ่งมีผลต่อการคำนวณโดยโมเดลทางคณิตศาสตร์

ผลลัพธ์ของการศึกษาและจัดทำวิทยานิพนธ์นี้คือ โปรแกรมการจำลองระบบการจราจร ซึ่งสามารถใช้ในการปรับปรุงเงื่อนไขและระบบจัดการการจราจรในกรุงเทพมหานครให้ดีขึ้น โดยหลักการวิเคราะห์ข้อมูลแบบ What-If ผู้ใช้โปรแกรมสามารถทดลองปรับปรุง เปลี่ยนแปลง พารามิเตอร์ต่างๆ ที่เกี่ยวข้อง เพื่อสังเกตการเปลี่ยนแปลงของความยาวของคิวที่เกิดขึ้น ในแต่ละแยกสัญญาณไฟและระบบเครือข่ายโดยรวม ทั้งนี้เนื่องจากระบบจราจรของกรุงเทพมหานคร มีเงื่อนไขต่างๆ ที่แตกต่างจากการจราจรในเมืองอื่นๆ ดังนั้น จึงเป็นการดีที่นักวิจัยไทยซึ่งใกล้ชิดและเข้าใจปัญหามากกว่า จะศึกษาวิจัย และพัฒนา โปรแกรมคอมพิวเตอร์ เพื่อช่วย ในการจัดการดังกล่าว

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CHAPTER I

INTRODUCTION

1.1 INTRODUCTION

Simulation is a technique used to simulate operations of various kinds of real world processes or facilities. The facilities or processes of interest are usually called a *system* to which we refer to a traffic system in this study. We often have to make a set of assumptions about how a system, which usually takes the form of mathematical relationships constituting a model that is used to try to gain some understanding of how the system behaves.

1.2 REASONS FOR THE PROBLEM

The traffic problem is a serious problem that occurs in many big cities of which are the centers of business and government offices, including Bangkok. Many previous researches done on the traffic problem of Bangkok indicated that the problem originated from an increasing number of vehicles and insufficient road space.

The increasing number of people migrating from other provinces and the high birth rate has made the living area in Bangkok insufficient. Then, the following problem concerns an increasing demand of vehicles and mass transit system. At the present time, Bangkok has insufficient road space to accommodate the increasing number of vehicles, that leads to the traffic problem.

As the demand for day-to-day transit has been increasing due to an increasing number of people, the government has still been unable to solve the problem by increasing either the capacity of mass transit or the capacity of road space.

Another considerable factor is the traffic light control in the Bangkok area that is only partially automatically control by the Traffic Center of the Police department (ATC system) and the rest in controlled manually.

Even though the manual system at the junction could solve the problem at one level during rush hours, an efficient performance appeared only on the main roads, not on the minor transit paths.

. The traffic system is a network system and the problem must be solved through the whole network system and not partially. The solution must be holistic and the data generated must be for the entire network.

1.3 OBJECTIVES

1.3.1 To develop a traffic system simulation software for a research purpose that is easier to interface whenever some conditions are changed.

1.3.2 To simulate the traffic conditions in Bangkok that are descried in terms of a model and queue system instead of a real-world system.

1.3.3 To transform the knowledge from the terms of a mathematical model and queue process into a graphic display.

1.3.4 To evaluate the efficiency of the developed program by comparison with a real-world system and investigate the feasibility of improvement of the system.

1.4 STATEMENT OF PROBLEM

A traffic system is a system with roads and junctions linked together as a network. Most of the time, traffic problems occur at the main junctions. The problem occurs whenever the queues of vehicles accumulated at the red light are longer then the length of the roads. These vehicles move to another place but a new queue will immediately accumulate. This situation depends on the optimal paths these queues go through that contain nodes to be visited.

1.5 SCOPE AND LIMITATION

1.5.1 To study the behavior of the traffic conditions at several types of junction

1.5.2 Setting up some assumptions concerning the conditions and the reasons for problems that simplify the model.

1.5.3 To design and build a traffic simulation model for a queuing process

1.5.4 To represent the real-world system (scope is in the Central Bangkok area) in terms of a computerized node-link model.

1.5.5 To describe the conditions of probability, statistics and randomization methods to be used in the simulation program.

1.5.6 To design and develop steps of the simulation software in steps according to the software development methodology.

1.5.7 To produce a simulation program as a deliverable item which is a graphical display traffic simulation model that allow changes in some parameters that affect the mathematical model for cyclic simulation to change.

1.5.8 To evaluate the simulation program comparing to a real-world system and discuss the feasibility of further improvement.

1.6 UTILITIES OF THESIS

1.6.1 This study is a case study of the simulation software development methodology that is applied to a study of the real-world problems and transform those problems into a computerized information system.

1.6.2 Simulation is a method that helps to enhance the what-if analysis circularly by maintaining or changing the conditions of strategy through changing parameters of mathematical models.

1.6.3 The result of this thesis will help to improve traffic problems. For example, in the case of an automatic traffic light control.

CHAPTER II

REVIEW OF LITERATURE

2.1 INTRODUCTION

The traffic simulation model was developed with several kinds of mechanism depending on the objectives and methodologies. Results of some simulation models have been used to study the behavior of traffic in specific countries. Usually, the studies are involved with the conditions of the approach and the arrival of vehicles. This made some of these models difficult to implement in other countries that have different conditions or have more varied conditions.

Examples of programs that have been developed and accepted in foreign countries are SATURN, TRAF-NETSIM, TRAFFICQ and AIMSUN.

2.2 TRAFFIC SIMULATION PROGRAM

Most of the basic ideas of simulation programs can be separated into two basic ideas. One is the *Macroscopic* model and the other is the *Microscopic* model.

The *Macroscopic model* is the model that considers the whole network. We form several strategies in terms of the mathematical model by choosing conditions that affect the whole network. For example we can use weighting of important zones or areas that vehicles tend to target as conditions for the generation of paths.

The *Microscopic model* considers the behavior of each vehicle. For example we can design rules for which a vehicle can move.

2.2.1 SATURN

SATURN (Simulation and Assignment of Traffic in Urban Road) was initially developed by ITS (Institute of Transport Studies), Leeds University, England. (16)

This program has been developed continuously up to version 8.0. The language used is FORTRAN 77 on a microcomputer. The capability of SATURN includes Traffic Simulation and Traffic Assignment. By iteration, it gives results of traffic assignment, that is the traffic volume in each road, volume of turning vehicles at the junction and length of queue of vehicles waiting to enter to the junction. These results are basic data for each traffic simulation. After simulation is completed, it produces a result of delay in each junction and a flow-delay curve for traffic assignment in the next cycle. This workflow continues until Trip Metrics is assigned to all routes in the traffic assignment.

For the part of simulation, each vehicle model is replaced by a *flow profile*, which is a relationship created from the volume of vehicles passing a detector on a road in a period of time. A flow profile is simulated each cycle of time, it is a *Cyclic Flow Profile*. In each cycle, a traffic sign is changed in a short period of time. Then, the program creates a flow profile that enters into a link and calculates a flow profile at a junction by adapting a *Platoon Dispersion Technique*.

A length of queue at a junction is calculated by multiplying the volume of vehicles from a cyclic flow profile with average of vehicle length. The length of queue does not reflect a real behavior of length. It is more or less, like vehicles stopping at the same waiting line as a *vertical queue*. So, this type of queue does not absorb an effect of length of queue on the length, vehicles can move freely on a road that is reduced by the length of queue.

Vehicles can be divided into two types, private vehicles and buses, by simulating together bus routes with private vehicle routes.

Capability of this program includes simulating a road network that has junctions, traffic signals, priority junctions, traffic circles and produces results in graphics.

2.2.2 TRAFF-NETSIM

TRAFF-NETSIM was developed for the Federal Highway Administration in USA. This program is tested and became acceptable by the unit. (16)

Traffic simulation use is in the type of *Microscopic* that simulates traffic in a period of time. The period of *Scanning Time Interval* is 1 second. This program is a simulation that produces only traffic simulation but not traffic assignment as like the SATURN program.

It simulates not only normal road network but also in-out parking areas or a lot of in-out vehicles in each area.

Traffic Control at a junction can be simulated by using *fixed-time* or *actuated* traffic signal control.

Capability of traffic simulation includes simulation of 16 different types of vehicles and behavior of pedestrians.

TRAFF-NETSIM uses FORTRAN 77 in its development. It can be worked on microcomputers and produces results in graphics.

2.2.3 TRAFFICQ

TRAFFICQ is classified as a program that simulates traffic of the *microscopic* type. It was initially developed by the London Borough of Wandsworth using CSL (Control and Simulation Language). Later, the MVA Systematica company changed to FORTRAN 77 under the control of the U.K. Department of Transport (DTP). (16)

At present, TRAFFICQ can be used on microcomputers and produces graphic diagram results. The objective of TRAFFICQ development is to analyze a *traffic management plan.*

The simulation of this program includes a consideration of queue behavior, platoon dispersion, delay of pedestrian waiting and change of road width. All these behaviors are very important factors when it reaches *over-saturated traffic condition.*

Length of queue is classified as the same type as *vertical queue* in the SATURN program. Difference is in traffic signal controls that are controlled by *fixed time* and *actuated.* It also simulates a junction that is not controlled by traffic signals, traffic circles or pedestrian's crossings.

The *Result* of the TRAFFICQ program includes length of time that vehicles take on each road section, total time take in network, length of queue at each road and delay of pedestrians at each crossing.

2.2.4 AIMSUN

AIMSUN (Advanced Interactive Microscopic Simulator for Urban Network) (16) is classified as a type of *microscopic* traffic simulation that was developed by the Department of Operation Research, Faculty of Information, Polytechnic University of Cataluya), Bacelona, Spain. The language used is FORTRAN 77. This program can be used only with mainframe computers (e.g. VAX). It produces results for graphic diagrams on screen. The outstanding point of this program is that it can demonstrate vehicles moving on the screen.

This *simulation model* was designed to fit with a *road network simulation.* It consists of junctions that are controlled or not controlled with traffic signals in a testing program of traffic control.

The most important *advantage* of this program is that user *can change parameter values* while the program is running without a data file being used with a case study. Changing parameters has two parts. The first part is the volume of traffic and the ratio of turning vehicles at a junction. The second part are parameters that involve traffic signal control (time cycle, green light ratio and offset value)

Vehicles in this simulation program can be divided into two types. The first type is private vehicles and the second type is buses. The car arrival model of vehicles is *Car Following Model* and *Lane Changing Model.*

Simulating network consists of *Node* and *Link.* Each link stands for two lanes with the maximum number of lanes on one road being eight lanes and equal number of lanes are used for each direction. Lanes are divided into normal lanes and bus lanes with no bus stop signs.

On each link, this program simulates a traffic island for pedestrians to cross over the road that divides a link into many sub-links. Changing lane occurs at connections between sub-links.

There are two types of traffic signal, traffic signals at junctions and traffic signals at cross overs.

2.2.5 TRAFFIC SIMULATION VERSION 1.0

This program use initially developed by the Department of Traffic and Transportation Research, Civil Engineer, Faculty of Engineering, Chulalongkorn University. Later in 1986, Mr. Thongchai Jintanavong of Chulalongkorn University improved the program as his Master degree's dissertation by using FORTRAN 4 (17). The objective of his dissertation is to study traffic behavior around junctions. His study was classified as a type of *microscopic* model.

The *Scanning time interval* is used to simulate movement of vehicles by calculating the position of each vehicle in each time cycle. Movement of vehicles are considered with details of turning behavior at junctions including right turns with green light signals or *gap acceptance* in case that a vehicle has changed speed.

A *Model of car arrival* at a junction, *Time Headway* is *Shifted Exponential* distribution or *Unshifted Exponential* distribution or *Composite Headway.*

A *Fixed-time* signal control is used and users indicate period of green and yellow signal and time cycle.

A *Geometric model* of each road is used for *turning behavior* of vehicles by calculating turning radius from road length, starting point, and turning behavior. Moreover, the program stimulates changing lane behavior of vehicles.

The *results* of this program include delay value, queue length, volume of car arrival and departure at junction.

2.2.6 CU-TRAFFIC SIMULATION

CU-TRAFFIC SIMULATION (16) is continuously developed from DESC (Dynamic Evaluator of Signal Control). Initially, this program was a co-operation between the Department of Traffic and Transportation Research, Civil Engineer, Faculty of Engineering, Chulalongkorn University, Thailand and the Department of Traffic and Transportation Research, Civil Engineer, Faculty of Engineering, Tokyo University, Japan. This program was tested in both Japan and Thailand. The primary objective is to evaluate the performance of traffic control. Later on, DESC was improved by the Department of Traffic and Transportation Research to be used to calculate length of queue and several parts of reports with results. Then, it was named CU-TRAFFIC SIMULATION.

This program is classified as of type macroscopic and only the case of turn-right vehicles is classified as of microscopic type. In each simulation time, the program will increase time by 1 second, and the macroscopic simulation helps to shorten the time in simulating traffic behavior of networks while microscopic simulation takes longer. A road network is simulated in a form of links and junctions as nodes.

Simulation equally divides roads into blocks. When a vehicle enters into a link at the block next second, the program will consider the volume of vehicles entering into the next block under 2 considerations. The first consideration is *maximum flow* will be indicated by the user where flow depends on the qualification of the link. The second consideration is the *free space* that vehicles can be filled in the next block. By this method, the program can simulate a behavior of a *Horizontal queue* which is close to the real situation.

Simulation on *traffic signal control* can be for both *fixed-time* and *semi-actuated* signals. Most important, it can simulate a situation where a traffic detector is set up and produces a parameter as a result of the program.

The *result* of the program is the *delay* of each approach at a junction, total delay at a junction, volume of arrival and departure vehicles at each link, the parameter value of each traffic detector (traffic volume checked and average value of time occupancy) and the length of queue at each link.

2.3 AREA TRAFFIC CONTROL SYSTEM

The *Area Traffic Control System* (ATC system) is the system that is used to control the traffic flow in major countries (23). They are developed by various strategies and implemented in different computer-based (size) and technology.

2.3.1 UNITED KINGDOM

2.3.1.1 General

At the present time in the U.K. there are 24 signal systems which are able to coordinate nearly 5,000 signal controllers altogether on fixed time plans. The largest such system is in London, where computers in New Scotland Yard are connected over telephone lines to about 1,200 signal controllers.

Many of the fixed time signal systems use timing plans which are based on TRANSYT, an off-line optimization tools which will be described in TRANSYT. Quite often the plans have been modified manually to make partial updates that accommodate changes in the local traffic situation. Whilst overall the fixed time signal systems have proved to be highly cost effective, experience has shown that it is difficult to devote resources to producing completely new signal plans as often as is desirable to maintain high efficiency. It is reported that the need for, but burden of updating fixed time plans is a key reason why in recent years in the U.K. most orders for new signal systems have specified traffic responsive control by

SCOOT. In some places, conventional fixed time signal systems are begin replaced by SCOOT. SCOOT is a highly automatically traffic dependent system.

2.3.1.2 SCOOT

SCOOT (Split Cycle and Offset Optimization Technique) is one of the most well-known on-line plan formation control methods in the world. It has been developed in the U.K. since 1973.

In SCOOT, although pre-time plan selection is basically performed, SCOOT has two features of traffic-responsive control as follows:

a) Green splits and offsets are modified cycle by cycle around the values of the selection plan on real time and traffic-responsive basis.

b) The signal plans which are loaded in the computer are automatically updated according to the results of real time modification.

The signal timing values for the plan in use are always readjusted by means of exponential smoothing of the existing and modified values. This automatic updating function assures that there are no needs not only for updating but also for preparing any initial plans. The system can start from any arbitrary traffic signal settings.

A detector is installed 5 to 15m from the upstream end of each lane of the approaches of all the intersections to detect vehicle passage as well as queue spill-back in the link (Figure 2.1). Using a *platoon flow profile* similar to what is used in TRANSYT, the arrival flow at the downstream stop line is predicted and according delay, number of stops, and queue length are estimated. To determine the optimum green split and cycle length, *degree of saturation* is used. Green splits are modified to balance the degree of saturation at each approach by small increments. Sub-areas are fixed in the SCOOT system, and the common cycle length is updated every 2.5 minutes between the upper and lower limits so that the maximum value of degree of saturation at each approach in the most heavily loaded intersection would be 90%. Together with the changing of cycle time, offset decisions are made in such a way that the weighted sums of delay and number of stops at each link are minimized.

The relative effectiveness of SCOOT varies by area and time of day but it is reported that SCOOT achieves an average saving of delay about 12 in the five areas in U.K. where it was compared with good fixed time plans.

There are some aspects to be considered in application of SCOOT as follows:

a) It is rather expensive to install and maintain a large numbers of detectors.

b) SCOOT can be applied to under-saturated conditions, and is not suitable for highly saturated conditions.

c) SCOOT may not be cost-effective for those cities where labor costs are not very high because the greatest merit of SCOOT is in automatic updating of timing plans.

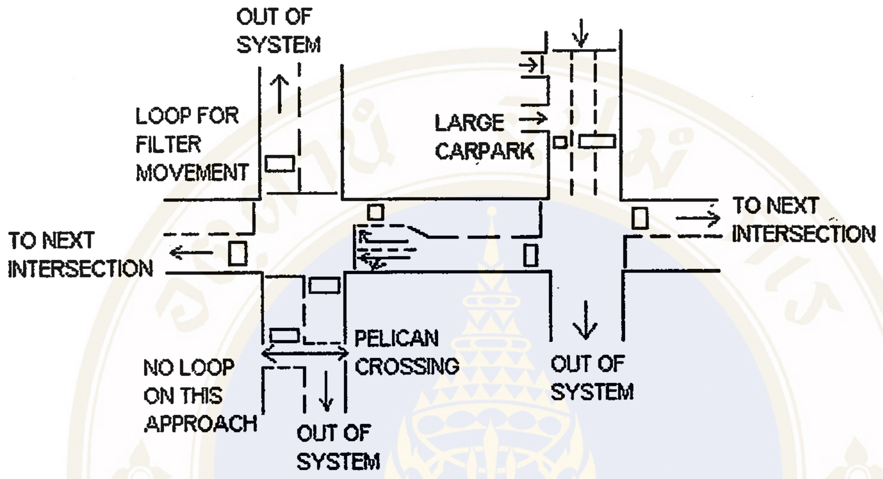


Figure 2.1 Typical Layout of Loop Detectors for SCOOT (23)

2.3.2 FRANCE

More than 50 French cities, representing almost all of the cities of more than 80,000 inhabitants are now equipped with centralized traffic signal systems.

A typical example of control strategies in France is as follows. The intersections in the control area are divided into a number of sectors based on the analysis of the coherence of the traffic in a given sector as compared to the others. A sector may comprise from 10 to 50 intersections. The strategies at the area level are based on the automatic selection of pre-computed traffic plans. The selection process works in two steps.

Firstly, the selection at the sector level is made in the following ways, unless any predictable variations of traffic flow occur in some sector, for example the end of work of a big factory or a big sporting event. Automatic analysis of the traffic every 3 minutes with either of two different processes are made depending on the level of congestion in the selected links:

a) if the level of congestion in these links is under a given threshold, the most suitable pattern of parameters is selected. The measurements use a linear combination of occupancy and volume and they are smoothed over 12 minutes periods.

b) If the level of congestion in the selected links of the sector exceeds the threshold, then the selection process uses only a subset of the measurement points in order to give a marked priority to the relief of the congestion in the selected links.

After the isolated selection of a traffic plan by each sector, eventually some adjustments between sectors and made by traffic engineers in order to modify this choice to take into consideration a special problem in a sector or group of sectors. For example, if a given sector has chosen a traffic plan for congestion and if the surrounding sectors are non-congested, it may be wise to modify the choice of the surrounding sectors in order to restrict the incoming flow and to allow a fast exit from the congested sector.

The switching process from a given traffic plan to another takes generally one to two cycles, exceptionally three.

Next to the plan selection for each sector, some automatic local modification may be made by the central computer on a cycle by cycle basis for individual intersections. The use of standard vehicle actuated control is usually limited to some pericds of the nighttime with very little traffic flows. Anti-congestion actions are performed to protect the pre-selected low capacity links from over-saturation by storing the excess of vehicles in the neighboring links with higher storage capacity. Special congestion detectors are installed at the end of the low capacity links and the green times of the high capacity links feeding the low capacity ones are modified at each cycle according to the level of congestion on these detectors.

2.3.3 AUSTRALIA

2.3.3.1 General

There are about 5,500 traffic signals in Australia, most of which are installed in capital cities each with a population of 1 million or more. Control methods of the ATC systems in Australia can be classified into four types as follows:

a) fixed-time control which is still used in some parts of the Melbourne CBD

b) traffic-adaptive selection of preset signal plans according to the information from strategically located detectors which is used in some arterial roads in Brisbane

c) linked vehicle-actuated (VA) control in which VA intersection controllers are used in a fixed-time area control system, e.g. in parts of the Melbourne, Adelaide and Brisbane CBD's

d) traffic responsive control using the Sydney Coordinated Adaptive Traffic System (SCAT)

2.3.3.2 SCAT

SCAT (Sydney Coordinated Adaptive Traffic System) is another resent research product of on-line plan formation control and developed by the Department of Main Roads, new South Wales (DMR-NSW) in the last decade in Australia. Over 3,000 signalized intersections in the world are now in operation under the control of SCAT as seen in table 2.1

Table 2.1 Implementation of SCAT as of September 1987 (23)

City	Number of signals connected to SCAT	Number of regional computers
Sydney & other NSW cities	1,350	17
Melbourne	984	14
Adelaide	300	6
Perth	124	2
Canberra	60	1
Hobart	60	2
Darwin	12	1
New Zealand cities	270	8
Shanghai	30	1
Tianjin	20	1
Singapore	24	1
Total	3,234	54

At all intersections under SCAT control loop detectors are required on all of the approach lanes at the location of 1.5m upstream from the stop lines except on the exclusive left turn lanes. In a SCAT system, the whole area is divided into smaller sub-areas of about one to 10 signalized intersections that share a common cycle time. The common cycle time is updated every cycle in steps of up to 6 sec according to the degree of saturation of that sub-area. Green times are so controlled cycle by cycle that the degrees of saturation of the phases of an intersection come closer. Various VA control tactics are also available. Each sub-area has five is selected in a traffic-responsive manner.

It is reported that SCAT was found to be particularly successful in reducing stops compared with a fine-tuned fixed time control which was optimized using TRANSYT.

The detectors installed closed to the stop line as shown in Figure 2.2 contribute to observe the degree of saturation precisely in response to the variation of traffic flow. This detector layout, however, makes it impossible to measure the flow profile, therefore the offset plans cannot be formed in SCAT but should be produced by an off-line tool such as CLOFFSET.

It should be noted that SCAT is applicable to under-saturated traffic conditions. The detector locations of SCAT which is immediately upstream of stop lines are suitable for measuring the degree of saturation only in the range of low degree of saturation.

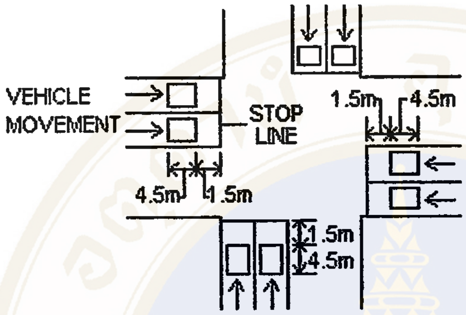


Figure 2.2 Typical Layout of Loop detectors of SCAT (23)

2.3.4 USA

From 1968 to 1975 in the USA, the Urban Traffic Control System (UTCS) project was established by the Office of Research of the Federal Highway Administration (FHWA). The objective of this project was to develop and test new computer-based control strategies under real world conditions. The control strategy research associated with the UTCS project has been divided into three generations:

a) First generation control – pre-stored timing plans developed by off-line an optimization technique

b) Second generation control – computers timing plans on-line based on current traffic data

c) Third generation control – computes timing plans on a cycle-by-cycle basis

The Institute of Transportation Engineers prepared a report in January 1987 based on a survey of traffic signal systems in the United States and Canada. A total of 245 traffic signal systems were identified with 143 in operation, 58 list of systems in shown in Table 2-2 which includes only those systems in the United States that have over 100 signalized intersections and 150 detectors.

About one-half of these systems use a UTCS-based software and the others use different software which have been developed by leading manufactures and system consultants, many of which utilize knowledge gained from the earlier UTCS experiments.

Most of the systems in operation today use conventional plan selection control (first generation control). The timing plans are established by using off-line optimization tools like TRANSYT. A few on-line control strategies based on current traffic data (the one and half – to the second generation control) are begin applied experimentally in some of the systems.

Table 2.2 Selected Traffic Signal System in U.S.

State	City	Type of Software	No. of signals	No of detectors
AL	Birmingham	Computran	278	185
AR	Little Rock	Honeywell	146	400
CA	Los Angeles	UTCS Enhanced	118	396
CT	Hartford	UTCS Enhanced	128	255
FL	Dade County	UTCS FORTRAN	1,500	1,400
ID	Ada County	Honeywell	149	300
IN	Evansville	Computran	207	350
KY	Lexington	Computran	240	228
LA	New Orleans	UTCS FORTRAN	206	264
MN	Minneapolis	CSE	705	450
NC	Durham	Sperry SRT	164	180
NC	Winston-Salem	UTCS 2nd Generation	211	548
NE	Lincoln	UTCS FORTRAN	205	400
NV	Las Vegas	UTCS Extended	345	1,080
NY	Nassau County	Sperry SRT	313	190
NY	Nassau County	Other CSI – FORTRAN IV	120	190
NY	New York City	Other NYC VTCS	3,000	2,700
NY	Rochester	UTCS FORTRAN	312	405
TN	Knoxville	Other MTCS	165	277
TX	Dallas	UTCS FORTRAN	206	353
VA	Arlington City	Sperry SRT	194	233

2.3.5 JAPAN

2.3.5.1 General

Table 2.3 shows the numbers of traffic signal controller intersections of various types in Japan as of March 1987. The total number of traffic signals is approximately 122,000 out of which 34,500 are in the area control systems in 74 cities. The control principle of the area control is basically conventional traffic-adaptive plan selection type. Green times of the critical intersections, however, are usually controlled in the manner of traffic-responsive plan-formation method.

A whole area of a system is divided into a number of sub-areas in such a way that the traffic condition varies in a similar manner within a sub-area. The signal timings that are cycle length, green splits and offsets are determined for each of the sub-areas individually in principle.

Ultrasonic vehicle detectors are usually used mainly because of maintenance reasons. The vehicle detectors are installed at 150 to 200 meters upstream of the stop lines of all the approaches of major intersections.

Since traffic-adaptive plan selection control is a widely used control method in the world today, the way in which the plans are selected in the Tokyo system is described in detail in 2.3.5.2 as a typical example of this type of control.

Table 2.3 Traffic Signals in Japan (as of March 1987)

Type	Number of Traffic Signalized Control Intersection
Area Control (74 cities)	34,510
Coordinated (3,886 groups)	19,499
Traffic-responsive	5,247
Pretimed multi-program	12,584
Pretimed single-program	460
Coordinated push button	1,208
Isolated	67,795
Full traffic-actuated	1,039
Semi traffic-actuated	6,439
Bus/rail-responsive	390
Pretimed multi-program	39,223
Pretimed single-program	588
Push button	19,471
Others	645
Total	121,804

2.3.5.2 Tokyo System

***M* Value,** the measure of traffic conditions (23)

A weighted sum of volume (*V*) and occupancy (*O*),

$$M_{ijk} = a * V_{ijk} + b * O_{ijk}$$

is used as the measure of the traffic condition of the i^th approach of the j^th phase at the k^th intersection. The weighting factors a and b are so determined that *a**V* is roughly equal to *b**O* when traffic is near-saturated. The value of *M* is considered to be a good measure of degree of saturation of the approach in under – to near-saturation conditions.

Cycle length

Cycle length of a sub-area is determined in such a way as follows:

The *M* value of the j^th phase of the k^th major intersection is defined as

$$M_{jk} = Max_i(M_{ijk})$$

where .i is the approach number.

The *M* value of the k^th^ intersection is defined as

$$M_k = \sum_h M_{jk}$$

The cycle length for the k^{th} major intersection C_k is determined depending on the M_k value in such a way that C_k is longer when the M_k value is larger as shown in Figure 2.3 and 2.4. The cycle time of the sub-area C is determined as the largest of C_k's for all k in the sub-area.

When the difference in the cycle times that are selected in the above mentioned manner between the two adjacent sub-areas is smaller than a preset value, the longer cycle time is used as the common cycle time for both of the two sub-areas. This procedure of cycle time determination is carried out every 5 to 15 minutes.

Green split

Green splits of major intersections are determined based on the *M* values of the phases as shown in figure 2.4. At critical intersections program formation type of control is used in near-saturation conditions. The average detector pulse length is upstream from the stop lines. This value which is called *P* value has been found to be a good indicator of the degree of saturation of the stop line and is used to control green splits so that all the phases are saturated to nearly the same extent. Green times of all the phases are reallocated every cycle depending on the *P* values of last cycle in such a way that the green time of a phase is increased/decreased when the *P* value of the phase is above/below the average of all the phases.

This method has advantages over the conventional vehicle-actuated control in two aspects. Firstly there is no difficulty in maintaining the given cycle time. Secondly there is no need to shut down the pedestrian flows earlier than the vehicular flows. In the conventional vehicle-actuated control pedestrian flows should be terminated before the vehicular extension period. This tends to cause too long cycle times and pedestrian complaints as well. In the method mentioned above, however, there is no need of early cut of pedestrian flows because the green times are decided before the cycle starts so that sudden end of green is necessary.

In case of over-saturated conditions at critical intersections queue length-responsive control of split is used. Vehicle detectors are installed at locations of 300, 500 and 1,000 meters upstream of the stop line to measure the queue length and the green times are so controlled that the length of the queue of the conflicting phases become closer to each other.

Offsets

Offset program selection is carried out every 5 minutes but there is a limit of minimum time of use of an offset program so that any one of the offset programs should stay in use at least for 15 minutes once it becomes in use. In case a new program is selected before expiration of the minimum time of the current keeps staying in use. This is for the purpose of avoiding too frequent disturbances caused by offset transition from one program to another which takes up to four cycles.

When a queue spills back from the downstream intersection to the exit area of the upstream intersection, the green time for this direction at the upstream intersection cannot be fully utilized because of the reduced saturation flow rate.

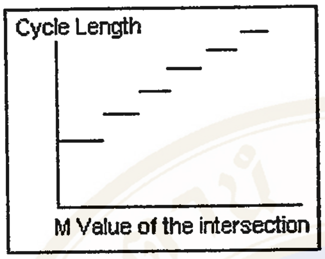


Figure 2.3 Cycle Length Selection (23)

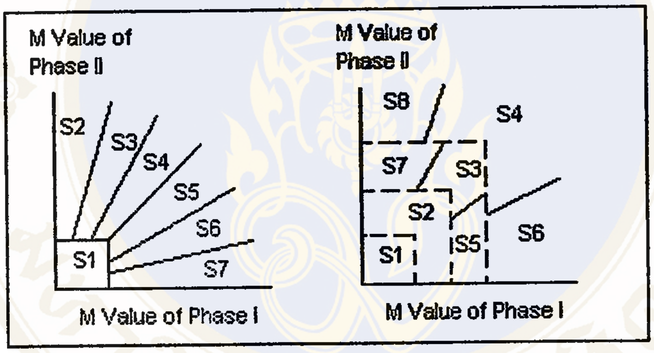


Figure 2.4 Green Split Program Selection (23)

2.4 OFF-LINE OPTIMIZATION TOOLS

For plan selection type of signal control, off-line preparation of signal timing plans is essential. Though traffic engineers can determine them manually, since it requires much skill and time to produce signal plan manually, computer-based methods of calculating these plans are now widely used.

2.4.1 TRANSYT

Several optimization programs for an area-wide control have been developed in the world. Most commonly used software is the TRANSYT (TRAffic Network Study Tool) method in U.K. (Robertson et al, 1968).

TRANSYT uses a static network simulation model in which traffic flow in a study network is expressed by the *cyclic flow profile* assuming that the traffic arrival and departure are identical in every cycle. The geometry of the networks and traffic volumes should be given in advance as the input data. TRANSYT optimizes mainly offsets so that a weighted sum of delay and number of stops in the area is minimized in a similar manner to a trial and error method. Several values of cycle times and green splits are tested if so commanded and the optimal ones are searched. It can be run on standard microcomputer.

It is reported that use of TRANSYT method for fixed time coordination is likely to yield savings in delay by 20 to 40% depending on the network configuration in the under-saturated conditions compared with isolated vehicle-actuated operation.

2.4.2 Others

There are several other optimization tools.

In French cities, in addition to TRANSYT a French program THEBES which is similar to TRANSYT is used to optimize coordination. UTCS which is widely used in U.S. is said to utilize the method similar to TRANSYT. In the F.R. of Germany, a new optimization procedure for network traffic signal control is begin developed. This procedure which has been named SIGMA (SIGnal MAnagement) is to make use of experiences gained with various models known internationally, e.g. SIGOP, combination method, TRANSYT and MITROP.

2.4.3 Problems

a) In order for traffic engineers to use these tools, an enormous amount of input data such as phase arrangements, green splits for the phases, volumes of all directions, and link length are required. Cost and labor for preparing those input data, especially for carrying out field traffic survey are often more than what the traffic engineers can afford. This is the major reason why the signal plans are generally not updated as frequently as desired and get obsolete world wide

b) These off-line optimization tools are mainly or only concerned with under-saturated conditions. In heavy traffic conditions like in most of Japanese cities, the signal plans produced by these tools are not suitable.

2.5 CONTROL STRATEGIES OF TRAFFIC SYSTEM

Table 2.4 Summary of control strategies of the traffic control system

System		**Cycle**		**Split**			**Offset**		**Location of Detectors**
		PS	**PF**	**PS**	**PF**	**VA**	**PS**	**PF**	
Existing Bangkok's	*	FT		FT			FT		No detectors
UTCS	*	TR		TR			TR		
Japan	*	TR		TR	FB		TR		150 to 200 m upstream from stop line
SCAT	*	FB		FB			TR		Close to stop line
SCOOT	*	FB		FB				FB	Upstream end of the links

Legends PS: Plan Selection
PF: Plan Formation
VA: Vehicle Actuated
FT: Fixed Time
TR: Traffic Responsive
FB: Feed-Back
* : Adaptation of under-saturation traffic flow

The simplest form of plan formation is vehicle-actuated (VA) control of green times which is not linking control but localized split control. Vehicle arrivals at an approach are detected by a vehicle detector and the green time to the approach is extended when the vehicles arrive continuously with the headway shorter than a certain preset value which is usually 2 to 3 seconds.

2.6 METHODS FOR COPING WITH TRAFFIC CONDITION VARIATION

Signal timings should be changed according to change of traffic conditions. Even for the same amount of traffic demand, longer green time should be given if the road capacity is reduced. There are several ways to change signal timings to cope with road and traffic conditions. These are grouped into the three major types of control methods as shown in Table 2-5.

Table 2.5 Matrix of ATC methods

	Pretimed Control	**Traffic-responsive Control**
Plan Selection	Pretimed Multi-plan Selection	Traffic-adaptive Multi-plan Selection
Plan Formation	Non Existing	Traffic-responsive Plan Formation

Note:

1) Plan selection means that one of several preset plans prepared off-line in accordance with patterns of traffic condition is selected according to the preset time or fixed interval.

2) Plan formation means that signal timing control is prepared on the basis of cycle-to-cycle fluctuations in traffic demand as indicated by detectors.

3) Pretimed plan selection control, the simplest method of signal timing control is pretimed plan selection control in which one out of several preset signal timing plans is selected to switched into operation according to the preset time schedule usually depending on time of day and day of week.

4) Traffic-adaptive plan selection control, the second simplest form of signal timing control is traffic adaptive plan selection control in which one out of several preset plans is selected to be put into use depending upon the prevailing traffic condition as being measured by the vehicle detector. The selection of plans is carried out usually once every 15 minutes, that means that a traffic condition in the last 15 minutes determines the signal plan for the coming 15 minutes.

CHAPTER III

QUEUING THEORY

3.1 INTRODUCTION

The study of waiting lines, called queuing theory, is one of the widely used quantitative analysis techniques. Waiting lines are an everyday occurrence. Queues, another term for waiting lines, may also take the form of machines waiting to be repaired, trucks in line to be unloaded, or airplanes lined up on a runway waiting for permission to take off. The three basic components of a queuing process are arrivals, service facilities, and the actual waiting line.

3.2 CHARACTERISTICS OF A QUEUING SYSTEM

There are three parts of a queuing system:

1. The arrivals or input to the system (referred to as the *calling population*)
2. The queue or the waiting line
3. The service facility

3.2.1 Arrival characteristics

The input source that generates arrivals for the service system has three major characteristics. It is important to consider the size of the calling population, the pattern of arrivals at the queuing system, and the behavior of the arrivals.

Size of the Calling Population. Population sizes are considered to be either unlimited (essentially *infinite*) or limited (*finite*). When the number of arrivals on hand at any given moment is just a small portion of potential arrivals, the calling population is considered unlimited. For practical purposes, we use examples of unlimited populations. Most queuing models assume such an infinite calling population. When this is not the case, modeling becomes much more complex.

Pattern of Arrival at the System. The arrivals at a service facility according to some known schedule (for example, one patient every 15 minutes or one student for advising every half-hour) or else they arrive randomly. Arrivals are considered random when they are independent of one another and their occurrence cannot be predicted exactly Frequently in queuing problems, the number of arrivals per unit of time can be estimated by a probability distribution known as the Poisson distribution. For any given arrival rate, such as two customers per hour. or four trucks per minute, a discrete Poisson distribution can be established by using the following formula. (6)

$$P(X) = \frac{e^{-\lambda}\lambda^{X}}{X!} \quad \text{for } X = 0,1,2,3,4,\ldots$$

where P(X) = probability of X arrivals,

X = number of arrivals per unit of time,

λ = average arrival rate, and

e = 2.7183.

Behavior of the Arrivals. Most queuing models assume that an arriving customer is a patient customer. Patient customers are people or machines that wait in the queue until they are served and do not switch between lines. Unfortunately, life and quantitative analysis are complicated by the fact that people have been known to *balk* or *renege*. Balking refers to customers who refuse to join the waiting line because it is too long to suit their needs or interests. Reneging customers are those who enter the queue, but then become impatient and leave without completing their transaction. Actually, both of these situations just serve to accentuate the need for queuing theory and waiting line analysis.

3.2.2 Waiting line characteristic

The waiting line itself is the second component of a queuing system. The length of a line can be either limited or unlimited. A queue is limited when it cannot, by law or physical restrictions, increase to an infinite length.

A second waiting line characteristic deals with queue discipline. This refers to the rule by which customers in the line are to receive service. Most systems use a queue discipline known as the first-in, first-out rule (FIFO). Patients who are critically injured will move ahead in treatment priority over other patients. Computer programming runs are another example of queuing system that operate under priority scheduling. In most large companies, when computer-produced paychecks are due out on a specific date, the payroll program has highest priority over other runs.

3.2.3 Service facility characteristic

The third part of any queuing system is the service facility. It is important to examine two basic properties: the configuration of the service system and the pattern of service times.

Basic queuing system configurations. Service systems are usually classified in terms of their number of channels, or number of servers, and number of phases, or number of service stops, that must be made. A *single-channel system*, with one server, is typified by the drive-in bank that has only one open teller, or by the type of drive-through fast-food restaurant. If, on the other hand, the bank had several tellers on duty, and each customer waited in one common line for the first available teller, then we would have a *multiple-channel system* at work.

A single-phase system is one in which the customer receives service from only one station and then exits the system. A fast-food restaurant in which the person who takes order also brings the food and takes money is a *single-phase system*. But if the restaurant requires to place your order at one station, pay at a second, and pick up the food at a third service stop, it becomes a *multiphase system*.

Service time distribution. Service patterns are like arrival patterns in that they may be either constant or random. If service time is constant, it takes the same amount of time to take care of each customer. This is the case in a machine-performed service operation such as an automatic car wash. More often, service times are randomly distributed. In many cases, it can be assumed that random service times are described by the *negative exponential probability distribution*. This is a mathematically convenient assumption if arrival rates are Poisson distributed.

The exponential distribution is important to the process of building mathematical queuing models since many of the model's theoretical underpinnings are based on the assumption of Poisson arrivals and exponential services. Before they are applied, however, the quantitative analyst can and should observe, collect, and plot service time data to determine if they fit the exponential distribution.

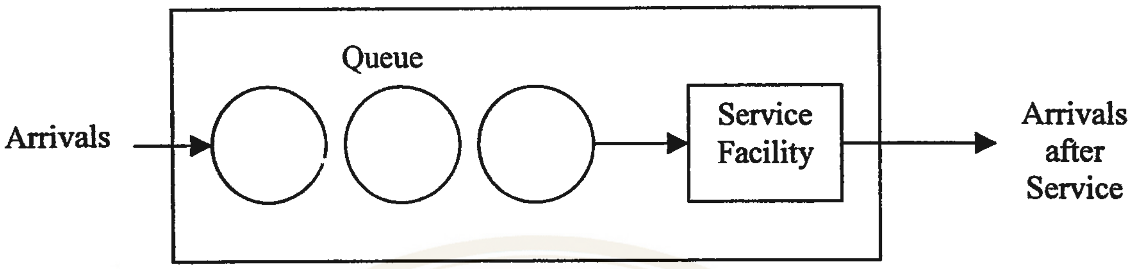


Figure 3.1 Single-Channel, Single-Phase Queue System

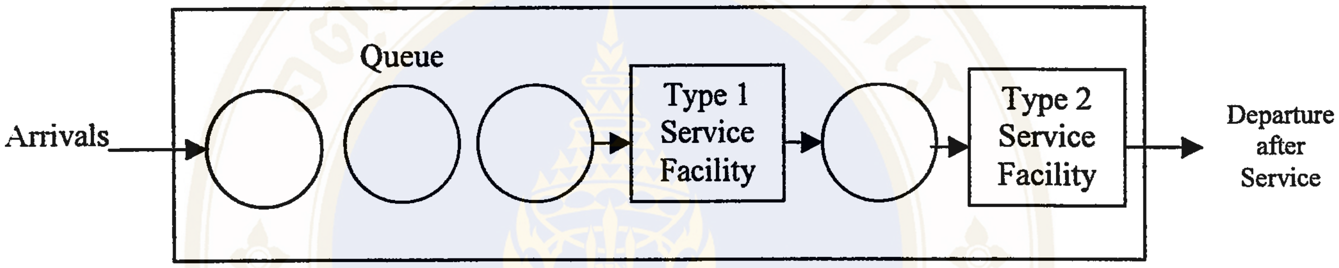


Figure 3.2 Single-Channel, Multiphase Queue System

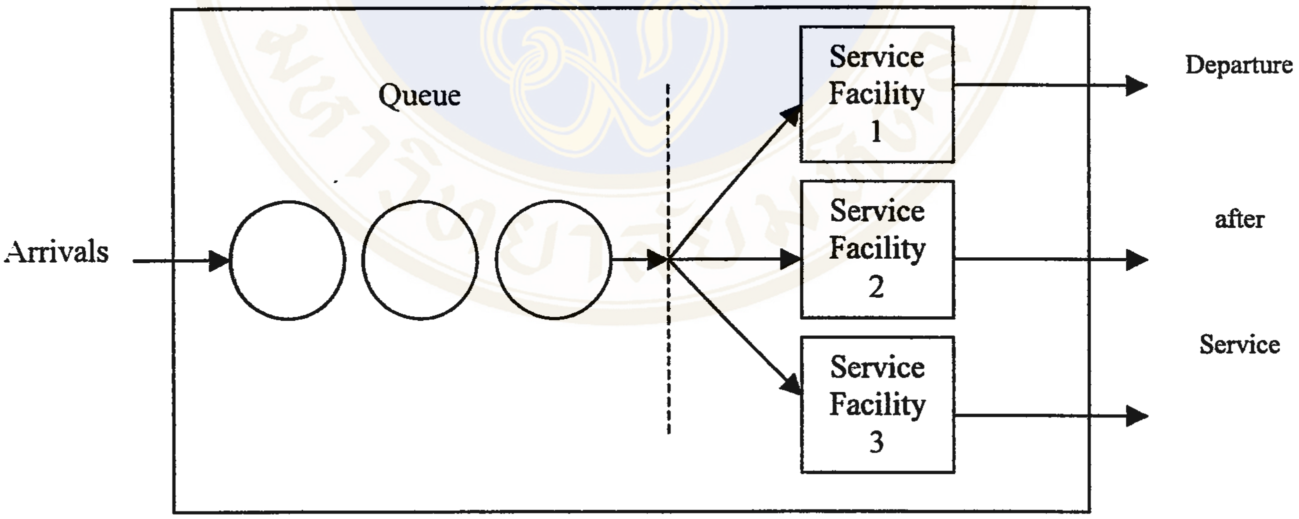


Figure 3.3 Multi-Channel, Single-Phase Queue System

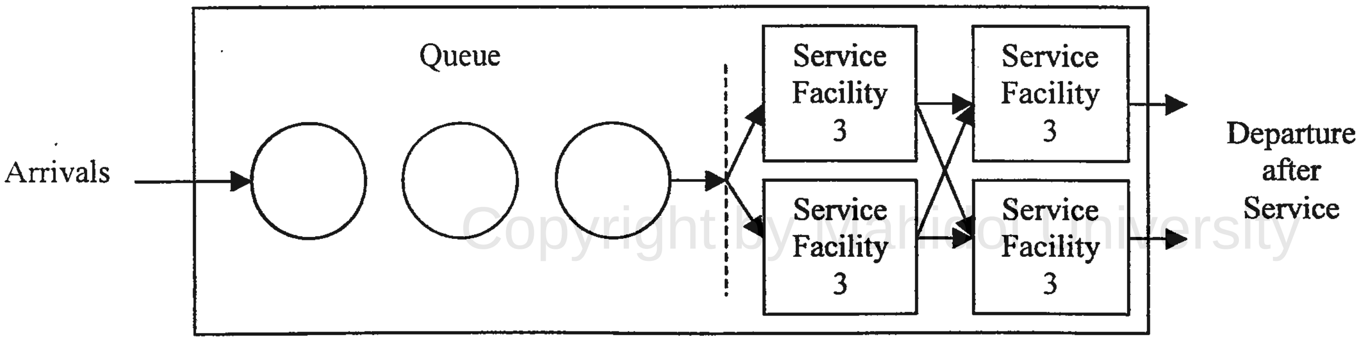


Figure 3.4 Multi-Channel, Multi-Phase Queue System

3.3 SINGLE-CHANNEL QUEUING MODEL

In this study, a single-channel queuing model with Poisson arrivals and Exponential service times is selected for approach. An important measures of performance in a typical service system can be determined by an analytical approach. Once these numeric measures have been computed, it will be possible to add in cost data and begin to make decisions that balance desirable service levels with waiting line service costs.

Assumptions of the model

The single-channel, single-phase model considered here is one of the most widely used and simplest queuing models. It assumes that seven conditions exist:

1. Arrivals are served on a first-in, first-out (FIFO) basis.
2. Every arrival waits to be served regardless of the length of the line; that is , there is no balking or reneging.
3. Arrivals are independent of preceding arrivals, but the average number of arrivals (the arrival rate) does not change over time.
4. Arrivals are described by a Poisson probability distribution and come from an infinite or very large population.
5. Service times also vary from one customer to the next and are independent of one another, but their average rate is known.
6. Service times occur according to the negative exponential probability distribution.
7. The average service rate is greater than the average arrival rate.

When these seven conditions are met, we can develop a series of equations that define the queue's operating characteristics.

Queuing equations (6)

Let λ = mean number of arrivals per time period (for example, per hour)

μ = mean number of people or items served per time period

The queuing equations follow:

1. The average number of customers or units in the system, L; that is, the number in line plus the number begin served:

$$L = \frac{\lambda}{\mu - \lambda}$$

2. The average time a customer spends in the system, W; that is, the time spent in line plus the time spent being served:

$$W = \frac{1}{\mu - \lambda}$$

3. The average number of customers in queue, L_q:

$$L_q = \frac{\lambda^2}{\mu(\mu - \lambda)}$$

4. The average time a customer spends waiting in the queue, W_q:

$$W_q = \frac{\lambda}{\mu(\mu - \lambda)}$$

5. The utilization factor for the system, ρ; that is, the probability that the service facility is being used:

$$\rho = \frac{\lambda}{\mu}$$

6. The percent idle time, P_0; that is, the probability that no one is in the system:

$$P_0 = 1 - \frac{\lambda}{\mu}$$

7. The probability that the number of customers in the system is greater than k, $P_{n>k}$:

$$P_{n>k} = \left(\frac{\lambda}{\mu}\right)^{k+1}$$

3.4 MULTI-CHANNEL QUEUING MODEL

In which two or more servers or channels are available to handle arriving customers. Let us still assume that customers awaiting service from one single line proceed to the first available server. An example of such a multi-channel, single-phase waiting line is found in many banks. A common line is formed and the customer at the head of the line proceeds to the first free teller.

The multiple channel system presented here assumes that arrivals follow a Poisson probability distribution and that service times are exponentially distributed. Service is first come, first served, and all servers are assumed to perform at the same rate. Other assumptions listed earlier for the single-channel model apply as well.

Equations for Multi-channel queuing model (6)

Let M equal the number of channels open, then the following formulas may be used in the waiting line analysis

λ = average arrival rate

μ = average service rate at each channel

The probability that are 0 customers or units in the system:

$$P_0 = \frac{1}{\left[\sum_{n=0}^{n=M-1} \frac{1}{n!}\left(\frac{\lambda}{\mu}\right)^n\right] + \frac{1}{M!}\left(\frac{\lambda}{\mu}\right)^M \frac{M\mu}{M\mu-\lambda}} \qquad \text{for } M_\mu > \lambda$$

The average number of customers or units in the system:

$$L = \frac{\lambda\mu\left(\lambda/\mu\right)^M}{(M-1)!(M\mu-\lambda)^2} P_0 + \frac{\lambda}{\mu}$$

The average time a unit spends in the waiting line or being serviced:

$$W = \frac{\mu\left(\lambda/\mu\right)^M}{(M-1)!(M\mu-\lambda)^2} P_0 + \frac{1}{\mu} = \frac{L}{\lambda}$$

The average number of customers or units in line waiting for services:

$$L_q = L - \frac{\lambda}{\mu}$$

The average time a customer or unit spends in the queue waiting for service:

$$W_q = W - \frac{1}{\mu} = \frac{L_q}{\lambda}$$

Utilization rate:

$$\rho = \frac{\lambda}{M\mu}$$

3.5 CONSTANT SERVICE TIME MODEL

Some service systems have constant service times instead of exponentially distributed times. When customers or equipment are processed according to a fixed cycle, as in the case of an automatic car wash or an amusement park ride, constant service rates are appropriate. Because constant rates are certain, the values for L_q, W_q, L, and W are always less than they would be in the models, which have variable service times. As a matter of fact, both the average queue length and the average waiting time in the queue are halved with the constant service rate model.

Equations for the constant service time model (6)

Constant service model formulas follow:

1. Average length of the queue:

$$L_q = \frac{\lambda^2}{2\mu(\mu - \lambda)}$$

2. Average waiting time in the queue:

$$W_q = \frac{\lambda}{2\mu(\mu - \lambda)}$$

3. Average number of customers in the system:

$$L = L_q + \frac{\lambda}{\mu}$$

4. Average waiting time in the system:

$$W = W_q + \frac{1}{\mu}$$

3.6 MORE COMPLEX QUEUING MODELS AND SIMULATION

Many practical waiting line problems that occur in production and operations service systems have characteristics like single- or multiple-channel waiting line, with Poisson arrivals and exponential or constant service times, an infinite calling population, and first-in, first-out service.

Often, however, variations of this specific case are present in an analysis. Service times in an automobile repair shop, for example, tend to follow the normal probability distribution instead of the exponential. A college registration system in which seniors have first choice of courses and hours over all other students is an example of a first-come, first-served model with a preemptive priority queue discipline. A physical examination for military recruits is an example of a multiphase system – one that differs from the single-phase models. A recruit first lines up to have blood drawn at one station, then waits to take an eye exam at the next station, talks to psychiatrist at the third, and is examined by the doctor for medical problems at he fourth. At each phase, the recruit must enter another queue and wait his or her turn.

Models to handle these cases have been developed by operations researchers. The computations for the resulting mathematical formulations are somewhat more complex. And many real-world queuing applications are too complex to be modeled analytically at all. When this happens, quantitative analysts usually turn to computer simulation.

Simulation is a technique in which random numbers are used to draw inferences about probability distributions (such as arrivals and services). Using this approach, many hours, days, or months of data can be developed by a computer in a few seconds. This allows analysis of controllable factors, such as adding another service channel, without actually doing so physically. Basically, whenever a standard analytical queuing model provides only a poor approximation of the actual service system, it is wise to develop a simulation model instead.

3.7 SUMMARY

Waiting line and service systems are important parts of the business world. The description of several common queuing situations and presented mathematical models for analyzing waiting lines follow certain assumptions. Those assumptions were that:

1. arrivals come from an infinite, or very large population
2. arrivals are Poisson distributed
3. arrivals are treated on a first-in, first-out basis and do not balk or renege
4. service times follow the negative exponential distribution or are constant
5. the average service rate is faster than the average arrival rate

The models illustrated for single-channel, single-phase and multiple-channel, single-phase problems.

Key operating characteristics for a system were shown to be:

1. utilization rate
2. percent idle time
3. average time spent waiting in the system and in the queue
4. average number of customers in the system and in the queue
5. probabilities of various numbers of customer in the system

It was emphasized that a variety of queuing models exist that do not meet all of the assumptions of the traditional models. In these cases, we can use a technique called computer simulation instead.

CHAPTER IV

SIMULATION

4.1 INTRODUCTION

The technique for using computers to imitate, or simulate, the operations of various kinds of real-world facilities or processes. The facility or process of interest is usually called a *system*, and in order to study it scientifically we often have to make a set of assumptions about how it works. These assumptions, which usually take the form of mathematical or logical relationships, constitute a *model* that is used to try to gain some understanding of how the corresponding system behaves.

Applications areas for simulation are numerous and diverse. Below is a list of some particular kinds of problems for which simulation has been found to be a useful and powerful tool:

1) Designing and analyzing manufacturing systems
2) Evaluating hardware and software requirements for a computer system
3) Evaluating a new military weapons system or tactic
4) Determining ordering policies for an inventory system
5) Designing communications system and message protocols for them
6) Designing and operating transportation facilities such as freeways, airports, subways, or ports
7) Analyzing financial or economic systems

4.2 SYSTEMS, MODELS, AND SIMULATION

A *system* is defined to be a collection of entities, e.g., people or machines, that act and interact together toward the accomplishment of some logical end. [This definition was proposed by Schmidt and Taylor (1970).] The collection of entities that compose a system for one study might be only a subset of the overall system for another. For example, if one wants to study a bank to determine the number of tellers needed to provide adequate service for customers who want just to cash a check or make a savings deposit, the system can be defined to be that portion of the bank consisting of the tellers and the customers waiting in line or being served. If, on the other hand, the loan officer and the safety deposit boxes are to be included, the definition of the system must be expanded in an obvious way.

The *state* of a system to be that collection of variables necessary to describe a system at a particular time, relative to the objectives of a study.

The system can be categorized into two types, discrete and continuous.

A *discrete system* is one for which the state variables change instantaneously at separated points in times. A bank is an example of a discrete system.

A *continuous system* is one for which the state variables change continuously with respect to time. An airplane moving through the air is an example of a continuous system.

Few systems in practice are wholly discrete or wholly continuous, but since one type of change predominates for most systems, it will usually be possible to classify a system as being either discrete or continuous.

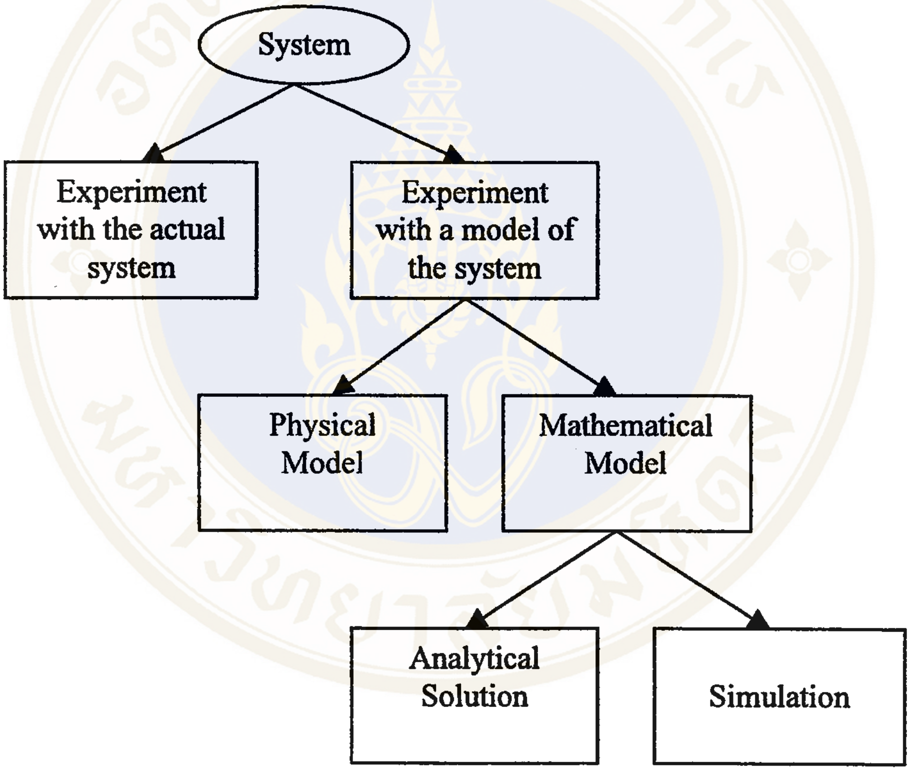

System
Experiment with the actual system
Experiment with a model of the system
Physical Model
Mathematical Model
Analytical Solution
Simulation

Figure 4.1 Ways to study system

At some point in the lives of most systems, there is a need to study them to try to gain some insight into the relationships among various components, or to predict performance under some new conditions being considered.

Experiment with a Actual System vs. Experiment with a Model of the System: If it is possible (and cost-effective) to alter the system physically and then let it operate under the new conditions, it is probably desirable to do so, for in this case there is no question about whether what we study is relevant. However, it is rarely feasible to do this, because such an experiment would often be too costly or too disruptive to the system. When using a model, there is always the question of whether it accurately reflects the system for the purposes of the decisions to be made.

Physical Model vs. Mathematical Model: The word "model" evokes images of clay cars in wind tunnels, cockpits disconnected from their airplanes to be used in pilot training, or miniature supertankers scurrying about in a swimming pool. These are examples of physical models (also called iconic models), and are not typical of the kinds of models that are usually of interest in operations research and systems analysis. Occasionally, however, it has been found useful to build physical models to study engineering or management systems; examples include tabletop scale models of material-handling systems, and in at least one case a full-scale physical model of a fast-food restaurant inside a warehouse, complete with full-scale, real (and presumably hungry) humans [Swart and Donno (1981)]. But the vast majority of models built for such purposes are mathematical, representing a system in terms of logical and quantitative relationships that are then manipulated and change to see how the model reacts, and thus how the system would react – if the mathematical model is a valid one. Perhaps the simplest example of a mathematical model is the familiar relation $d = rt$, where r is the rate of travel, t is the time spent traveling, and d is the distance traveled. This might provide a valid model in one instance, but a very poor model for other purposes.

Analytical Solution vs. Simulation: Once we have built a mathematical model, it must then be examined to see how it can be used to answer the questions of interest about the system it is supposed to represent. If the model is simple enough, it may be possible to work with its relationships and quantities to get an exact, analytical solution. If an analytical solution to a mathematical model is available and is computationally efficient, it is usually desirable to study the model in this way rather than via a simulation. However, many systems are highly complex, precluding any possibility of an analytical solution. In this case, the model must be studied by means of simulation.

4.3 DISCRETE-EVENT SIMULATION

A *Discrete-event simulation* concerns the modeling of a system as it evolves over time by a representation in which the state variables change instantaneously at separate points in time. In mathematical terms, we might say that the system can change at only a *countable* number of points in time. This point in time are the ones at which an *event* occurs, where an event is defined as an instantaneous occurrence that may change the state of the system. Although discrete-event simulation could conceptually be done by hand calculation, the amount of data that must be stored and manipulated for most real-world systems dictates that discrete-event simulations be done on a digital computer.

4.3.1 Time-Advance Mechanisms

Because of the dynamic nature of discrete-event simulation models, we must keep track of the current value of simulated time as the simulation proceeds, and we also need a mechanism to advance simulated time from one value to another. We call the variable in a simulation model that gives the current value of simulated time the *simulation clock.* The unit of time for the simulation clock is never stated explicitly when a model is written in a general-purpose language such as FORTRAN, Pascal or C, and it is assumed to be in the same units as the input parameters. Also, there is generally no relationship between simulated time and the time needed to run a simulation on the computer.

Historically, two principal approaches have been suggested for advancing the simulation clock: *next-event time advance* and *fixed-increment time advance*. Since the first approach is used by all major simulation languages and by most people coding their model in a general-purpose language, and since the second is a special case of the first, we shall use the next-event time-advance approach for all discrete-event simulation models.

With the next-event time-advance approach, the simulation clock is initialized to zero and the advanced to the time of occurrence of the most imminent (first) of these future events, at which point the state of the system is updated to account for the fact that an event has occurred, and our knowledge of the times of occurrence of future events is also updated. Then the simulation clock is advanced to the time of the (new) most imminent event, the state of the system is updated, and future event times are determined, etc. This process of advancing the simulation clock from one event time to another is continued until eventually some prespecified stopping condition is satisfied. Since all state change occur only at event times for a discrete-event simulation model, periods of inactivity are skipped over by jumping the clock from event time to event time. (Fixed-increment time advance does not skip over these inactive periods, which can eat up a lot of computer time) It should be noted that the successive jumps of the simulation clock are generally variable (or unequal) insize.

We now illustrate in detail the next-event time-advance approach for the single-server queuing system. We using following notation:

t_i = time of arrival of the i^{th} car ($t_0 = 0$)

$A_i = t_i - t_{i-1}$ = interarrival time between (.$i - 1$)

4.3.2 Components and Organization of Discrete-Event Simulation Model

Although simulation has been applied to a great diversity of real-world systems, discrete-event simulation models all share a number of common components and there is a logical organization for these components that promotes the coding, debugging, and future changing of a simulation model's computer program. In particular, the following components will be found in most discrete-event simulation models using the next-event time advance approach:

System state: The collection of state variables necessary to describe the system at a particular time.

Simulation clock: A variable giving the current value of simulated time

Event list: A list containing the next time when each type of event will occur.

Statistical counter: Variables used for storing statistical information about system performance

Initialization routine: A subprogram to initialize the simulation model at time zero.

Timing routine: A subprogram that determines the next event from the event list and then advances the simulation clock to the time when that event is to occur.

Event routine: A subprogram that updates the system state when a particular type of event occurs (there is one event routine for each event type).

Library routines: A set of subprogram used to generate random observations from probability distributions that were determined as part of the simulation model.

Report generator: A subprogram that computes estimates (from the statistical counters) of the desired measures of performance and produces a report when the simulation ends.

Main program: A subprogram that invokes the timing routine to determine the next event and then transfers control to the corresponding event routine to update the system state appropriately. The main program may also check for termination and invoke the report generator when the simulation is over.

The logical relationships (flow of control) among these components is shown in Figure 4.2. The simulation begins at time 0 with the main program invoking the initialization routine, where the simulation clock is set to zero, the system state and the statistical counters are initialized, and the event list in initialized. After control has been returned to the main program, it invokes the timing routine to determine which type of event is most imminent. If an event of type I is the next to occur, the simulation clock is advanced to the time that event type I will occur and control is returned to the main program. Then the main program invokes event routine I, where typically three types of activities occur:

1) the system state is updated to account for the fact that an event of type I has occurred
2) information about system performance is gathered by updating the statistical counters
3) the times of occurrence of future events are generated and this information is added to the event list

Often it is necessary to generate random observations from probability distributions in order to determine these future event times; we will refer to such a generated observation as a random variant. After all processing has been completed, either in event routine I or in the main program, a check is typically made to determine (relative to some stopping condition) if the simulation should now be terminated. If it is time to terminate the simulation, the report generator is invoked from the main program to compute estimates (from the statistical counters) of the desired measures of performance and to produce a report. If it is not time for termination, control is passed back to the main program and the main program-timing routine-main program-event routine-termination check cycle is repeated until the stopping condition is eventually satisfied.

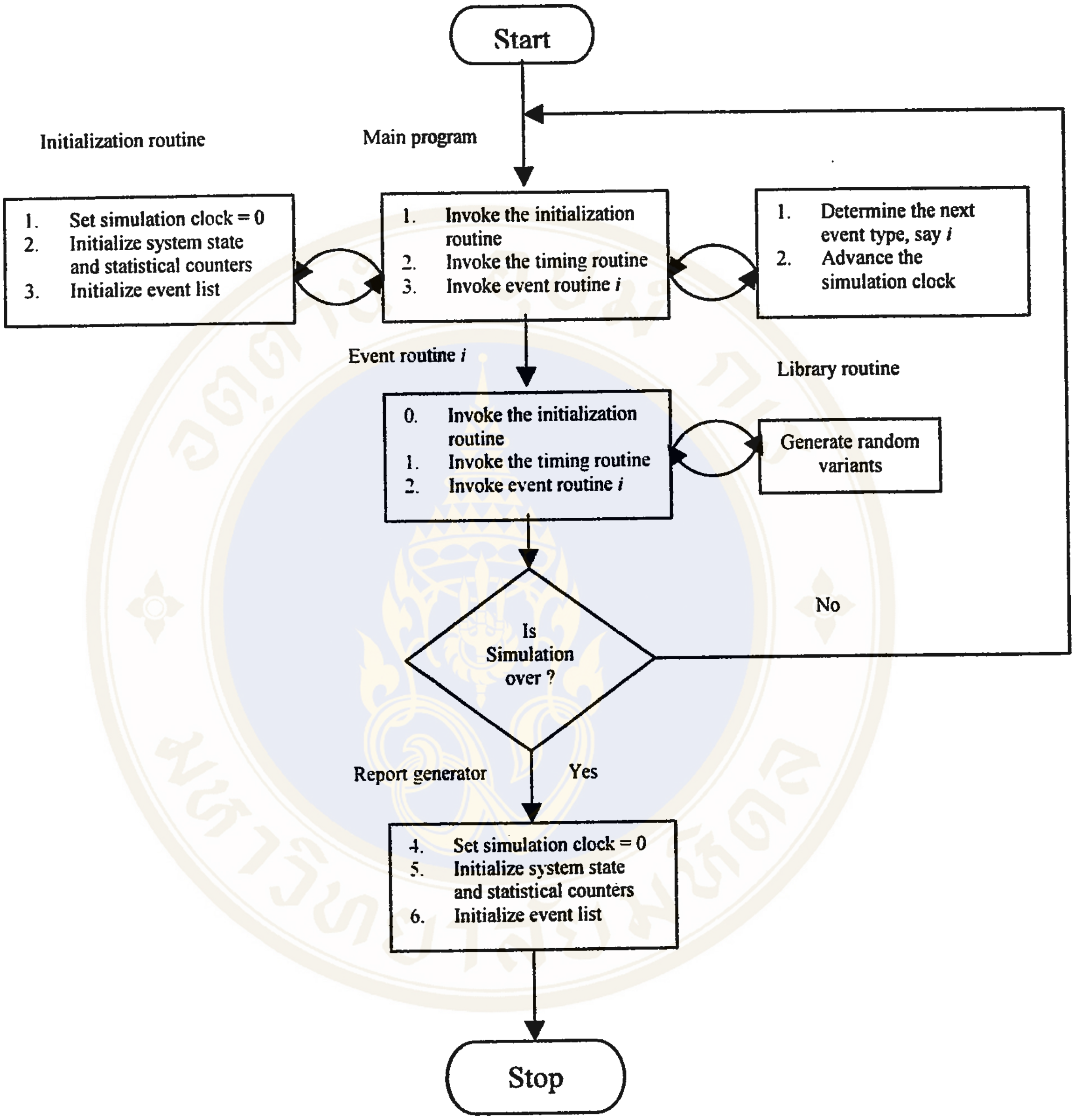

Start
Initialization routine
Main program
1. Set simulation clock = 0
2. Initialize system state and statistical counters
3. Initialize event list
1. Invoke the initialization routine
2. Invoke the timing routine
3. Invoke event routine *i*
1. Determine the next event type, say *i*
2. Advance the simulation clock
Event routine *i*
Library routine
0. Invoke the initialization routine
1. Invoke the timing routine
2. Invoke event routine *i*
Generate random variants
No
Is Simulation over ?
Report generator
Yes
4. Set simulation clock = 0
5. Initialize system state and statistical counters
6. Initialize event list
Stop

Figure 4.2 Flow of control for the next-event time-advance approach

4.4 SIMULATION OF A SINGLE-SERVER QUEUEING SYSTEM

This section show in detail of our traffic problem and condition and how to apply for single-server queuing system.

4.4.1 Problem Statement

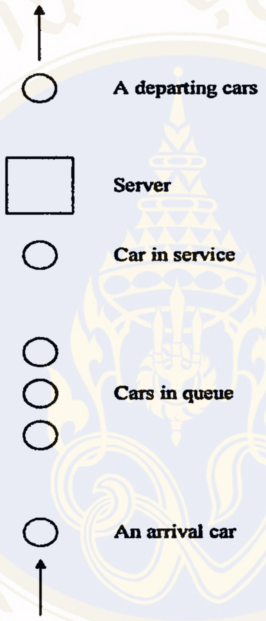


Figure 4.3 Single-server queuing system

4.4.2 Program Organization and Logic

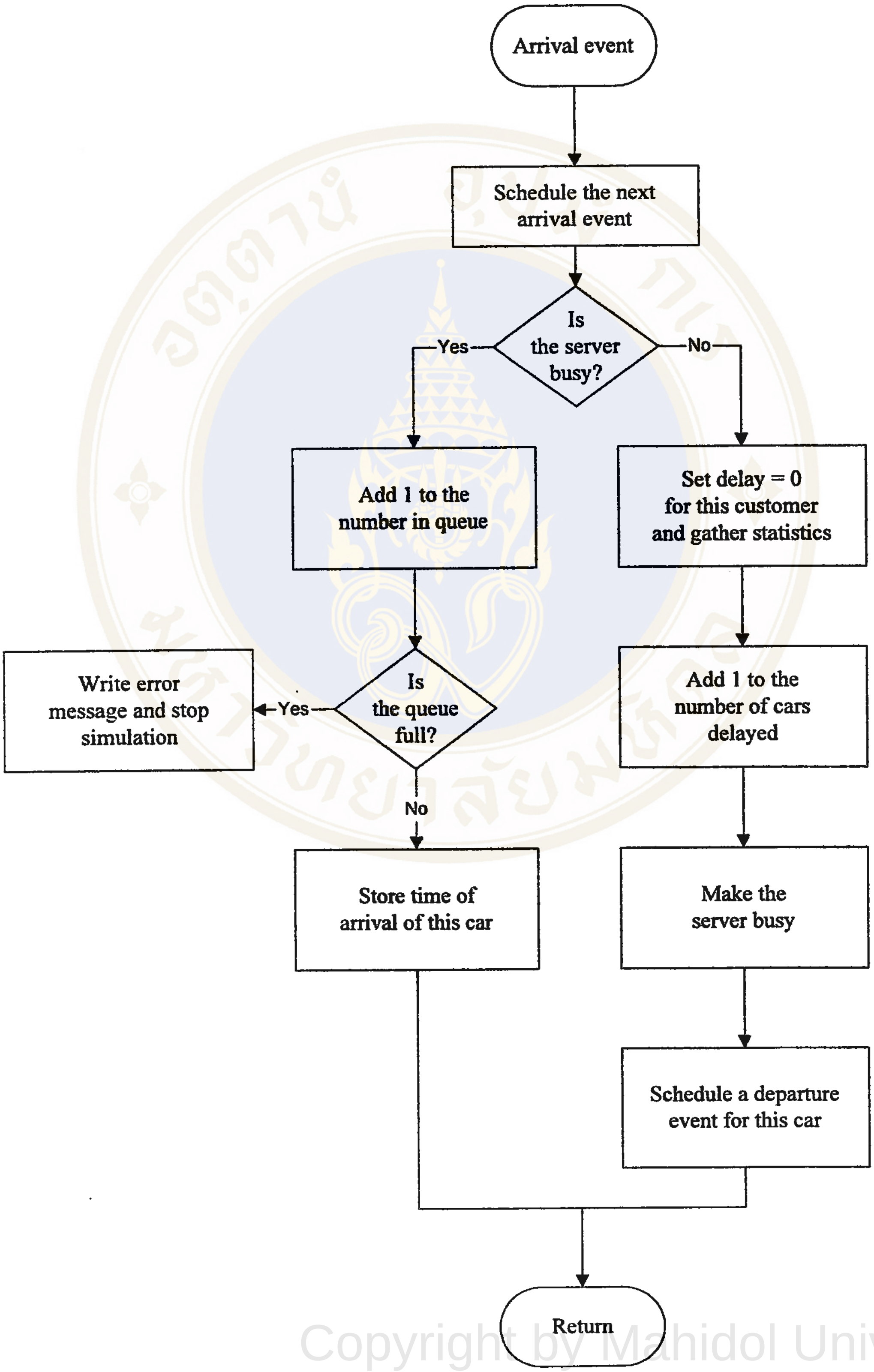

Arrival event
Schedule the next arrival event
Is the server busy?
Yes
No
Add 1 to the number in queue
Set delay = 0 for this customer and gather statistics
Is the queue full?
Yes
Write error message and stop simulation
No
Add 1 to the number of cars delayed
Store time of arrival of this car
Make the server busy
Schedule a departure event for this car
Return

Figure 4.4 Flowchart for arrival routine, queuing model.

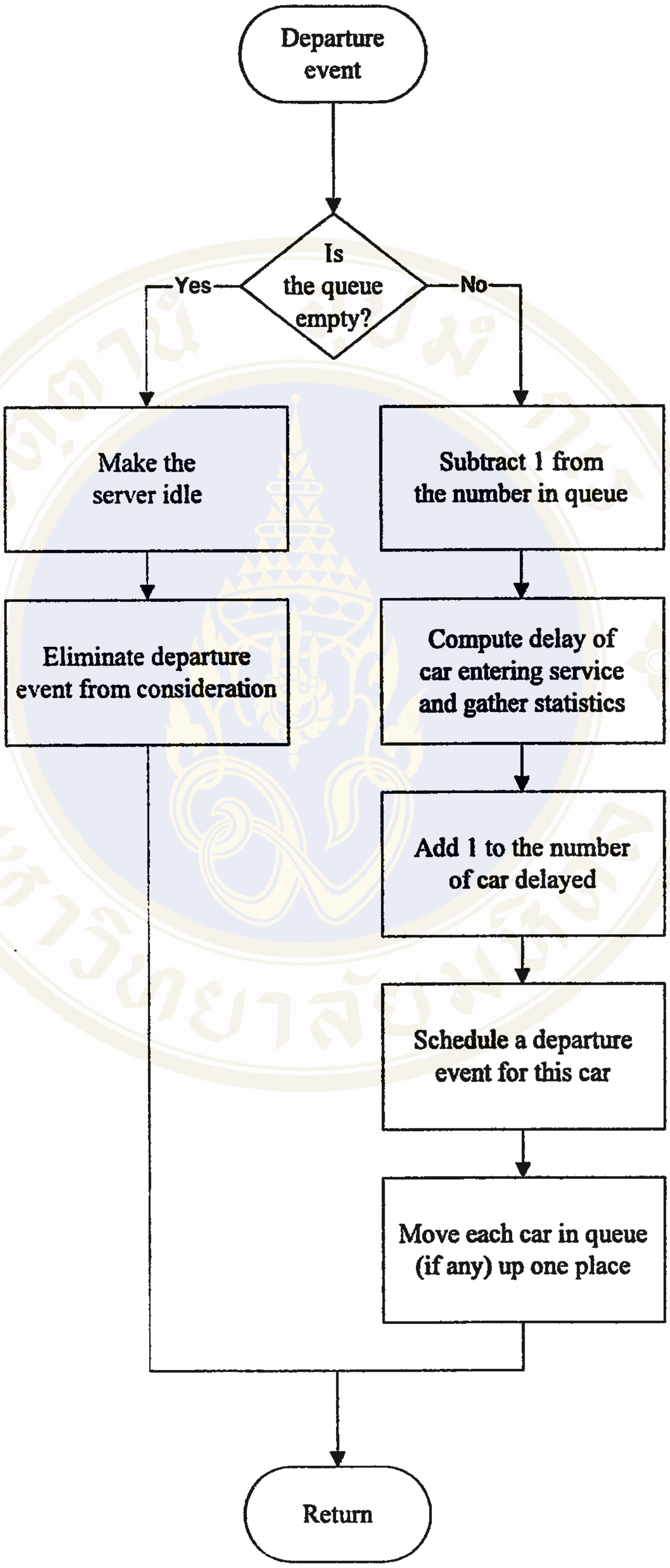

Departure event
Is the queue empty?
Yes
No
Make the server idle
Eliminate departure event from consideration
Subtract 1 from the number in queue
Compute delay of car entering service and gather statistics
Add 1 to the number of car delayed
Schedule a departure event for this car
Move each car in queue (if any) up one place
Return

Figure 4.5 Flowchart for departure routine, queueing model.

4.5 SIMULATION SOFTWARE

The simulation program probably noticed several features needed in programming most discrete-event simulation models, including:

1) Generating random numbers, that is, random values from the U(0,1) probability distribution
2) Generating random values from a specified probability distribution (e.g., exponential)
3) Advancing simulated time
4) Determining the next event from the event list and passing control to the appropriate block of code
5) Adding records to, or deleting records from, a list
6) Collecting and analyzing data
7) Reporting the results
8) Detecting error conditions

4.5.1 Simulation language and simulators

There are currently two major classes of simulation software: languages and simulators.

A **simulation language** is a computer package that is general in nature but may have special features for certain types of applications. For example, SIMAN and SLAM II have manufacturing modules for conveyors and automated guided vehicles. A model is developed in a simulation language by writing a program using the language's modeling constructs. The major strength of most languages is their ability to model almost any kind of system, regardless of the system's operating procedures or control logic. Possible drawbacks of simulation language are the need for programming expertise and the possibly long coding and debugging time associated with modeling complex systems.

A simulator is a computer package that allows one to simulate a system contained in a specific class of systems with little or no programming. For example, there are currently simulators available for certain types of manufacturing, computer, and communication systems. The particular system of interest (in the domain of the package) is typically selected for simulation by the use of menus and graphics, without the need for programming. The major advantage of a simulator is that "program" development time may be considerably less than that for a simulation language. This may be very important given the tight time constraints in many business environments. Another advantage is that most simulators have modeling constructs related specifically to the components of the target class of systems, which is particularly desirable for operational personnel. Also, people without programming experience or who use simulation only occasionally (e.g., a manufacturing engineer in a factory) often prefer simulators because of their ease of use. The major drawback of many simulators is that they are limited to modeling only those system configurations allowed by their standard features. This difficulty can be some what overcome if the simulator has "programming-like" commands to model complex decision logic; most of the model would still be developed using menus and graphics. (This capability might be available in the simulator itself or external routines called by the simulator.) Simulators are currently most often used for high-level analyses, where the system is modeled at an aggregate level without including details of the control logic.

4.6 MODELING APPROACHES

Almost all simulation languages use one of two basic approaches to discrete-event simulation modeling; these approaches are also used by modelers using a general-purpose language. In the event-scheduling approach, used in the programs of a system in modeled by identifying its characteristic events and then writing a set of event routines that give a detailed description of the state changes taking place at the time of each event. The simulation evolves over time by executing the events in increasing order of their time of occurrence. Here a basic property of an event routine is that no simulated time passes during its execution. The event-scheduling approach is available in SIMAN, SIMSCRIPT II.5, and SLAM II.

A process is a time-ordered sequence of interrelated events separated by passages of time, which describes the entire experience of an "entity" as it flows through a "system". The process corresponding to an entity arriving to and being served at a single server shown in Fig. 4.1. Corresponding to each process in the model, there is a process "routine" that describes the entire history of its "process entity" as it moves through the corresponding process. A process "routine" explicitly contains the passage of simulated time and generally has multiple entry points.

To illustrate the nature of the process approach more succinctly, Fig.4.2 gives a flow chart for a prototype customer-process routine in the case of a single-server queuing system.

Unlike an event routine, this process routine, this process routine has multiple entry points at blocks 1, 5, and 9. Entry into this routine at block 1 corresponds to the arrival event for a customer entity that is the most imminent event in the event list. At block 1 an arrival event record is placed in the event list for the next car entity to arrive. (This next car entity will arrive at a time equal to the time the current car entity arrives plus an interarrival time.) To determine whether the customer entity currently arriving can begin service, a check is made (at block 2) to see whether the server is idle. If the server is busy, this customer entity is placed at the end of the queue (block 3) and made to wait (at block 4) until selected for service at some undetermined time in the future. (This is called a conditional wait.) control is then returned to the "timing routine" to determine what customer entity's event is the most imminent now. (If we think of a flowchart like the one in Fig. 4.2 as existing for each customer entity in the system, control will next be passed to the appropriate entry point for the flowchart corresponding to the most imminent event for some other car.)

When this car entity (the one made to wait at block 4) is activated at some point in the future (when it is first in queue and another car completes service and makes the server idle), it is removed from the queue at block 5 and begins service immediately, there by making the server busy (block 6). A car entity arriving to find the service is determined, and a corresponding event record is placed in the event list. This car entity is then made to wait (at block 8) until its service has been completed. (This is an unconditional wait, since its activation time is known.) Control is returned to the timing routine to determine what customer entity will be processed next. When the customer made to wait at block 8 is activated at the end of its service, it makes the server idle at block 9 (allowing the first customer in the queue to become active immediately), and then this car is removed from the system at block 10.

A simulation using the process approach also evolves over time by executing the events in increasing order of their time of occurrence. Internally, the two approaches to simulation are very similar (e.g., both approaches use a simulation clock, an event list, a timing routine, etc.). They differ mainly in the language constructs that they make available to model a system. Process statements are more "macro" in nature and automatically translate certain situations commonly occurring in a simulation model, e.g., cars arriving to a queuing system, into the corresponding event logic.

The process approach has several advantages over the event-scheduling approach. For many types of systems the process approach is more natural in some sense, since one process routine describes the entire experience of the corresponding process entity. Furthermore, a process simulation model of a system usually requires fewer lines of code than the comparable program using the event-scheduling approach. On the other hand, the process approach as implemented in some simulation languages is less flexible than the event-scheduling approach.

The process approach is the major modeling orientation in GPSS/H, GPSS/PC, SIMAN, SIMSCRIP II.5, and SLAM II.

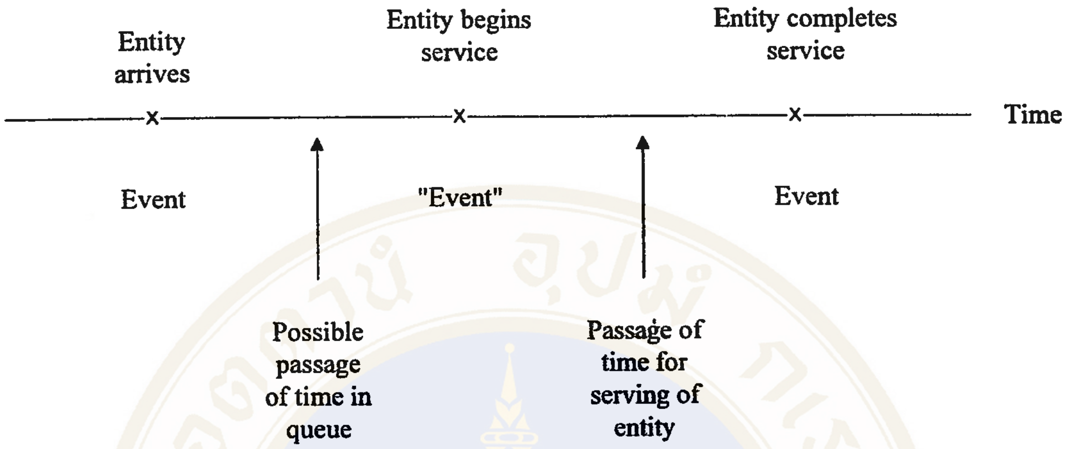


Figure 4.6 Process describing the flow of an entity through system.

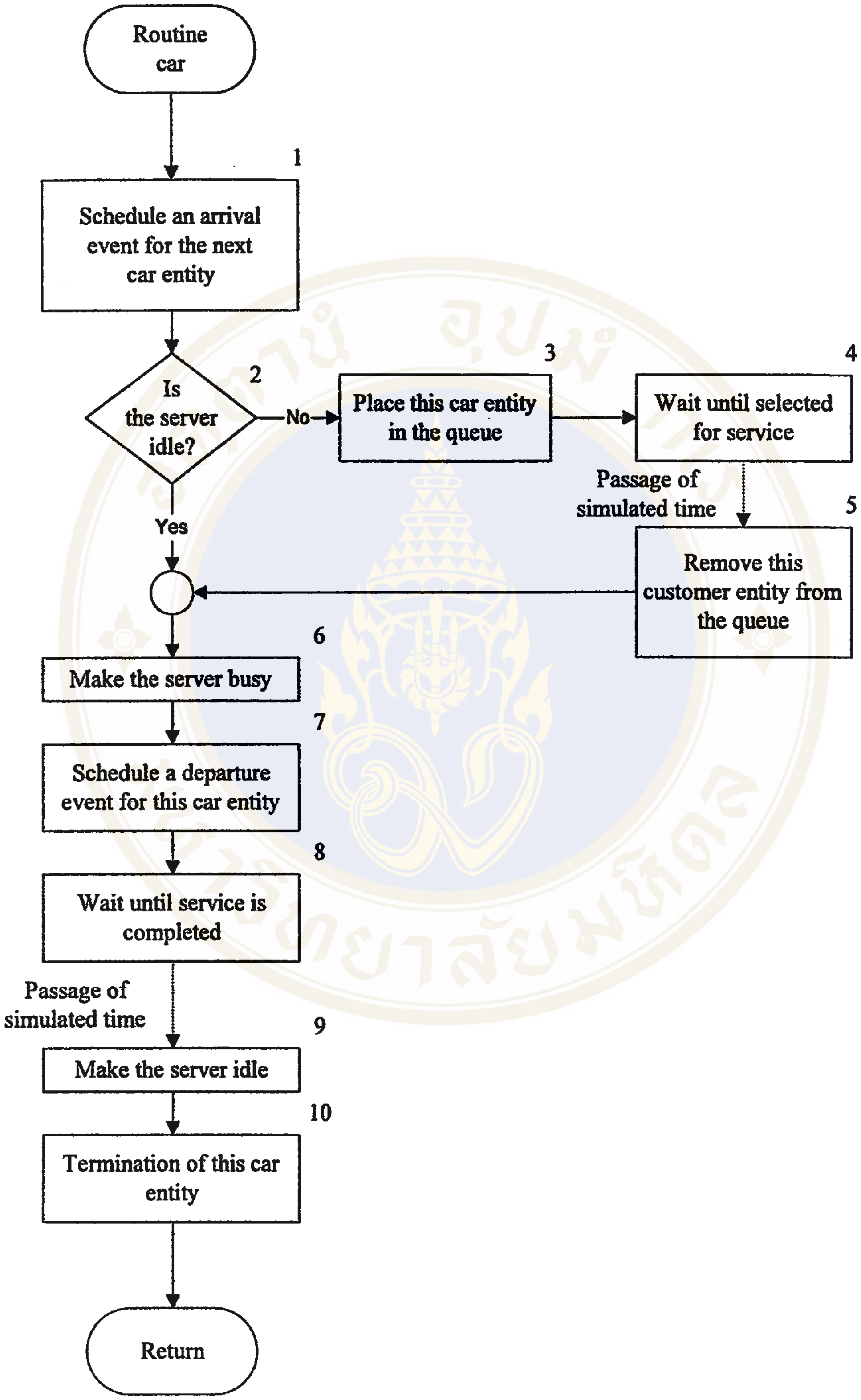

Routine car
1
Schedule an arrival event for the next car entity
2
Is the server idle?
No
3
Place this car entity in the queue
4
Wait until selected for service
Passage of simulated time
5
Remove this customer entity from the queue
Yes
6
Make the server busy
7
Schedule a departure event for this car entity
8
Wait until service is completed
Passage of simulated time
9
Make the server idle
10
Termination of this car entity
Return

Figure 4.7 Prototype car-process routine for a single-server queueing system.

4.7 DESIRABLE SOFTWARE FEATURES

In the introduction section, some basic features or capabilities needed in programming a simulation model was described. This section represent a number of additional features that should be available in a contemporary simulation package, with this features being grouped into five categories [Law and Haider, (1989) and also the discussion of material-handling modules].

4.7.1 GENERAL FEATURES

The most important feature for a simulation package to have is *modeling flexibility*, because no two systems are exactly the same. If the simulation package does not have the necessary capabilities for a particular application then the system must be approximated, resulting in a model with unknown validity. Entities should have general attributes (e.g., due date, message length, etc.), which can be appropriately changed; this capability is generally available in simulation languages but is less common in simulators.

Ease of model development is another very important feature, due to the short time frame for many projects. The accuracy and speed of the modeling process will be increased if the package has good debugging aids, such as interactive debugger, on-line input error checking, and on-line help.

Fast model execution speed is particularly important for very large models (e.g., certain military applications) and when the simulation model is to be run on a microcomputer. For a complicated simulation model of a 40-machine food packaging plant, it took 7 hours to simulate 2 weeks of production on a 16-megahertz microcomputer.

The *maximum model size* allowed by the simulation package may be an important factor when the model is to be executed on a microcomputer. For some packages, the maximum model size is currently less than 100K bytes. This potential difficulty will become less important as many vendors are beginning to offer versions with extended model sizes.

It is also desirable for a simulation package to be available for number of different computer classes (i.e., microcomputer, work station, and minicomputer, mainframe), and for the software to be compatible across these classes. Thus, for example, a model could be developed on a microcomputer and then uploaded to a minicomputer or mainframe for execution of the production runs.

4.7.2 ANIMATION

Easy-to-use animation is one of the main reasons for the increased popularity of simulation modeling. In an animation, key elements of a system (e.g., machines and parts) are represented on a CRT by icons that change shape, color, or position when there is a change of state in the simulation, Thus, a system can be seen graphically to change over time. Most contemporary animation packages operate in a concurrent mode, where the animation is displayed while the simulation is actually running (perhaps slowed down to allow for visual comprehension). On the other hand, some animation packages function in a playback mode, where the animation is displayed after the simulation is completed from state changes recorded in a disk file. Several examples of animation and graphics are given in color Plate 1.

The major reason for the popularity of animation is its ability to communicate the essence of a simulation model (or of simulation itself) to managers and other key project personnel, greatly increasing the model's credibility. Other potential benefits of animation are:

Debugging a simulation computer program

Showing that a simulation model is not valid

Suggesting improved operational procedures or control logic for a system

Understanding the dynamic behavior of a system

Training operational personnel

Animation also has certain shortcomings or disadvantages. In particular, it is not a substitute for a careful statistical analysis of the simulation output data. One cannot conclude that a system is "well defined" by watching an animation for a "short" period of time since, if the simulation were run for a longer period of time, a crucial piece of equipment might fail and cause a major system bottleneck.Animating a simulation model increases model development time, and simulation packages with an animation capability are often considerably more expensive. Finally, only part of a simulation model's logic can actually be seen in an animation; thus, a "correct" animation is no guarantee of a valid or debugged model.

There are number of desirable features for an animation package. First and foremost, since animation is primarily a communication tool, it is important for it to look realistic (particularly for presentations to high-level managers). The user should be able to create high-resolution icons using bit-mapped rather than character screen, rather than "jumpy" or "pulsating" movement. It should be possible to store icons in a library for use in a future model, and the library should come with standard icons to facilitate animation development. The animation should be easy to develop, relying more on menus and graphics that on programming. These should be the capability for multiple screen layout, since some models will not "fit" on a single standard computer screen. (Additional animation features are discussed in Law and Haider (1989)

A useful graphical companion to animation is dynamic presentation quality graphics, where histograms, level meters, dials, etc., are updated as the simulation progresses through time.

4.7.3 STATISTICAL CAPABILITIES

Since most real-world systems exhibit some sort of random behavior, a simulation package must contain good statistical capabilities that should actually be used. In general, each source of system randomness (interarrival times, service times, machine operation times, etc.) needs to be modeled by a probability distribution, not just its mean. A simulation package should contain a wide variety of standard distributions (e.g., exponential, gamma, and triangular), should be able to use distributions based on observed system data, and should contain a multiple-stream random-number generator to facilitate comparing alternative system designs.

Since random samples from the input probability distributions "drive" a simulation model through time, simulation output data (e.g., daily throughputs in a factory) are also random and appropriate statistical techniques must be used to design and interpret the simulation runs. A simulation package should contain a single command to make independent replications of the model automatically, with each replication using different random numbers, starting in the same initial state, and resetting the statistical counters to zero. We should be able to specify a warm up period (at the end of which statistical counters are reset to zero) and to construct confidence intervals for desired measures of performance (e.g., mean daily throughput) in order to determine the statistical precision of the simulation results.

4.7.4 CUSTOMER SUPPORT

Most users of simulation software require some level of ongoing support from the vendor. First, the software vendor should present public seminars on the use of the software on a regular basis. Also, the vendor should provide timely technical support for specific modeling problems encountered by the user. (A toll-free phone number is desirable.) Good documentation, including a well-written textbook, a user's manual, and numberous detailed examples, is important for software use as well as initial installation. Free software trails and demo disks are helpful to the prospective user in evaluating the software for their particular needs.

4.7.5 OUTPUT REPORT

A simulation package should provide time-saving standard reports for commonly occurring performance statistics (e.g., utilization, queue sizes and delays and throughput), but should also allow tailored reports to be developed easily. For example, standard reports of often not suitable for management presentations. Furthermore, it is often of interest t obtain (static) presentation-quality graphical displays [e.g., histograms, bar charts, pie charts, or time plots of important variables] and to have access to the individual model output observations (rather than just the usual summary statistics) so that additional analyses can be performed. For example, one might want to export the output observations (e.g., daily throughputs) to a graphics package, a spreadsheet, or a statistics package.

```
RELATIVE CLOCK           1014.1565       ABSOLUTE CLOCK          1014.1565

BLOCK CURRENT                 TOTAL
1                              1000
2                              1000
3                              1000
LVEQ                           1000
5                              1000
6                               999
STOP                           1000
8                              1000

              --- AVG ---    --UTIL---     DURING--
   FACILITY       TOTAL        AVAIL        UNAVL       ENTRIES      AVERAG     CURRENT     PERCENT     SEIZING      PREEMPTING
                   TIME         TIME         TIME                 TIME/XACT      STATUS       AVAIL        XACT            XACT
    SERVER        0.516                                    1000       0.523       AVAIL

      QUEUE      MAXIMUM        AVERAGE       TOTAL        ZERO     PERCENT        AVERAGE    $AVERAGE      QTABLE     CURRENT
                CONTENTS       CONTENTS     ENTRIES     ENTRIES       ZEROS      TIME/UNIT   TIME/UNIT      NUMBER    CONTENTS
    SERVERQ            8          0.605        1000         454        45.4          0.614       1.124                       0

    RANDOM    ANTITHETIC     INITIAL     CURRENT     SAMPLE      CHI-SQUARE
    STREAM      VARIATES    POSITION    POSITION      COUNT      UNIFORMITY
         1           OFF      100000      101001       1001            0.71
         2           OFF      200000      200999        999            0.69
```

Figure 4.8 GPSS/H standard output report, queuing model.

```
                    SIMAN Summary Report

                    Run Number 1 of 1

Project:            M M 1 QUEUE
Analyst:            A. LAW
Date:               7/12/1989


Run ended at time .9783E+03

                                     Tally Variables

  No.   Identifier              Average   Standard   Minimum   Maximum    Number
                                          Deviation    Value     Value   of Obs.
    1   DELAY IN QUEUE           .49558    .80138     .00000   4.04199     1000


                                Discrete Change Variables

  No.   Identifier              Average   Standard   Minimum   Maximum      Time
                                          Deviation    Value     Value    Period
    1   NUMBER IN QUEUE          .50658   1.14931     .00000  10.00000    978.28
    2   SERVER UTIL.             .51872    .49965     .00000   1.00000    978.28

                                       Counters

  No.   Identifier                Count     limit
    1   CAR DELAYS                 1000      1000
```

Figure 4.9 SIMAN output report, queuing model

4.8 COMPARISON OF SIMULATION LANGUAGES

These simulation languages actually have very similar basic modeling constructs, due to language cross-fertilization over the years. This can be seen in Table 4.1, where show the GPSS (H or PC), SIMAN/Cinema, SIMSCRIPT II.5, and SLAM II/SLAMSYSTEM language statements for creating new entities, for entities to seize and release resources, for a passage of time (e.g., a service time), and for collecting discrete-time and continuous-time statistics.

Many simulations have a queuing orientation, and GPSS and the process parts of SIMAN and SLAM II have modeling constructs well suited for these types of problems. SIMAN and SLAM II also have constructs for the more basic event-scheduling approach. This should allow them to model conveniently a somewhat larger class of non-queuing-oriented systems than GPSS. On the other hand, there is some indication that GPSS/H has the fastest compilation and execution times [Abed, Barta, and McRoberts (1985)].

SIMSCRIPT II.5 has the most general process approach of the major simulation languages; thus, virtually any system can be modeled without using the event-scheduling approach. However, because of its general structure, it may require more lines of code than GPSS, or SLAM II for "standard" queuing problems. For "complicated" simulation models (particularly those that are large or non-queuing-oriented), SIMSCRIPT II.5 is an attractive choice because it is a general programming language with sophisticated control statements and data structures.

Many important simulation software features are quite subjective in nature (e.g., ease of model development and vendor technical support) and, thus, will not be used to compare the simulation languages discussed above. As an alternative, we present in Table 4.2 a comparison of the simulation languages based on nine quantitative features or factors. This list is not exhaustive, and whether a feature is important could depend on the particular application. For example, most simulation studies do not require capabilities for combined discrete-continuous simulation. In table 4.2 a simulation language is said to have a particular feature if it is part of the software usually distributed by the vendor.

Some additional information on simulation language is given in Banks and Carson (1985). In particular, they provide GPSS/H, SIMAN, SIMSCRIPT II.5 and SLAM II programs for a simple manufacturing system.

Table 4.1 Implementation of basic simulation capabilities

	Language			
Feature	**GPSS (H or PC)**	**SIMAN/ Cinema**	**SIMSCRIPT II.5**	**SLAM II/ SLAMSYSTEM**
Create new entities	GENERATE	CREATE	ACTIVATE	CREATE
Seize and release a resource	SEIZE/ RELEASE	SEIZE/ RELEASE	REQUEST/ RELINQUISH	AWAIT/ FREE
Passage of time (e.g., a service time	ADVANCE	DELAY	WORK, WAIT	ACTIVITY
Discrete-time statistics	QUEUE/ DEPART, TABULATE	TALY	TALLY	COLCT
Continuous-time statistics	QUEUE/ DEPART, ENTER/ LEAVE, TABULATE	DSTAT	ACCUMULATE	TIMST

CHAPTER V

TRAFFIC FLOW CHARACTERISTICS

5.1 INTRODUCTION

This chapter will describe traffic flow characteristics such as flow of vehicles moving individually or in a groups on a roadway. It is vital to be used for design and operate the traffic and transport system. At the present time, there is no unified theory of traffic flow. Much of the knowledge currently available in this field is largely empirical. Mainly on observation and understanding the nature of traffic and how to approach each parameter and formulate an equation for the mathematical model.

5.2 THE NATURE OF TRAFFIC FLOW

Traffic flow is a complex phenomenon. It requires little more than casual observation while driving on a freeway to discover that as traffic flow increases, there is generally a corresponding decrease in speed. Speed also decreases when vehicles tend to bunch together for one reason or another.

Traffic flow is a stochastic process, with random variations in vehicle and driver characteristics and their interactions. It is quite common to construct models of reality in which the effects of chance variation are ignored or averaged out, where any given input will produce an exactly predictable output. These models are deterministic. The alternative situation is to allow random variation in the model and then look at the probabilities of different outcomes. This method of stochastic modeling takes into consideration the variability among possible outcomes, not just average outcome (Lay, 1986a, 1986b).

5.3 APPROACHES TO UNDERSTANDING TRAFFIC FLOW

The interaction between vehicles and their drivers, and also among vehicles, is a highly complex process. There are three main approaches to the understanding and quantification of traffic flow. The first is a macroscopic approach that looks at the flow in an aggregate sense. Based on such physical analogies as heat flow and fluid flow, the macroscopic approach is most appropriate for studying steady-state phenomena of flow and hence best describes the overall operational efficiency of the system. The second is a microscopic approach that considers the response of each individual vehicle in a segregate manner. Here the individual driver-vehicle combination is examined, such as car maneuvering. This approach is used extensively in highway safety work. The third approach is the human-factor approach. Basically, it seeks to define the mechanism by which an individual driver (and his or her vehicle) locates himself or herself with reference to other vehicles and to the highway/guidance system. Notice that the microscopic and the human-factor approaches are closely related (Drew, 1968).

One way of combining all three approaches is to assume initially that a stream of traffic is composed of identical vehicles and identical drivers, thus permitting easy integration of the various approaches. The simple's combination also assumes that the traffic moves at uniform speed and that the vehicle spacing is dependent on speed. In other words, a vehicle's behavior is forced on it by other vehicles in the traffic stream. Indeed, speed is assumed to be the only variable that influences flow. Naturally, there is one particular vehicle flow associated with a speed adopted by the traffic stream (Lay, 1986a, 1986b).

5.4 PARAMETERS CONNECTED WITH TRAFFIC FLOW

There are at least eight basic variables or measures used in describing traffic flow, and several other stream characteristics are derived from these. The three primary variables are speed (v), volume (q), and density (k). Three other variables used in traffic flow analysis are headway (h), spacing (s), and occupancy (R). Also, corresponding to measures of spacing and headway are two parameters: clearance (c) and gap (g). (1)

5.4.1 Speed

Speed is defined as a rate of motion, as distance per unit time, generally in miles per hour (mph) or kilometers per hour (km/hr). Because there is a broad distribution of individual speeds in a traffic stream, an average travel speed is considered. Thus, if travel times $t_1, t_2, t_3, \ldots, t_n$, are observed for n vehicles traversing a segment of length L, the average travel speed is

$$V_s = \frac{L}{\sum_{i=1}^{n} \frac{t_i}{n}} = \frac{nL}{\sum_{i=1}^{n} t_i}$$

(1)

Where

V_s = average travel speed or space mean speed (mph)

L = length of the highway segment (miles)

t_i = travel time of the i^{th} vehicle to traverse the section (hours)

n = number of travel times observed

The average travel speed calculated is referred to as the *space mean speed*. It is called *space* mean speed because the use of average travel time essentially weights the average according to the length of time each vehicle spends in *space*.

Another way of defining the *average speed* of traffic stream is by finding the *time mean speed* (V_t). This is the arithmetic mean of the measured speeds of all vehicles passing, say, a fixed roadside point during a given interval of time, in which case, the individual speeds are known as *spot speeds*.

$$V_t = \frac{\sum_{i=1}^{n} V_i}{n}$$

(2)

Where V_i is the spot speed, and *n* is the number of vehicles observed.

It can be shown that whereas the time mean speed is the arithmetic mean of the spot speeds, the space mean speed is their harmonic mean. Time mean speed is always greater than space mean speed except in the situation where all vehicles travel at the same speed. It can shown that an approximate relationship between the two mean speeds is

$$V_t = V_s + \frac{\sigma_s^2}{V_s}$$

(3)

Also,

$$V_s = V_t - \frac{\sigma_t^2}{V_t}$$

(4)

Where

σ_s^2 is the variance of the space mean speeds and

$$\sigma_t^2 = {\left[\sum (V_i - V_t)^2\right]}\Big/_{n}$$

5.4.2 Volume

Volume and rate of flow are two different measures. *Volume* is the actual number of vehicles observed or predicted to be passing a point during a given time interval. The *rate of flow* represents the number of vehicles passing a point during a time interval less than 1 hour, but expressed as an equivalent hourly rate. Thus, a volume of 200 vehicles observed in a 10-minute period implies a rate of flow of (200 X 60)/10 = 1200 veh/hr. Note that 1200 vehicles do not pass the point of observation during the study hour, but they do pass the point at that rate for 10 minutes.

5.4.3 Density or Concentration

Density or *concentration* is defined as the number of vehicles occupying a given length of lane or roadway, averaged over time, usually expressed as vehicles per mile (vpm). Direct measurement of density can be obtained through aerial photography, but more commonly it is calculated from Eq. (5) if speed and rate of flow are known.

$$q = v \times k \qquad (5)$$

where

q = rate of flow (veh/hr)

v = average travel speed (mph)

k = average density (veh/mi)

5.4.4 Spacing and Headway

Spacing and headway are two additional characteristics of traffic streams. *Spacing (s)* is defined as the distance between successive vehicles in a traffic stream as measured from front bumper to front bumper. *Headway* is the corresponding time between successive vehicles as they pass a point on a roadway. Both spacing and headway are related to speed, flow rate, and density.

$$\text{Avg. density (k), veh/mi} = \frac{\text{5280, ft/mi}}{\text{Avg. spacing (s), ft/veh}}. \qquad (6)$$

$$\text{Avg. headway (h), sec/veh} = \frac{\text{Avg. spacing (s), ft/veh}}{\text{Avg. speed (v), ft/sec}}. \qquad (7)$$

$$\text{Avg. flow rate (q). veh/hr} = \frac{\text{3600, sec/hr}}{\text{Avg. headway (h), sec/veh}}. \qquad (8)$$

Spacing of vehicles in a traffic lane can be generally observed from aerial photographs. Headway of vehicles can be measured using stopwatch observations as vehicles pass a point on a lane.

5.4.5 Lane occupancy

Lane occupancy is a measure used in freeway surveillance. If one could measure the lengths of vehicles on a given roadway section and compute the ratio:

$$R = \frac{\text{Sum of lengths of vehicles}}{\text{Length of roadway section}} = \frac{\Sigma L_I}{D} \tag{9}$$

Then R could be divided by the average length of vehicle to give an estimate of the density (k).

Lane occupancy (LO) can also be described as the ratio of the time that vehicles are present at a detection station in a traffic lane compared to the time of sampling.

$$LO = \frac{\text{Total time veh. detector is occupied}}{\text{Total observation time}} = \frac{\Sigma t_0}{T} \tag{10}$$

Figure 5.1 illustrates the use of a detector in use of a detector in traffic engineering work. Here

$$t_0 = \frac{L + C}{v_s}$$

.where L is the average length of vehicle, and C is the distance between the loop of the detector.

It is necessary to know the effective length of a vehicle as measured by the detector in use to calculate lane occupancy. Density can be calculated by using the expression.

$$K = \frac{LO \times 5280}{L + C} \tag{11}$$

In most cases, the detector is actuated as soon as the front bumper crosses the detector and remains on until the rear bumper leaves the detector .

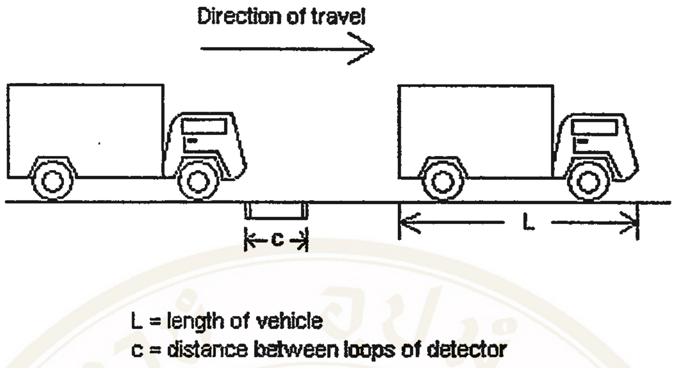


Figure 5.1 Loop detector

Lane occupancy applications are of much concern in on-line surveillance and control systems. For example, freeway surveillance is accomplished by monitoring lane occupancy from numerous stations such as entrance ramps. Proper records of lane occupancy can be useful in evaluating traffic stream performance.

5.4.6 Clearance and Gap

Clearance and *gap* correspond to parameters of spacing (ft) and headway (sec). These four measurements are shown in Figure 5.2. The difference between spacing and clearance is obviously the average length of a vehicle in feet. Similarly, the difference between headway and gap is the time equivalence of the average length of a vehicle (L/v):

$$g = h - (L/v) \qquad (12)$$

and

$$c = g \times v \qquad (13)$$

where

g = mean gap (sec)

L = mean length of vehicles (ft)

c = mean clearance (ft)

h = mean headway (sec)

v = mean speed (ft/sec)

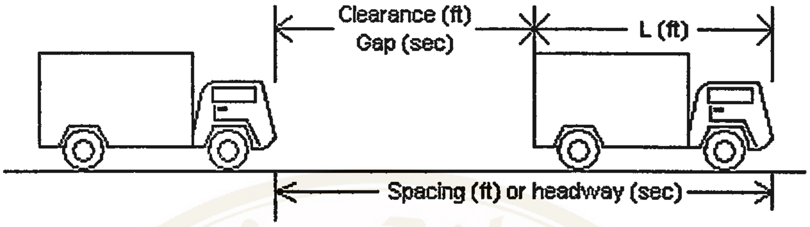


Figure 5.2 Clearance-Gap and Spacing-Headway Concept

5.5 CATEGORIES OF TRAFFIC FLOW

Vehicle flow on transportation facilities may be generally classified into tow categories.

5.5.1 Uninterrupted flow

Uninterrupted flow can occur on facilities that have no fixed elements, such as traffic signals, external to the traffic stream, that cause interruptions to traffic flow. Traffic flow conditions are thus the result of interactions among vehicles in the traffic stream and between vehicles and the geometric characteristics of the guideway/roadway system. Also, the driver of the vehicle does not expect to be required to stop by factors external to the traffic stream.

5.5.2 Interrupted flow

Interrupted flow occurs on transportation facilities that have fixed elements causing periodic interruptions to traffic flow. Such elements include traffic signals, stop signs, and other types of controls. These devices cause traffic to stop (or significantly slow down) periodically irrespective of how much traffic exists. Naturally, in this case, the driver expects to be required to stop as and when required by fixed elements that are part of the facilities.

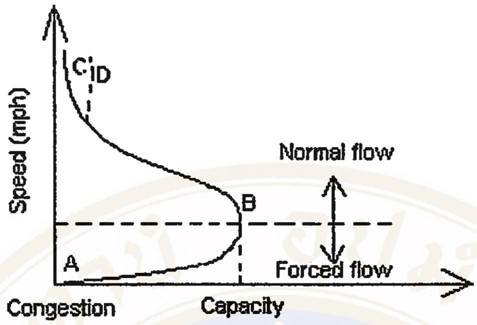


Figure 5.3 Speed-Flow Curve

5.6 SIGNALIZATION

5.6.1 TYPE OF SIGNAL

In general, three types of signals available: pretimed, semi-actuated and fully actuated. Their characteristics are as follows:

Pretimed

Preset times and phases

Cycle lengths are constant

Simple and inexpensive

Less efficient in fluctuating demand

Effective in progressive signal system

Can be operated on different timing plans

Semiactuated

Vehicle detector on minor street

Green is always on Major Street unless minor-street actuation occurs

Two-phase plan is common

Cycle length may vary from cycle to cycle

Good for low to moderate side-street demand

Usually installed when insufficient gaps occur in major stream

Can be used in overall progressive signal system

Fully actuated

All approaches have vehicle detectors

Each phase is subject to minimum and maximum green time

Some phases can be "skipped" if no demand is detected

A phase is terminated when there are no further actuation within a specific time interval or when the maximum green time has been reached

Cycle length varies from cycle to cycle

Most flexible form of signal control

Most efficient use of available green time

Best used at isolated intersections that is not coordinated with other signals

May be used in progressive signal system

Local policies, guidelines, standards, demands, and budgets are the primary factors in selecting a controller.

5.6.2 Phase plan

An appropriate selection of a phase plan is most critical for efficient movement of vehicles, and this includes the determination of the number of phases and their sequence. It is best to adopt a simple two-phase control unless conditions need something more elaborate. Remember that change intervals between phases contribute to lost time per cycle.

Figure 5.4 shows a number of common phase plans that may be used with pretimed or actuated controllers. The two-phase control is the most straightforward and simple. Multiphase control is adopted where one or more left or right turns are determined to require protected phasing. Usually, the left-turn movements require a protected phase. Local agencies have guidelines that require protected left-turn control when such left-turn volumes exceed 100 to 200 veh/hr. Left-turn phasing may also be considered where the speed of opposing traffic is greater than 40 mph. Figure 5.4 (b) shows a three-phase plan in which an exclusive left-turn phase is provided for both left-turn movements on the major street. It is followed by a through and right-turn phase for the major street, driving which left turns may be permitted on an optional basis. Figure 5.4 (c) is commonly referred to as "leading and lagging green" phasing. The initial phase is a through and left-turn phase for one direction of the major street, followed by a through phase for both directions during which left turns in both directions may be permitted on an optional basis. The direction of flow started in the first phase is then stopped, providing the opposing direction with a through plus left-turn phase. The final phase provides all movements on the minor street. Such phasing is extremely flexible. Figure 5.4 (d) is a four-phase sequence if both streets need left-turn phases.

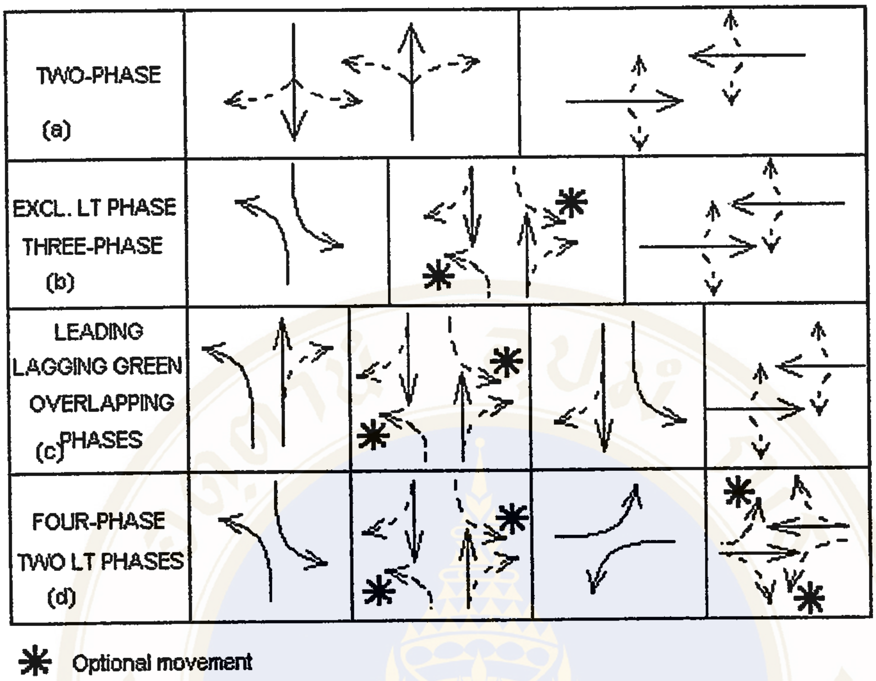


Figure 5.4 Common phase plans that may be used with pretimed or actuated controllers (TRB 1994).

CHAPTER VI

TRAFFIC OF CENTRAL BANGKOK SIMULATION

6.1 INTRODUCTION

In this chapter, information and statistics of Bangkok and traffic facilities used as the basis of this study are mentioned. Then, the steps to organize this data, algorithms and flow control for program development will be described. At the end of this chapter is explanation of the functionality for the user.

6.2 INFORMATION AND STATISTICS OF BANGKOK

There is some information and statistics of Bangkok that we can use as input for estimation and prediction such as population, transportation information and information of roads and junctions in the study area.

6.2.1 Population

For the purpose of plan formulation, policy making, and investment program selection, a number of estimations have been made about future population size. The following tables are the population of the Central Bangkok used as the basis of this study (end of 1994 - end of 1997).

Table 6.1 Statistic of population and house as on 31th December 1994

Province / District	Male	Female	Total	No. of House
Bangkok	**2,760,025**	**2,824,201**	**5,584,226**	**1,562,110**
Phra Nakhon	44,610	42,645	87,255	19,935
Dusit	94.639	76,667	171,306	26,003
Pathumwan	58,615	58,626	117,241	27,469
Pom Prap	41,217	40,425	81,642	18,938
Sattru Phai				
Phaya Thai	88,506	82,941	171,447	26,619
Ratchathewi	53,973	55,330	109,303	22,805

Table 6.2 Statistic of population and house as on 31th December 1995

Province / District	Male	Female	Total	No. of House
Bangkok	**2,745,431**	**2,825,312**	**5,570,743**	**1,661,311**
Phra Nakhon	42,605	41,066	83,671	20,036
Dusit	91,528	75,089	166,617	26,264
Pathumwan	58,032	58,163	116,195	27,985
Pom Prap	40,875	40,057	80,932	19,180
Sattru Phai				
Phaya Thai	56,010	52,718	108,728	27,107
Ratchathewi	81,517	81,693	163,210	23,868

Table 6.3 Statistic of population and house as on 31th December 1996

Province / District	Male	Female	Total	No. of House
Bangkok	**2,746,352**	**2,838,611**	**5,584,963**	**1,703,128**
Phra Nakhon	42,144	40,741	82,885	17,858
Dusit	90,128	73,444	163,572	25,971
Pathumwan	56,255	56,665	112,920	25,169
Pom Prap Sattru Phai	40,421	39,752	80,173	18,292
Phaya Thai	52,564	49,569	102,133	24,596
Ratchathewi	66,666	67,206	133,872	23,184

Table 6.4 Statistic of population and house as on 31th December 1997

Province / District	Male	Female	Total	No. of House
Bangkok	**2,749,947**	**2,854,825**	**5,604,772**	**1,810,530**
Phra Nakhon	41,376	40,280	81,656	18,023
Dusit	89,051	72,944	161,995	26,693
Pathumwan	55,945	56,652	112,597	26,939
Pom Prap Sattru Phai	39,892	39,290	79,182	18,204
Phaya Thai	47,900	45,396	93,296	25,837
Ratchathewi	53,882	55,134	109,016	25,418

Source: Department of Local Administration, Ministry of Interior.

Compiled by : Statistical Data Bank and Information Dissemination Division, National Statistical Office.

Table 6.5 Statistics of population from registration record in Bangkok Metropolis

Year	Number of population			Birth	Death	Rate of population growth	Density per Sq.km.
	Total	**Male**	**Female**				
1990	5,546,937	2,770,895	2,776,042	128,080	14,934	(4.90)	3,543.92
1991	5,620,591	2,799,941	2,820,650	147,617	19,635	1.33	3,590.97
1992	5,562,141	2,766,101	2,796,040	146,800	23,321	(1.04)	3,553.63
1993	5,572,712	2,760,480	2,812,232	224,896	24,603	0.19	3,560.38
1994	5,584,226	2,760,025	2,824,201	147,113	11,256	0.21	3,567.74
1995	5,570,743	2,745,431	2,825,312	130,243	19,884	(0.24)	3,559.13
1996	5,584,963	2,746,352	2,838,611	151,138	24,548	0.26	3,568.21
1997	5,604,772	2,749,947	2,854,825	141,658	25,656	0.35	3,580.87

Source: Department of Local Administration, Ministry of Interior.

Compiled by : Statistical Data Bank and Information Dissemination Division, National Statistical Office.

Table 6.6 Population projections, natural growth rate, TFR, NRR, CBR, CDR and IMR for Thailand : 1995-2002

Year	No. of population (Million)	Natural growth rate (%)	Total fertility rate (TFR)	Net re-production rate (NRR)	Crude birth rate (per 1000) (CBR)	Crude death rate (per 1000) (CDR)	Infant mortality rate (IMR)
1995	59.40	1.08	2.07	0.96	18.36	7.52	32.04
1996	60.00	1.03	2.03	0.94	17.98	7.66	31.43
1997	60.60	0.98	2.00	0.92	17.60	7.80	30.82
1998	61.20	0.95	1.98	0.91	17.32	7.84	30.27
1999	61.81	0.92	1.96	0.90	17.04	7.88	29.72
2000	62.41	0.88	1.93	0.89	16.76	7.92	29.17
2001	62.91	0.85	1.91	0.89	16.48	7.96	28.62
2002	63.43	0.82	1.89	0.88	16.20	8.00	28.07

Source: Population Projections for Thailand: 1990-2020, Office of the National Economic and Social Development Board.

6.2.2 Transportation

The transportation statistics are found at the statistical databank and information dissemination division of the national statistic office shown in table 6.4. The statistics show that in Bangkok metropolis area, the rate of population per private car for year 1992 is 5.6, year 1993 is 5.1, year 1994 is 4.6, year 1995 is 4.4 and year 1996 is 4.2.

Table 6.7 Statistics of Transportation of Population in Bangkok Metropolis

	1992	1993	1994	1995	1996
Number of Vehicles	2,373,288	2,656,107	2,963,043	3,241,081	3,549,082
Population per vehicle	2.3	2.1	1.9	1.7	1.6
Private car	987,999	1,091,836	1,214,927	1,262,069	1,342,813
Population per Private car	5..6	5.1	4.6	4.4	4.2
Motorcycle	1,006,302	1.105,084	1,233,503	1,373,072	1,527,834
Population per Motorcycle	5.5	5.0	4.5	4.1	3.7
Truck	84,328	90,349	83,250	91,427	98,234
Bus	23,394	24,074	24,139	24,364	24,647
Private Bus	217,336	272,190	323,902	402,680	462,803

Source : Statistical Data Bank and Information Dissemination Division, National Statistical Office.

According to the information of population growth in the study area and the rate of private car ownership, we can use the mathematical method to estimate how the population will grow in the near future. And also the calculation of how the rate of private car ownership is increasing. The estimated value can be useful to put in as a condition for control logic of the simulation program. Especially, the appropriate number of cars that will be generated into the node-link (junction – road) network. In addition, if more analysis of estimation has been done, the outcome of different sources of car arrival ratio into the network can be more actually predicted. That has made the simulation program more creditable. But, in this study, we consider more the realization of the traffic flow characteristics and conditions.

6.3 TRAFFIC SIGNAL FACILITIES

The purpose of study is to create the traffic simulation program. The program must simulate the real traffic status and conditions in the study area. After research, we found that there is an existing ATC (Area Traffic Control) system currently used in the study area. There are some details of this system described in the consequent section.

6.3.1 Existing ATC system facilities

The central facilities of the existing ATC system are housed in the OPP building. Local control covers the old city and the government office district located directly to the north of the old city. The system was installed in 1979. An outline of the existing ATC system is given below.

a) Control system. A time-fixed control system, established by TRANSYT-7, that applies four patterns of timing plans to five time periods.

b) Number of Intersections Controlled. The maximum capacity is 64 intersections, but currently only 47 intersection are covered.

c) Communication System. A half duplex TDM system with a 1:N multi-drop circuit configuration. The maximum value of N is 8. The system can accept eight modems, but is currently equipped with only 6.

d) Monitoring Functions. Indications of on-line, permitted manual, independent operation (poor communication or unpermitted manual) and major road green appear on the graphic panel. Based on observation at 10:00 on a weekday, about 20% are estimated to be in an on-line status and 80% in other status. Printout of errors and control parameter changes are also provided.

6.3.2 Existing ATC system operation

The existing ATC system is begin operated as follows:

a) During the 10 years since the ATC system was introduced, its control parameters were renewed twice. When renewing the parameters, traffic survey data were sent to an overseas organization and newly-calculated parameters were obtained by return mail, which were then fed into the computer.

b) As mentioned above, there are four patterns of timing plans. Of these, three have cycle lengths of 60, 90 and 120 seconds respectively.

c) Circuit conditions are poor during the rainy season. There are no data on the actual reliability of TOT circuits. The only information available is that restoration work targets, 80% recovery within 24 hours and 99% within seven days.

d) The TOT circuit leads directly into the ATC local controller.

6.3.3 Existing signal control facilities and operation

Signal control facilities in current use have their operations are as follows:

a) Nearly all signalized intersections are manually controlled at site by traffic policeman. According to observations, manual cycles are about 2.5 – 8 minutes. However, there is no concept on cycles owing to skipping and backtracking of phases. Manual operations are based on assessments of spot conditions as indicated by visual observations by traffic policemen and/or information received via transceivers.

b) Some of the traffic signals are mounted on high poles and have small lenses of approximately 20 cm in diameters. Signal illumination tends to be dark. Electric power (about 12V, 50W) is supplied via transformers.

c) Each traffic signals is connected directly to the local controller by a single cable; no relays are used.

6.4 CURRENT PROBLEMS

Problems concerning current traffic flow and current signal facilities which have a bearing on the ATC system are below.

6.4.1 The traffic flow problem

The following problems concerning traffic flow were identified from field survey results and from available reference data:

1) Within the area that constitutes the city's business and commercial center, a substantial volume of traffic is concentrated in the area bordered by Rama IV Rd, Middle Ring Rd., Din Daeng Rd, Ratchwithi Rd, and Chao Phraya River, causing chronic congestion within the area.

2) Congestion in the above mentioned area is severe during peak hours, when major signalized intersections become saturated, as indicated by hourly traffic volume per lane. Moreover, travel speeds during the morning and evening peak hours fall to less than 10 km/h, and nearly all stoppages are caused by intersection waiting time or spill back.

3) A large number of major signalized intersections have saturation degree of more than 1.0, indicating that these intersections are over-saturated.

4) Traffic volumes on major roads fluctuate in complicated and diverse patterns during a day, with especially large fluctuations seen during a day, with especially large fluctuations seen during business hours. There are also wide fluctuations from day to day. Owing to these factors, it is extremely difficult to control such as traffic volume by pre-timed signal control.

5) Within the area mentioned above, especially heavy congestion is seen on one-way arterial roads. The high concentration of traffic on these roads is partially attributed to the fact that trip lengths become of longer owing to the one way scheme in the sparse network of roads in the area, which results in longer detour trips.

6) There is a tendency toward high accident frequency on Rama IV Rd, Sukhumvit Rd, Petburi Rd, Phaya Thai Rd, and Sri Ayutthaya Rd, where congestion is severe. The rate of rear-end collisions is high.

7) In consideration of frequency of traffic flow intersection caused by the official events a green band control system should be considered.

6.4.2 Signal facility problem

The following problems concerning traffic signal facilities were identified from field survey results and from collected reference data:

1) The existing ATC system has several problems related to its operation as follows:

    a) During the 10 years since the ATC system was introduced, its control parameters in traffic conditions are not being responded to quickly and effectively enough.

2) Problems related to existing signal control facilities are as follows:

    a) Nearly all signalized intersections are manually controlled by traffic policemen. This means that the intersection capacity is decreased by no coordinated situation and too long cycle time.

    b) Most traffic lights are mounted on low poles and have small lenses, resulting to poor visibility.

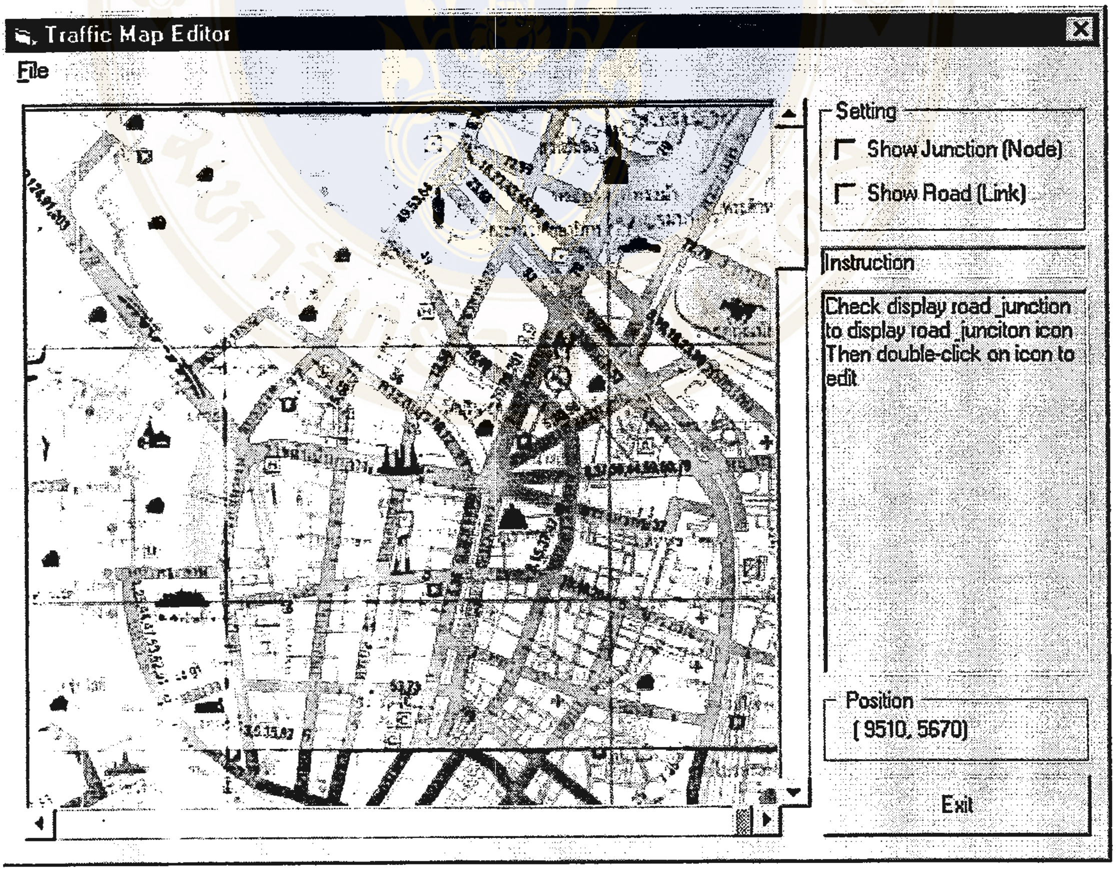
    c) The maintenance setup seems inadequate owing to the very small number of staff, lack of spare parts and other problems.

6.5 TRAFFIC SIMULATION PROGRAM

6.5.1 General information

6.5.1.1 Road and Junctions

In this study, the first step is to transform a real-word system into a model which includes the transformation of roads and junctions in Bangkok into a node-link system. At this step, information as a public map is the appropriate data. This example of a Bangkok map can be founded and used as a reference source of information. Then the name of roads and junctions were prepared as the reference of linkage and node numbers accordingly. Figure 6.1 shows the Central Bangkok map used in the simulation program. The coverage study area is bounded by the conjunction of Pinklao bridge and Ratchadamnoen Klang road in the west, along Samsen and Phra Sumen road to the north. From the south, the study area runs down to Bamrung Muang road and is bounded by Krung Kasem road in the east.



Setting
□ Show Junction (Node)
□ Show Road (Link)

Instruction
Check display road junction to display road junciton icon Then double-click on icon to edit

Position
(9510, 5670)

Figure 6.1 Map of Bangkok

For reference, in this study, we assign the identifier number for each node and link in the study area that are listed in table 6.8 and 6.9.

Table 6.8 Representative node number for junction

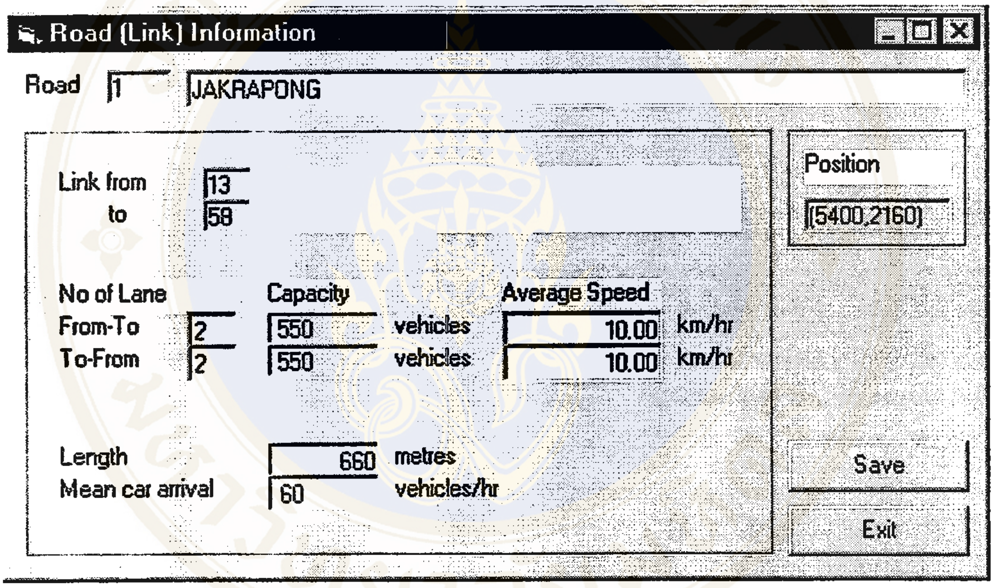
Number	ID	Junction name
1	78	PRACHATHIPATAI – PHRA SUMEN
2	11	RATCHADAMNOEN NOK – KRUNG KASEM
3	22	KRUNG KASEM – BAMRUNG MUANG
4	44	WORACHAK – BAMRUNG MUANG
5	70	MAHA CHAI – BAMRUNG MUANG
6	148	BAMRUNG MUANG – UNAKAN
7	26	NAKHON SAWAN – KRUNG KASEM
8	73	BAMRUNG MUANG – BORIPHAT
9	77	PRACHATHIPATAI – WISUT KASAT
10	32	CHAKKARAT DIPHONG – NAKHON SAWAN
11	79	RATCHADAMNOEN KLANG – TANAO
12	227	DEMOCRACY MONUMENT
13	37	KRUNG KASEM
14	9	RATCHADAMNOEN KLANG – PHRA SUMEN
15	10	LANLUANG – RATCHADAMNOEN NOK – NAKHON SAWAN
16	13	RATCHADAMNOEN KLANG – RATCHADAMNOEN NAI
17	144	NA PHRA LAN – LAK MUANG – SA NAM CHAI
18	147	BAMRUNG MUANG – TI THONG
19	177	TANAO – BAMRUNG MUANG
20	189	ATSADANG – BAMRUNG MUANG
21	58	SAMSEN – JAKRAPONG – PHRA SUMEN
22	59	SAMSEN – WISUT KASAT
23	160	BAMRUNG MUANG – YUKHOL 2
24	161	BAMRUNG MUANG – PHLAPPHLA CHAI

Table 6.9 Representative number for roads

Road number	Name	Link from	Link to
1	JAKRAPONG	13	58
2	RATCHADAMNOEN KLANG	13	79
3	SAMSEN	58	59
4	PHRA SUMEN	58	78
5	RATCHADAMNOEN KLANG	79	227
6	BAMRUNG MUANG	177	147
7	BAMRUNG MUANG	147	148
8	TI TONG	147	227
9	PRACHATIPPATAI	78	227
10	PRACHATIPPATAI	78	77
11	PHRA SUMEN	78	9
12	RATCHADAMNOEN KLANG	227	9
13	BAMRUNG MUANG	148	70
14	MAHA CHAI	70	9
15	BAMRUNG MUANG	70	73
16	BORIPAT	73	10
17	LAN LUANG	10	99
18	NAKHON SAWAN	10	32
19	SAPAN PAN PI POP LEE LA	9	10
20	LAN LUANG	99	37
21	NAKHON SAWAN	32	6
22	KRUNG KASEM	26	37
23	KRUNG KASEM	37	2
24	BAMRUNG MUANG	73	44
25	BAMRUNG MUANG	44	160
26	JAKRAPADIPONG	44	99
27	BAMRUNG MUANG	160	161
28	BAMRUNG MUANG	161	2
29	TANAO	177	79
30	WISUT KRASAT	59	77
31	JAKRAPADIPONG	32	99

Data for roads and its links (junctions) can be updated via the screen shown in Figure 6.2. The important information used for simulation processes are the number of lanes, and average speed for both from-to and to-from directions, length of the link and the mean car arrival (vehicle/hr). This information is used for calculating the delay time or time consumed by a car to pass through this link (road).

This screen is designed for future development of road plan of construction. Such as when a road is planned to increase the number of lanes or change to a one-way system. The capacity of a road is recalculated automatically by average car length, number of lanes and length of road.



Road 1 JAKRAPONG

Link from 13
to 58

Position
(5400,2160)

No of Lane		Capacity		Average Speed	
From-To	2	550	vehicles	10.00	km/hr
To-From	2	550	vehicles	10.00	km/hr

Length 660 metres
Mean car arrival 60 vehicles/hr

Figure 6.2 Road (Link) information screen

After identifying a node number to a junction and a link number to a road in the study area, the node-link network model can be formulated from the real-word system and shown in Figure 6.3.

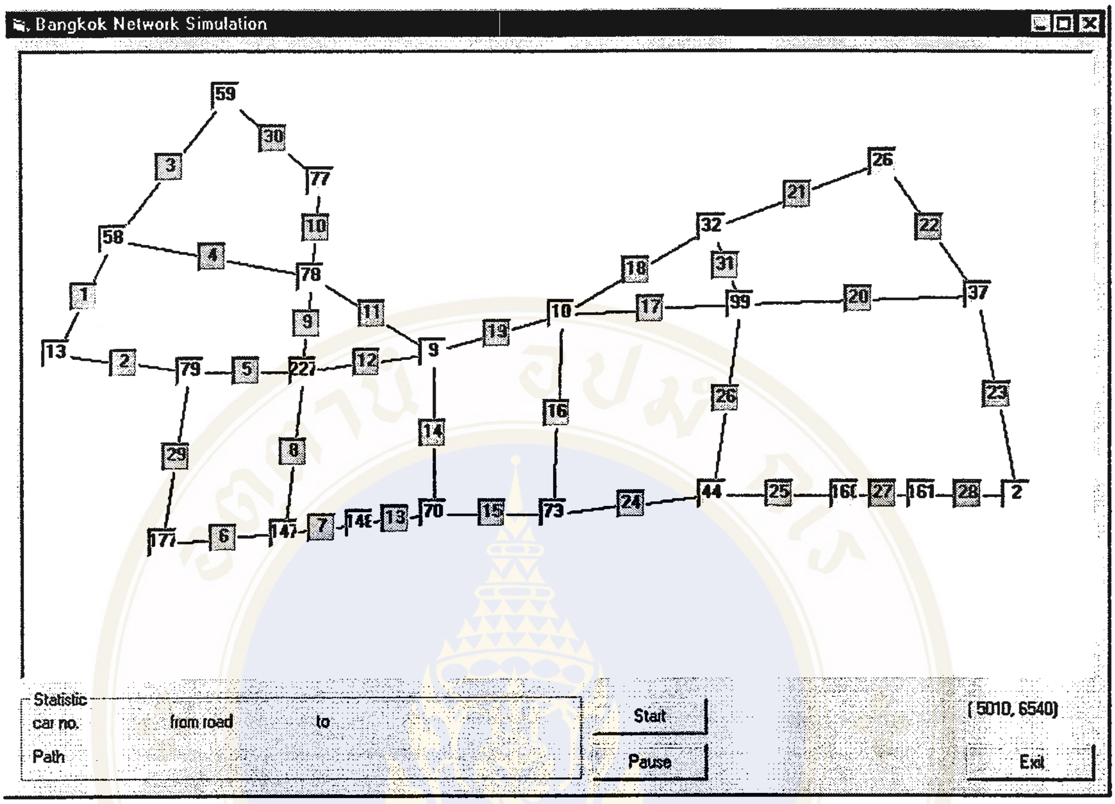


Figure 6.3 Node-link system transformed from map of Bangkok

The node-link model is the result of the first step of analysis and design. The next step is to analyze the traffic volume and characteristics of the traffic flow. Also the traffic flow control strategy. This is very important data for designing the control process and logic of the simulation program. In the next section we will describe how to realize this data for the simulation program.

6.5.1.2 Traffic volume and traffic flow

The statistical data of traffic volume in Bangkok is quite small. Generally, the officer has a work plan to observe and sampling (count) the traffic volume at a junction once a year. The different formats of traffic volume observation worksheets have been made several years in the past.

Figure 6.5 is one of the traffic volume observation worksheets. This figure shows the traffic volume on 12 December, 1997 at the junction number 78 – Sapan Wan Chat, located at the intersection of Prachatippatai, Dinsor and Phra Sumen roads. In this figure, we select only important information that was used for the simulation program.

Normally, the worksheet of traffic volume observations was designed to fit with the SCOOT plan operation manual of the ATC system. In this system, the traffic flow directions is separated into 4 main directions of flow per junction, named NB, EB, SB and WB according to the North, East, South and West accordingly. In these 4 main directions, they separated into 4 traffic flows each.

Counting from left to right as 1, 2, 3, 4 for NB, 5, 6, 7, 8 for EB, 9,10, 11, 12 for SB and 13, 14, 15, 16 for WB. Therefore at each junction, there are 16 traffic flow arrivals.

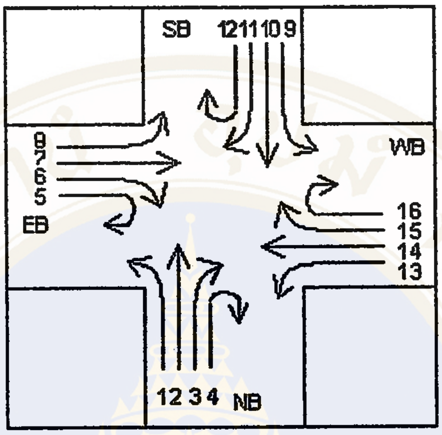


Figure 6.4 Traffic flows

Table 6.10 Example of traffic volume at junction worksheet, department of transportation, Bangkok metropolitan office

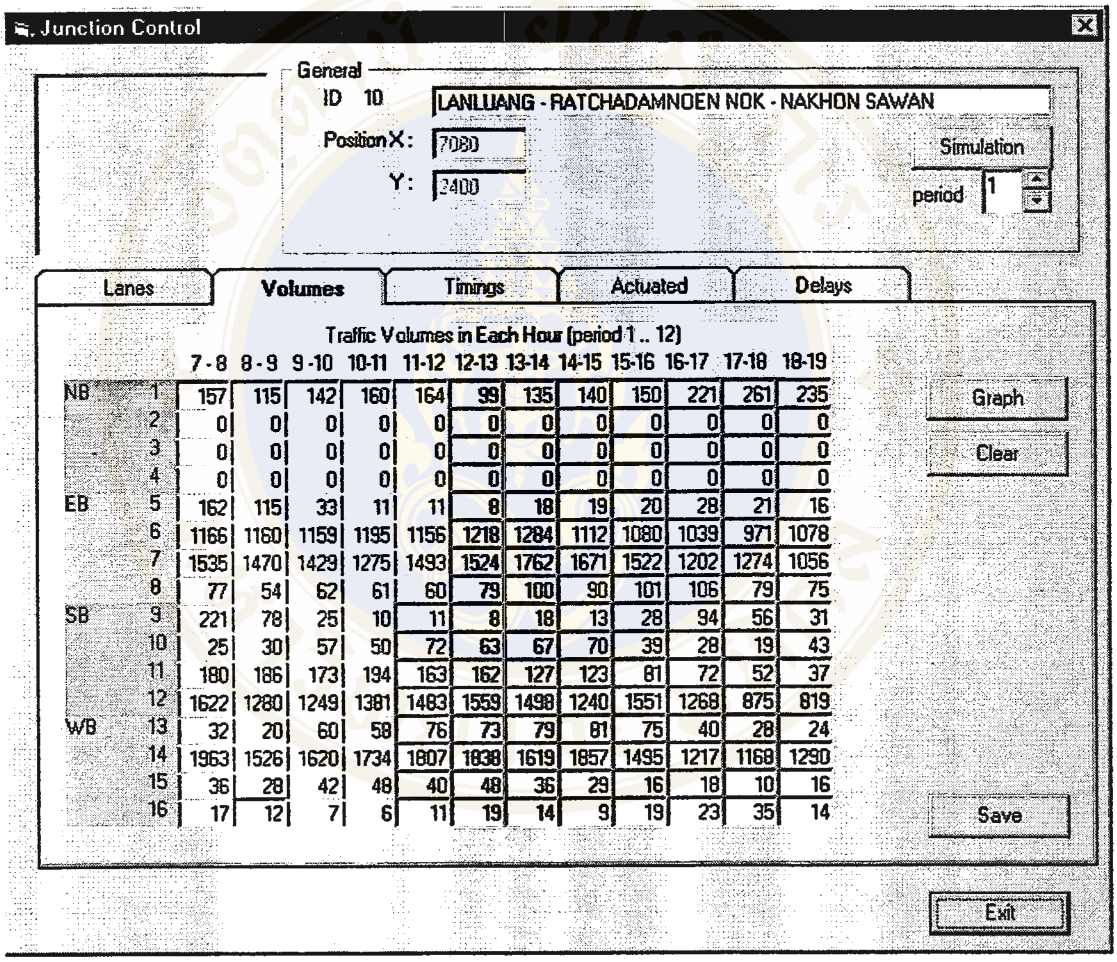
Traffic volume at junction (Year 1997)

Junction name Sapan Wan Chat

Road Prachatippatai-Dinsor-Pra Sumen **Junction No.** 78 **Date** 12 September 1997 **Weather status** Normal

Time		Traffic volume per hour (PCU/Hour) - Exclude motorcycle													PCU/ Hour	Volume	
Direction		07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	Total		Min	Max
NB	1	261	210	295	222	166	154	158	252	202	92	70	76	2158	203	70	295
	2	1040	1014	931	758	729	774	678	646	596	631	651	641	9089	784	596	1040
	3	47	63	56	72	68	75	83	67	68	96	90	84	859	71	47	96
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
In NB		1348	1287	1282	1052	963	1003	919	965	866	819	811	791	12106	1059	791	1348
Out NB		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
QL (meters)		-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50				
EB	5	894	805	826	819	788	890	542	657	669	504	453	419	8266	716	419	894
	6	472	466	432	461	455	448	606	602	657	719	705	774	6797	571	432	774
	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
In EB		1366	1271	1258	1280	1243	1338	1148	1259	1326	1223	1158	1193	15063	1287	1148	1366
Out EB		365	291	375	318	281	275	331	414	340	213	203	223	3629	348	203	414
QL (meters)		234	118	-50	54	51	54	47	48	41	55	96	35				
SB	9	90	62	46	59	60	49	23	20	50	38	58	43	598	75	20	90
	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11	38	35	21	18	32	33	22	19	11	8	11	9	257	39	8	38
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
In SB		128	97	67	77	92	82	45	39	61	46	69	52	855	115	39	128
Out SB		1995	1891	1850	1682	1630	1837	1312	1427	1355	1258	1217	1189	18643	1609	1189	1995
QL (meters)		-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50				
WB	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	14	66	46	59	78	83	88	151	143	127	113	122	138	1214	106	46	151
	15	61	72	93	105	113	173	92	124	90	123	113	129	1288	109	61	173
	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
In WB		127	118	152	183	196	261	243	267	217	236	235	267	2502	215	118	267
Out WB		609	591	534	592	589	572	712	689	775	853	853	891	8254	718	534	891
QL (meters)		-50	-50	-50	-50	-50	-50	0	0	0	0	0	0				

According to an information of travel volume at junctions, in this study uses the standard 16 traffic flows to implement the simulation program. The Figure 6.5 shows how the user can maintain and update the statistics of traffic volume into this system. This program is designed to allow the user to change these statistical data. Because, this information will used as a statistical base to generate car arrival into a junction when the simulation is running.



General
ID 10 LANLUANG - RATCHADAMNOEN NOK - NAKHON SAWAN
Position X: 7080
Y: 2400
period 1

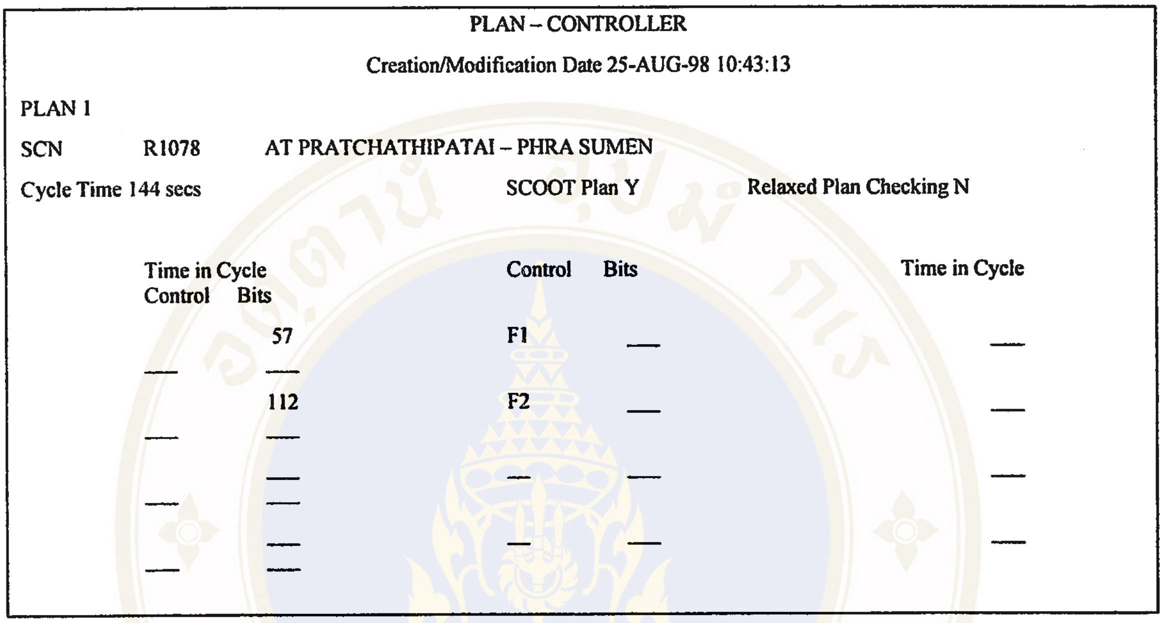
Traffic Volumes in Each Hour (period 1 .. 12)

		7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19
NB	1	157	115	142	160	164	99	135	140	150	221	261	235
	2	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0	0	0
EB	5	162	115	33	11	11	8	18	19	20	28	21	16
	6	1166	1160	1159	1195	1156	1218	1284	1112	1080	1039	971	1078
	7	1535	1470	1429	1275	1493	1524	1762	1671	1522	1202	1274	1056
	8	77	54	62	61	60	79	100	90	101	106	79	75
SB	9	221	78	25	10	11	8	18	13	28	94	56	31
	10	25	30	57	50	72	63	67	70	39	28	19	43
	11	180	186	173	194	163	162	127	123	81	72	52	37
	12	1622	1280	1249	1381	1483	1559	1498	1240	1551	1268	875	819
WB	13	32	20	60	58	76	73	79	81	75	40	28	24
	14	1963	1526	1620	1734	1807	1838	1619	1857	1495	1217	1168	1290
	15	36	28	42	48	40	48	36	29	16	18	10	16
	16	17	12	7	6	11	19	14	9	19	23	35	14

Figure 6.5 Junction information screen

6.5.1.3 Junction and Traffic Control

By interview with the operator of the SCOOT operation base in the Bangkok Metropolis Office, we found that the SCOOT and Bangkok ATC system were set up with a set of parameters called *plan*. Each plan is a group traffic light control system of the adjacent intersections that are linked together. For example in Figure 6.6 shows the Plan-Controller of junction Pratchathipatai-Phra Sumen. It shows that this junction was assigned to a SCOOT node, plan group R1 with node number 078, it has a fixed-time controller of 144 seconds per cycle. The first control called F1 is started at the 57th second and next control, F2 is started at 112nd second.



```
                                  PLAN – CONTROLLER
                    Creation/Modification Date 25-AUG-98 10:43:13
PLAN 1
SCN        R1078      AT PRATCHATHIPATAI – PHRA SUMEN
Cycle Time 144 secs                  SCOOT Plan Y          Relaxed Plan Checking N

          Time in Cycle              Control    Bits                    Time in Cycle
          Control   Bits
                     57              F1          __                          __
          __        __
                    112              F2          __                          __
          __        __
                    __               __          __                          __
          __        __
                    __               __          __                          __
          __        __
```

Figure 6.6 Example of Traffic control plan controller

There are controls F1 and F2 assigned to junction no. 78 shown in figure 6.8. The control description is written down in separated operation manual of the SCOOT operation called ………… In this manual, the description of control was drawn as a graphical model according to a NB, EB, SB and WB traffic flow diagram. In addition, the physical road and junction layout sketch founded in this manual can be use for comparison with the traffic flow diagram. The information of control of this junction is shown in figure 6.7.

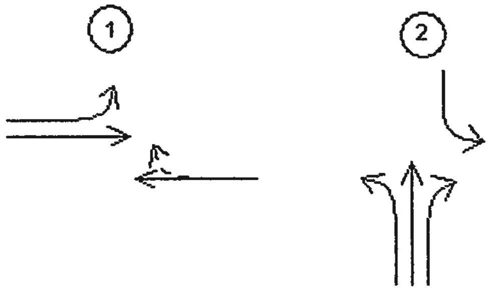
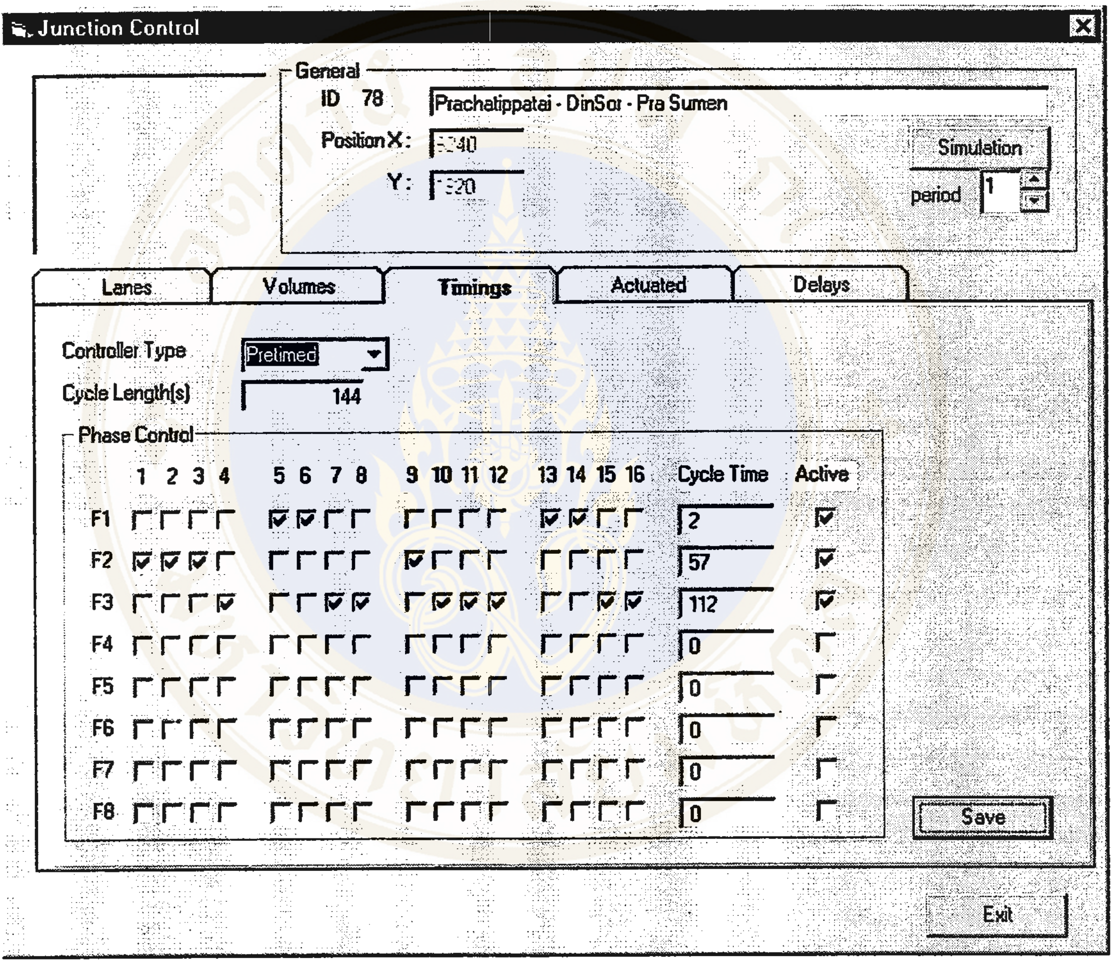


Figure 6.7 Example of control description found in SCOOT operation manual

By combination of these two sources of information, in this study the simulation program use a fixed-time base as a simulation clock run-time strategy. The control F1 and F2 in this example will be called Phase in the simulation program. The simulation program allows the user to change the setting of the time cycle and phase control differently from the SCOOT plan to see how to optimize the queue length and utilize the traffic flow.



General

ID 78 Prachatippatai - DinSor - Pra Sumen

Position X: 5240

Y: 1320

period 1

Controller Type: Pretimed

Cycle Length(s): 144

Phase Control

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Cycle Time	Active
F1	□	□	□	□	☑	☑	□	□	□	□	□	□	☑	☑	□	□	2	☑
F2	☑	☑	☑	□	□	□	□	□	☑	□	□	□	□	□	□	□	57	☑
F3	□	□	□	☑	□	□	☑	☑	□	☑	☑	☑	□	□	☑	☑	112	☑
F4	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	0	□
F5	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	0	□
F6	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	0	□
F7	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	0	□
F8	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	0	□

Figure 6.8 Traffic light control screen

6.5.2 Single Junction Simulation

Single junction simulation uses information of traffic volume in a time period as base data to calculate the mean car arrival and also predict the direction of car arrival in each traffic flow direction by calculating the accumulate probability of car arrival. Meanwhile, we can use the random mechanism of any programming language to generate the car arrival into an appropriate direction base on the accumulated probability of car arrival in each direction. And use the SCOOT plan traffic control as a base unit of time of fixed-time interval. We can assign the status of idle or service to the service facility. In this study, the service facility is the traffic light control. They can be the status of GREEN, RED and YELLOW. But in the simulation model we can simplify the traffic light status only as pass or not. That means the traffic light can be modeled as a facility that has 2 states, one is GREEN as service, another is RED as idle. The timer is the control object that is suitable for controlling the relative clock, by a set time cycle equal to the mean car arrival to generate one car into the system. And another timer to control the traffic signal with fixed-time interval of the SCOOT plan.

6.5.2.1 Model and Characteristics

Queuing model, in this study a single-server queue was applied to represent an event of service queue in each traffic flow direction. Therefore, in a single junction simulation, there are 16 single servers (facilities) for service of an arrival car. They have 2 states, green light equivalent to busy state and red light equivalent to idle state.

Car arrival and mean car arrival, in this study the traffic volume of traffic flow direction can be used for calculate the mean car arrival (PCU/hr) and also calculate the accumulated probability of car arrival into the junction from each direction.

For example, in the case of junction no. 78 (Prachatippatai - DinSor - Phra Sumen), the traffic volume statistics of the period 07-08 can used for calculating mean car arrival and accumulated probabilities by

Let V_i = Traffic volume in direction i in period 07-08

Mean car arrival $= 3600 / \sum_{i=1}^{16} V_i$ second / vehicle

$= 0.824722$

The accumulated probabilities of each traffic flow direction can be calculated by following table

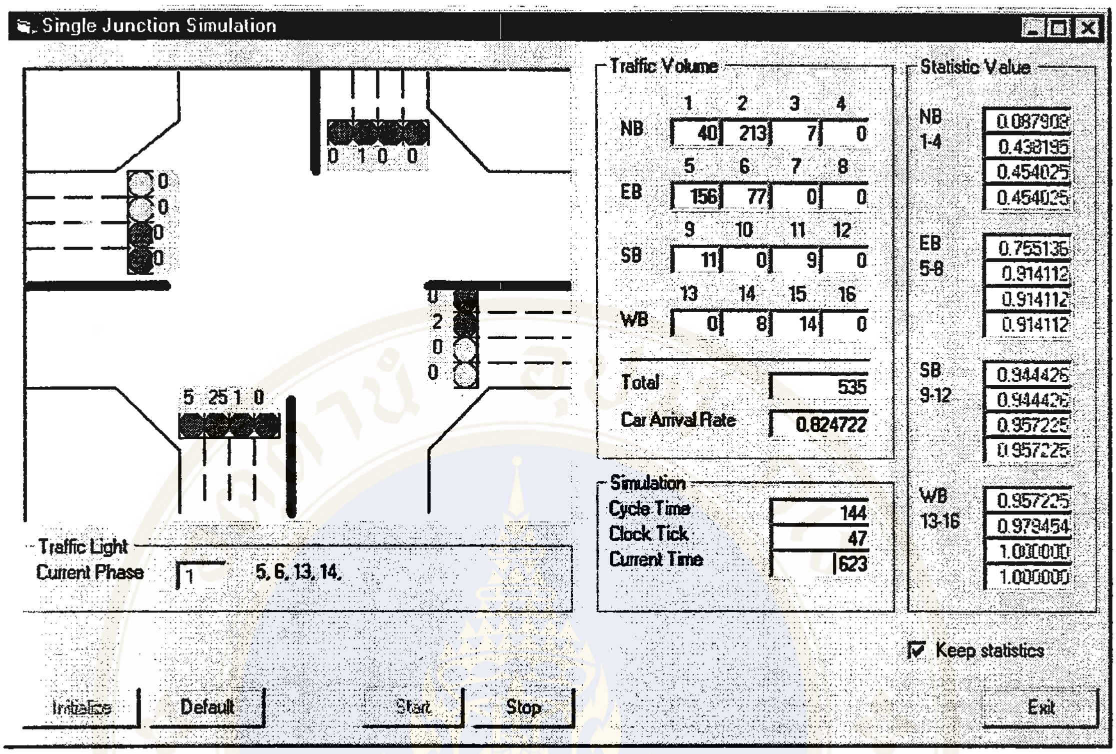
Table 6.11 Calculation of accumulated probabilities

Traffic flow direction	Volume	Accumulated volume	Accumulated probability	
1	V_1	V1	V_1/V_n	0.087908
2	V_2	V1+V2	$(V_1+V_2)/V_n$	0.438195
…	…		…	…
16	V_{16}	$\sum_{i=1}^{16} V_i$	$\sum_{i=1}^{16} V_i / V_n$	1.000000
TOTAL	$V_n = \sum_{i=1}^{16} V_i$			

6.5.2.2 Simulation run

This simulation program can simulate the traffic conditions within each hour, for example 07-08 based on the traffic volume statistics. In the traffic volume maintenance screen, the user has to select a period (1 to 12) that will tell the simulation program to select the correct set of traffic volume data to calculate the mean car arrival and accumulated probabilities. After selecting the period to be simulated, then click on Simulate button and the program will show the "Single Simulation" screen as shown in Figure 6.9.

In this screen, the main part is the map that shows 16 traffic flow directions. With the simulation program running, the number of cars and the length of the queue in each traffic flow direction are show on the traffic volume panel and the stop line respectively. If a user selects "keep statistics" check-box, the program automatically generates a log file containing this information every second until the user stops the simulation. The current phase (traffic control) always shows under the map with the green light traffic flow direction.



Single Junction Simulation

Traffic Volume

	1	2	3	4
NB	40	213	7	0
	5	6	7	8
EB	156	77	0	0
	9	10	11	12
SB	11	0	9	0
	13	14	15	16
WB	0	8	14	0

Total 535

Car Arrival Rate 0.824722

Simulation

Cycle Time 144

Clock Tick 47

Current Time 623

Statistic Value

NB 1-4	0.087908 0.438195 0.454025 0.454025
EB 5-8	0.755136 0.914112 0.914112 0.914112
SB 9-12	0.944426 0.944426 0.957225 0.957225
WB 13-16	0.957225 0.979454 1.000000 1.000000

☑ Keep statistics

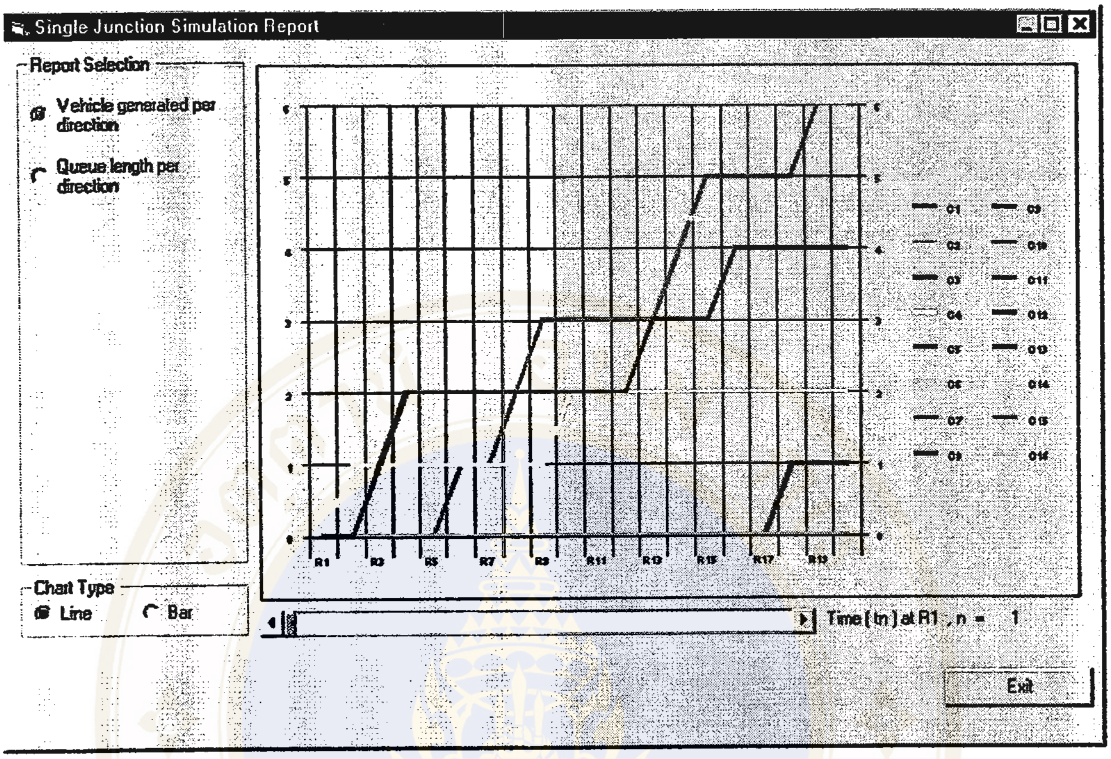
Traffic Light

Current Phase 1 5, 6, 13, 14,

Figure 6.9 Single simulation screen

6.5.2.3 Results

While running the simulation program with option "Keep statistics", the program creates the report file that is input for the reporting module. The report can be show in graphics. They is the report of vehicles generated per direction as shown in Figure 6.10 and the report of queue length per direction in Figure 6.11. Both of these reports can be displayed in line graphs and bar graphs. The number of cars generated and a queue length is shown on the Y-axis. Its horizontal scroll bar can be used to scroll along from t_0 to t_n of the simulation time along the X-axis. All of traffic flow directions in the junction show up as a series on the X-axis and labeled on the right side of the graph with different colors.



Single Junction Simulation Report

Report Selection

● Vehicle generated per direction

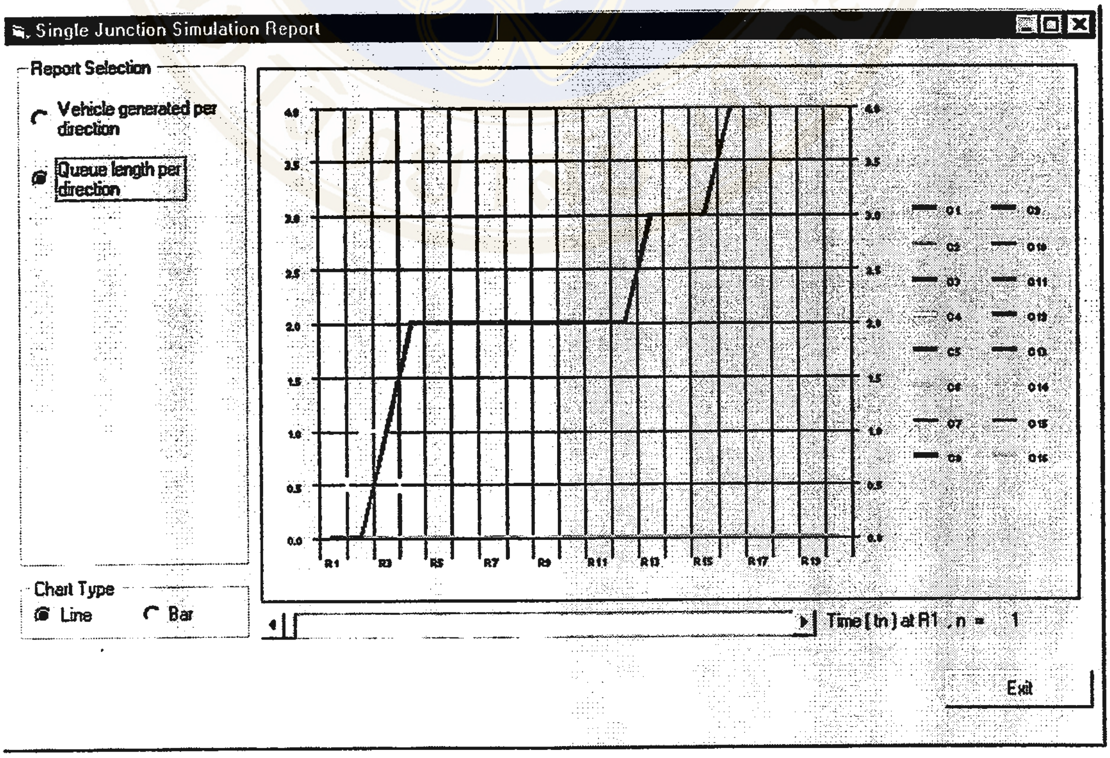
○ Queue length per direction

Chart Type

● Line ○ Bar

Time (tn) at R1 , n = 1

Figure 6.10 vehicle generated per direction



Single Junction Simulation Report

Report Selection

○ Vehicle generated per direction

● Queue length per direction

Chart Type

● Line ○ Bar

Time (tn) at R1 , n = 1

Figure 6.11 queue length per direction

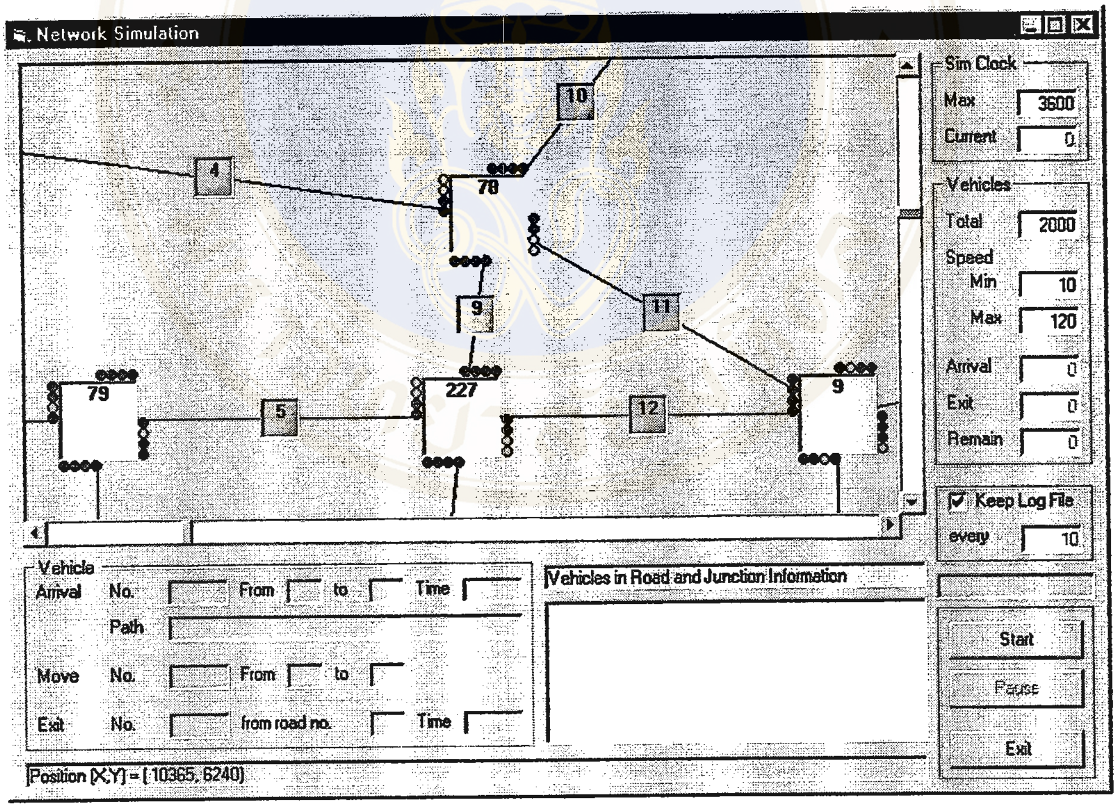
6.5.3 Network Simulation

Single junction simulation provides us with a queue length that represents the volume of the cars waiting at each direction. This information can be used to improve the traffic management in each junction efficiently.

Since the junction is, in fact, connected by roads and the cars always move from one junction to another, the single junction simulation can no longer represent the real-world of traffic. Junctions are not independent, which is why we need the network simulation. In the network simulation, we need to have another new entity that can represent the connection (link) between junction. That is the road node.

6.5.3.1 Model and Characteristics

6.5.3.1.1 Road and Junction Network



Sim Clock
Max 3600
Current 0

Vehicles
Total 2000
Speed
Min 10
Max 120
Arrival 0
Exit 0
Remain 0

☑ Keep Log File
every 10

Position (X,Y) = (10365, 6240)

Figure 6.12 Represents a logical network system simulated from the real-world traffic system

In the logical traffic network, there are two main different nodes:

1) ROAD node will manage the cars that pass along it. This includes the cars that first come into the system, move from one junction, move to another junction and exit the system.

2) JUNCTION node in network, this node is similar to the one in the single junction simulation. It will manage the queue of cars in each direction depending on traffic light control.

6.5.3.1.2 Car's Event and Status in Network

To make the road node and junction node know how to manage the cars that come into the system, we have to define the status of the cars. In the system, there are 6 different statuses assigned to the cars in the network according to its event and life time :-

START : All the car first coming into the network are assigned to this status according to start event.

ARR_ROAD : After START, all the cars coming onto the road are assigned to this status. It represents that a car is arriving to the road.

RUNNING : After the cars come onto the road, the system will calculate the time spent to arrive at the junction based on speed and length of the road. While the cars are moving to the junction, their status are "RUNNING".

ARR_JUNC : At the time that the cars arrive at the junction, the status will be changed to "ARR_JUNC".

WAIT : When the cars arrive at the junction and the traffic light of its traffic flow direction is "RED", the status will be changed from "ARR_JUNC" to "WAIT".

Note that, if the traffic light of the traffic flow direction is "GREEN", the status will be changed from "ARR_JUNC" to "ARR_ROAD" immediately. It is the status of the next road node to be approached.

STOP: When the cars reach their destination roads, the status is set to "STOP".

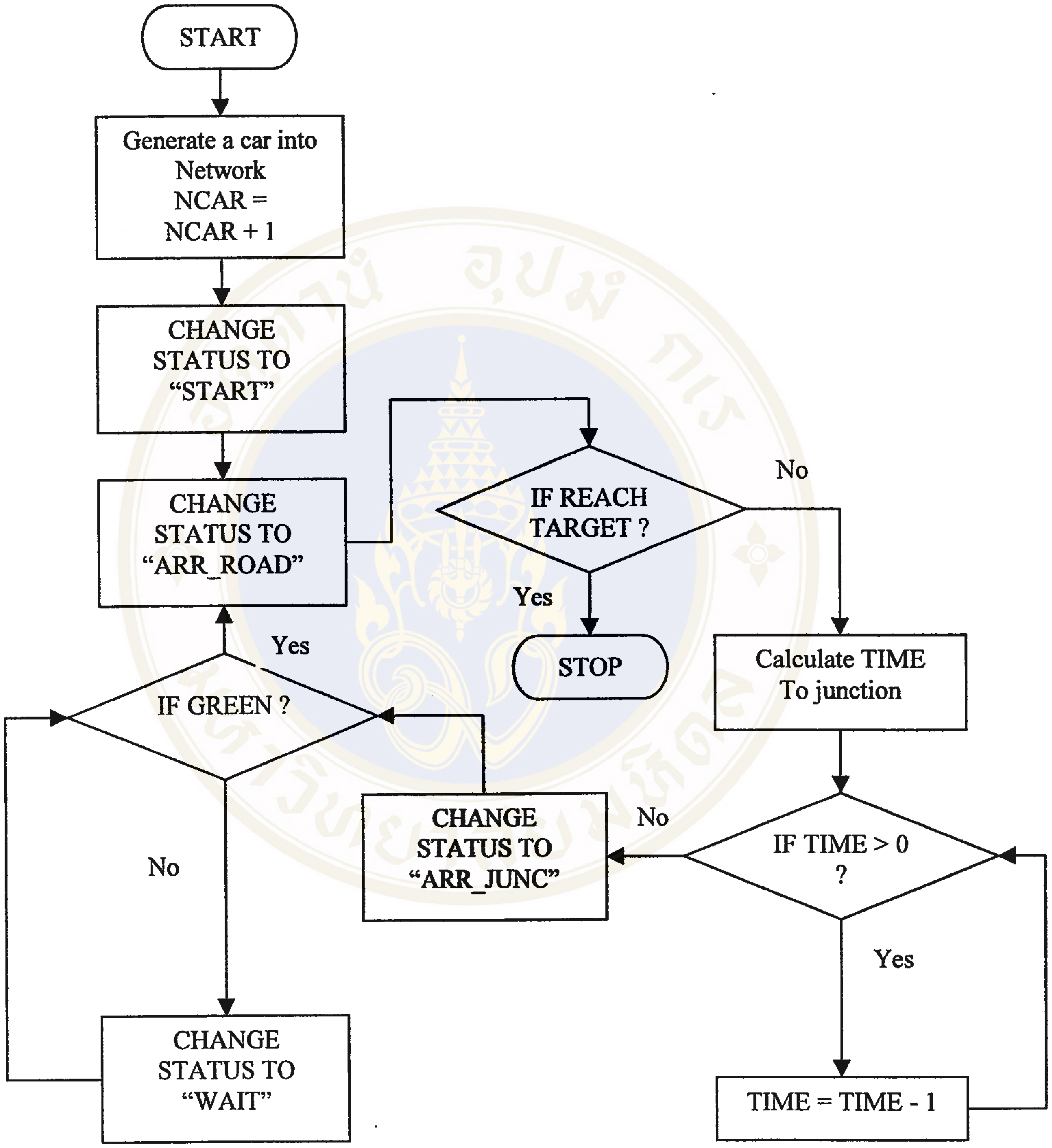


Figure 16.13 Status and Event of car in network

6.5.3.1.3 Simulation Clock and Event Control

In this study, the time interval control designed to use 4 processes work in parallel. There are 4 control processes :-

Car Generator : This process generates one arrival car into a network every cycle of mean car arrival time. The rate can be calculated from the amount of traffic volume.

Traffic Light Control : This process reads the data of the traffic light control phase plan for all junctions and updates the network every 1 second.

Car Status Update Control: This process analyzes all cars in the network, both at the junctions and on the roads. It determines the status of each car and decide to move the car through a link in the network and change its status. This process is the most important and takes a lot of processor time. Sometimes, asynchronous simulation the clock happens in this routine.

Simulation Clock Tick : This process is the reference of the relative simulation clock. Another process and control has to synchronize the time reference here.

6.5.3.2 Network Simulation Run

6.5.3.2.1 Initialization

Figure 16.12 shows the initial screen of the Network Simulation. This screen was designed to show information in a separated area. The largest area shown is the logical node-link system. Because the node-link system can not fit with a standard screen, providing both horizontal and vertical scroll bars allows a user to move through the network while the simulation is running, and monitor what is going on in the network. Below the monitor screen, the block of vehicle information shows the car arriving into the network with information of car number (ID), road number that the car is entering, road number to exit from network, time that the car is arriving and its path through the network. On the right hand side, the user can specify the simulation clock (cycle), the total number of cars to be generated into the network, the speed of a car in terms of maximum speed, minimum speed and average speed. The next down block provides the check-box to specify whether the user needs to keep a log file for reporting or not. In the right-bottom, there are 3 control buttons, START, PAUSE and EXIT button. Between the Vehicle block and control button block, the "Vehicles in Road and Junction Information" show the status and information of cars in the specific road or junction selected while the simulation is running.

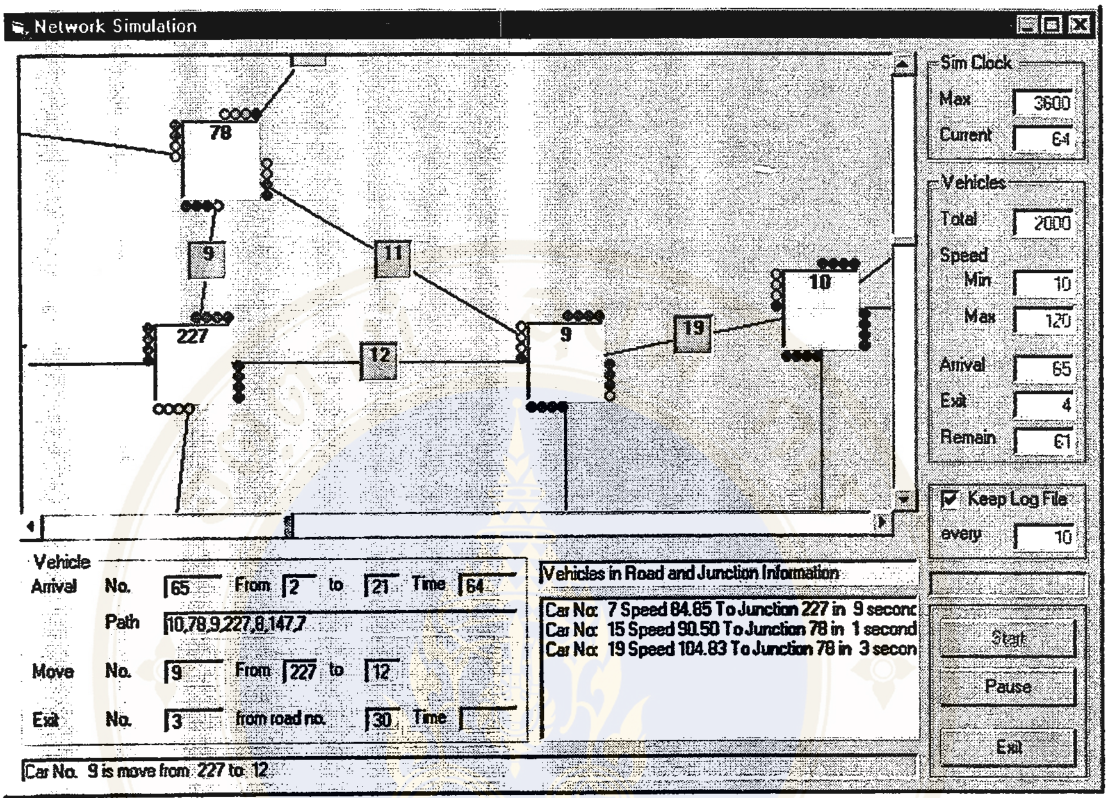
6.5.3.2.2 Simulation Run

After the network simulation has been started, the control processes are enabled. The initial values are used to calculate and determine the behavior of cars in the network and are displayed on the graphics monitor.

Firstly, the car will generate into various starting roads, its path (route to move through the network), average speed and its destination. First status assigned is “START” (car is generated into network). In the second, the car status will change to “ARR_ROAD” (arrive to road) with calculated of time to be spent in the starting road to go to the junction. Secondly, this car’s status will be changed to “RUNNING” (car is running) and the time to the next junction will decrease to zero every second depending on the Simulation Clock Tick control process. After the time to the next junction reaches zero, that means this car is already moving to the stop-line of the next junction, the system will change its status to “ARR_JUNC” (arrive to junction). Then we check against the traffic light that is “GREEN” or “RED” to determine the next status as “WAIT” or “ARR_ROAD”. Time to time, the status is changed between “ARR_ROAD”, “RUNNING”, “WAIT” and “ARR_JUNC”. Until it reaches its destination road, when the status will change to “STOP”. Figure 6.14 shows that there are 3 cars in road number 9, the cars ID are 7,15 and 19, its average speed is 84.85, 90.50 and 104.83 Km/hr and they will reach junction 227, 78 and 78 in 9, 1 and 3 seconds respectively. Figure 6.15 shows that, at junction 147 there are 6 cars assigned their status as “WAIT”. Four of them are waiting for a green light for traffic flow direction no. 15 (move from road no. 7 to road no. 8). The other two cars are waiting for a green light for traffic flow direction no. 7. (move from road no. 6 to road no. 7). The other important information such as the number of car arrival, number of cars already exited from network and the number of cars remaining are shown on the right-hand side. A new car arriving into the network always shows on the block below the graphic monitor.

6.5.3.3 Result

The result from network simulation is the queue length of each junction. The report is designed to display a graphic diagram in the same way as the single junction simulation. This result is more realistic than a single junction simulation. This is because we also take the cars from adjacent junctions into consideration while single simulation uses the statistics of traffic volume to generate the cars arriving at a junction. Moreover, the time that the car has to spend to travel to the next junction is also calculated. This is to make the information about the frequency of the cars that arrive at the junction more realistic.



Sim Clock
Max 3600
Current 64

Vehicles
Total 2000
Speed
Min 10
Max 120
Arrival 65
Exit 4
Remain 61

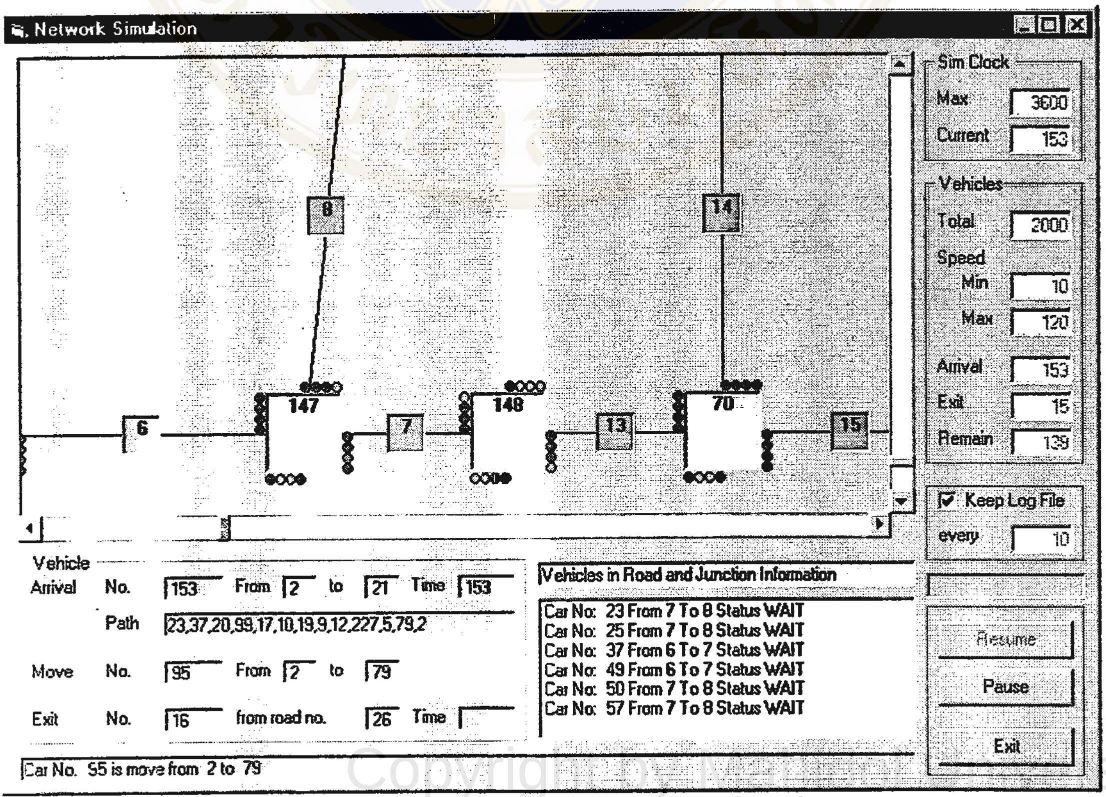
☑ Keep Log File
every 10

Vehicle
Arrival No. 65 From 2 to 21 Time 64
Path 10,78,9,227,8,147,7
Move No. 9 From 227 to 12
Exit No. 3 from road no. 30 Time

Vehicles in Road and Junction Information
Car No: 7 Speed 84.85 To Junction 227 in 9 seconc
Car No: 15 Speed 90.50 To Junction 78 in 1 second
Car No: 19 Speed 104.83 To Junction 78 in 3 secon

Car No. 9 is move from 227 to 12

Figure 6.14 Information of car's status and properties in road



Sim Clock
Max 3600
Current 153

Vehicles
Total 2000
Speed
Min 10
Max 120
Arrival 153
Exit 15
Remain 139

☑ Keep Log File
every 10

Vehicle
Arrival No. 153 From 2 to 21 Time 153
Path 23,37,20,99,17,10,19,9,12,227,5,79,2
Move No. 95 From 2 to 79
Exit No. 16 from road no. 26 Time

Vehicles in Road and Junction Information
Car No: 23 From 7 To 8 Status WAIT
Car No: 25 From 7 To 8 Status WAIT
Car No: 37 From 6 To 7 Status WAIT
Car No: 49 From 6 To 7 Status WAIT
Car No: 50 From 7 To 8 Status WAIT
Car No: 57 From 7 To 8 Status WAIT

Car No. 55 is move from 2 to 79

Figure 6.15 Information of car's status and properties in junction

CHAPTER VII

DISCUSSION

7.1 PORTAGE TO A LARGE MACHINE

This simulation program is developed on a PC platform. This causes a limitation on the memory to be allocated for basic data (roads and junctions) and processing such as the process of generating the vehicles into the network. If we want to study in a wider area of traffic, we surely need more memory to store new entities or new types of junctions and roads, vehicle properties, log reports and also statistics report. A large machine has to be taken into consideration to make the study more realistic and practical.

A large machine can provide not only more memory, but also a better performance of the simulation program. On a larger machine, the program can be processed faster, even a complex program. We can say that the PC feature scopes down the study area. We cannot implement more complex logic to be processed in time.

In the real situation, the traffic light control in each junction has to be processed independently. This means that the traffic light status in each junction can be changed to a proper status without having to wait for others to finish the process. But due to the fact that a small computer like a PC has only one processor, the instruction is processed sequentially. We, therefore, cannot have a real parallel process in a single processor like a PC. To improve the capability of the system performance, a multi-processor machine is one possibility. The multi-processor machine can provide parallel processes, as we need them.

To have the simulation program work in a multi-processor machine properly, the points to be aware of are:

Process organizations : we need to organize which process has to be run in parallel and which process has to be run sequentially.

Process scheduling : all of these processes have to be scheduled properly in order to make all of processes synchronized.

7.2 NETWORK FLEXIBILITY

In order to utilize a simulation program, the network flexibility has to be considered. This is already provided in this study with a network definition file. This file was designed as a text-file for simple editing by text editor tools. In this file, a user can define a junction, its location (coordinate (x, y) of a graphic screen), and its links (roads). Currently, if a user needed to use this simulation program to analyze a wider area, he has to maintain this file manually, by adding new lines for junction definitions and road definitions.

For advanced improvement, we can study and adapt a more complicated technique called *pattern recognition*. By this technique, we can make a simulation program more flexible. If we are successful in implementing this technique, the program itself can recognize the junctions and roads from a geographic map. The node-link network can be transformed immediately after pattern recognition has been executed, only some details need to be adjusted.

7.3 OPTIMIZATION

An optimization is one topic that should be considered in a study. Some traffic control systems have an optimizer, which is the most important component. This optimizer has several basic strategies, concepts and theories. Some of them use the cost basis. In this group, the fuel, cost of travelling, time spent in a network are the factors for the optimizing tool. Another optimizer may take data detected from vehicle movement as basic data to optimize a relative time-cycle of each traffic light control at junctions. The basis idea of this type has its purpose to make a shortest queue in the traffic network.

Most area traffic control systems have their own optimizer, the difference is a frequency of update and tune up parameters to the overall system. An on-line system optimization may be a future trend for development.

In this way, the raw data gathered by a physical detector installed in roads and at junctions can provide a current status of traffic flow. The statistics seem obsolete and cannot compare with current data detected. Information, such as speed of vehicles and mean car arrival time will be transferred to an optimization tool via several media. A number of advance technologies such as Internet, Gateway, High-Speed Modem can be used as an alternative for online-transaction.

7.4 TRIP ASSIGNMENT

The trip assignment is a common part of a traffic simulation system. Most of them have a routine to generate a travelling trip based on the population, usage of land, residential, commercial and industrial areas. This basic idea to create a trip assignment is powerful if we can clarify that trips that are generated are realistic with a reasonable distribution.

In general, the travelling trip of a vehicle in Bangkok is in different directions for over a whole day. In the morning, most of a travelling trip is on the in-bound direction. That is the trip form home to office. On the other hand, in the evening, most of them turn in the reverse direction. The travelling trip is changed to, from office to home. If we use the concept of trip generation which depends on usage of area, we always get a travelling trip from home to office every period of time for a whole day.

Due to the increasing of population in Bangkok, we also make a number of travelling trips increment. More complex behaviors of travelling trips may be considered in a further study. For example, the family that has a child has to add more nodes to pass along the route between home and the child's school instead of a directed route between home and office.

Currently in Bangkok, the express way is the alternative for travelling trips in the rush hour. But, not all drivers in an area that has an express way exit takes this route for travel. The statistics of average vehicles that take the express way route should be researched as a first step. Then the assignment of jump relationships between road-express way-road has to be implemented in a further study. The queue length and obstacles of a long queue on a main road have to be considered.

7.5 TRAFFIC FLOW CHARACTERISTICS

7.5.1 Traffic Circle

The traffic circle is a normal operation that can be found in a big city. This type of traffic flow frequency is used for intersection that has more than two roads crossing. A traffic circle is a complex system to study in a same traffic simulation network with X intersections. The traffic flow in the circle is difficult to predict.

However, to simplify a traffic circle, we can split it into a sub node-link system by T-intersection and directed flow.

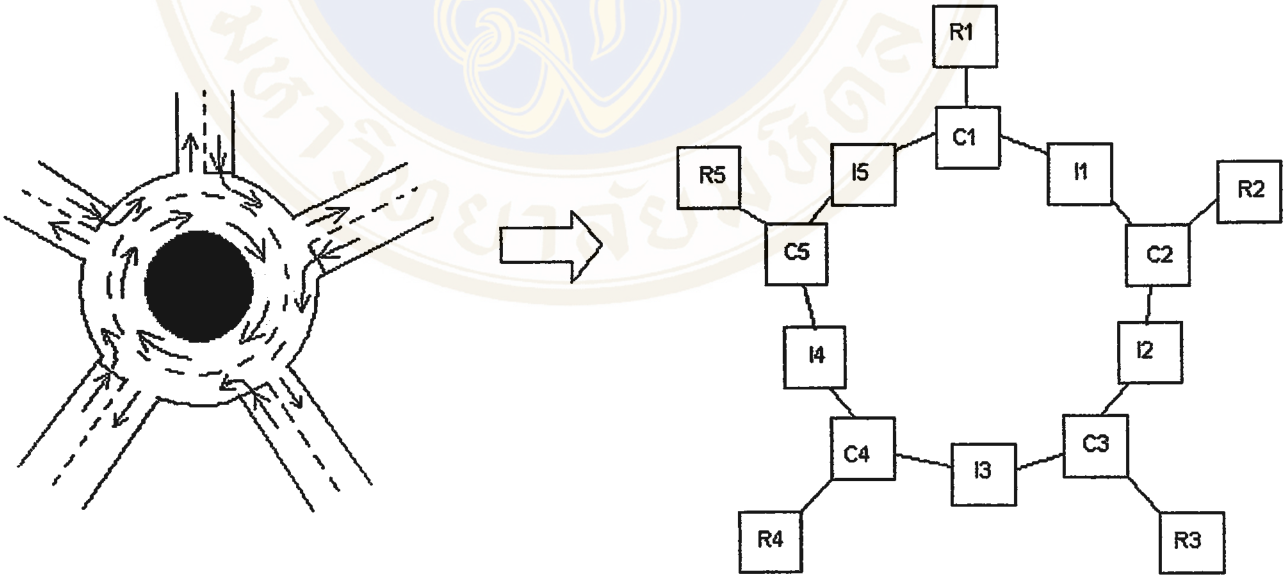


Figure 7.1 simplification of traffic circle operation

In Figure 7.1, a simplification of a traffic circle makes 5 T-intersections C1, C2, C3, C4 and C5 and separated sub-links between T-intersections in inner flow as I1, I2, I3, I4 and I5.

In advance, a further study should consider the queue at a T-intersection and how the accumulated queue in the inner traffic circle flow should be managed. Normally, a small traffic circle has no traffic light control at a T-intersection (entrance to inner flow of traffic circle). The study could describe how the traffic light installed at a T-intersection can optimize a queue length in the inner traffic circle flow as appropriate. A long green light will cause overflow in the inner traffic circle and a long red light will produce long queue lengths of vehicles that want to enter into a traffic circle.

7.5.2 U-Turning

As with a traffic circle, a U-turning operation is a normal operation in a traffic flow. Especially, the long-length roads in the network always provide a number of U-turns. U-turning is one cause of interrupted flow. This effects the overall speed on the road. Not only the vehicles in different directions are interrupted, but also, if the queue of vehicles waiting for a U-turn is accumulated more than a capacity that is designed for a special lane, the same direction flow is also interrupted. To simplify this operation, we may be able to split the road node into sub-links as in figure 7.2.

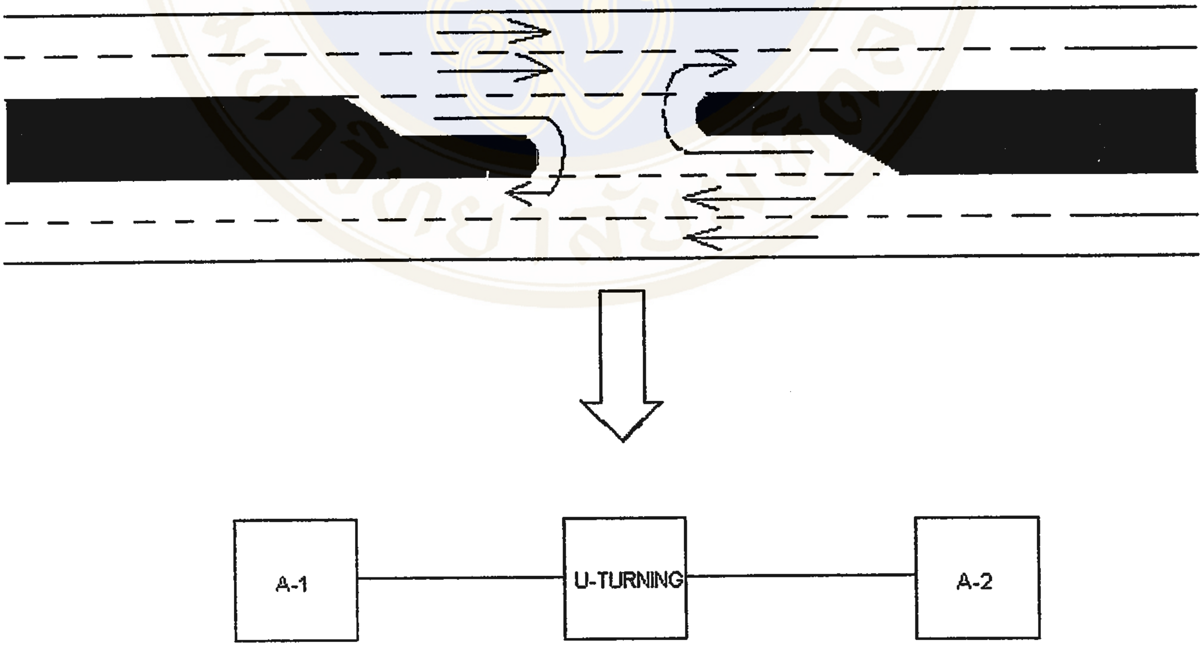


Figure 7.2 Simplification of U-turning operation

For further study, the control process of U-turning should be described in terms of how the queue is accumulated. Normally, U-turning has no traffic light control, the study should consider the queue that occurs at U-turn that has a traffic light installed compared to the U-turn that has not.

CHAPTER VIII

CONCLUSION

8.1 TRAFFIC SYSTEM AN D MODEL

A traffic system is the one real-world system that has its own behavior and conditions. In this study, an understanding of various topics must be involved. The main topics are system modeling, traffic flow conditions and characteristics, queue theory and simulation technique.

System modeling describes the methodology and techniques to simplify the problem of the real-world system into scientific methodology. In this study, we are concerned with the simulation technique. The transformation of a physical system (real-world system) of roads and junctions to a node-link (network) system is an example.

Traffic flow conditions and characteristics are described as a mathematical model. This mathematical model is constructed with many variables representing each condition. Such as the relationship between vehicle speed, length of road, number of lanes and time spent to pass through the road.

Queue theory describes how to manage an arrival entity that passes through the service queue. Many systems are defined in queue theory. The best that fits the problem is the single-server queue system as used in this study.

8.2 TRAFFIC INFORMATION

In this study, the traffic simulation program is developed based on an information from various sources of government agency.

Information that is collected and used in this study included:-

Population indicates how large the amount of vehicles should be tested. To make sure that the program can handle a real world condition, the program has to be designed to have enough capacity to handle a number of cars that is calculated from the population and rate of car's owner in a study area.

Traffic Volume at Junction is a useful statistic to generate the arrival cars into a single junction simulation. By using statistics and an accumulated probability technique, we can generate car with appropriate directions (1 to 16).

Traffic Flow Control Phase Plan is defined for the ATC system that is now used in some areas of Bangkok

ATC system is the template system and provides some basic idea to design the processes and routines that need to be used.

8.3 RESULTS

The traffic system simulation program is the result of this study. It has two main simulation processes. One is the single junction simulation, another is the network simulation.

The single junction simulation is designed to use the statistics of traffic volume and traffic light control phase plan as its input and condition to handle the simulation run. By the simulation technique, the car arrivals have been generated to the simulation traffic flow as well based on the accumulative probabilities. The graphical display shows the status of traffic lights in color, red and green. The movement of cars at a single junction is also shown at simulation run-time.

The network simulation is designed to use characteristics of cars in the network to calculate the relative time against the simulation clock. The event and status management has been defined. This status can be used to determine how to handle the cars on the road and at junctions by control processes.

This program provides other functionality to update or re-define the traffic light control phase plan and update traffic volume, because the simulation run will provide more realistic results if the statistics and conditions are up to date.

8.4 RECOMMENDATIONS

1) In this study for the program model, the queue at the stop line is a vertical queue, that is it can not represent a real-world system. We should use a horizontal queue instead for a more realistic model.

2) The speed of cars in the network simulation may be reduced or increased by use of other variables to be considered. Such as, road maintenance status - road is clear or under construction, different type of vehicles – bus or private car, type of engine – time to accelerate speed, number of years after register.

3) The trip assignment (path) does not cover all travelling routes, different directions of trips in the morning (to work) and in the evening (back home) should be considered.

4) By the reporting functionality, queue length is the most important information. All of them can be used by the decision maker, who has authorization to tune-up the parameter of the ATC system. The optimization of parameters such as cycle time of each junction, time for green lights can be made to test for minimization of a queue length.

5) In the case when the whole system of ATC is running in Bangkok, and the detector at a junction has been installed, we can use this realistic information as an input and condition for advanced development. Optimizing tools should be studied from the on-line update from the physical count of traffic volume via the detector.

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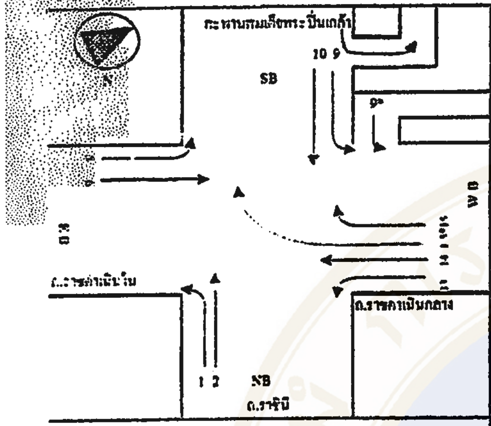
APPENDIX A

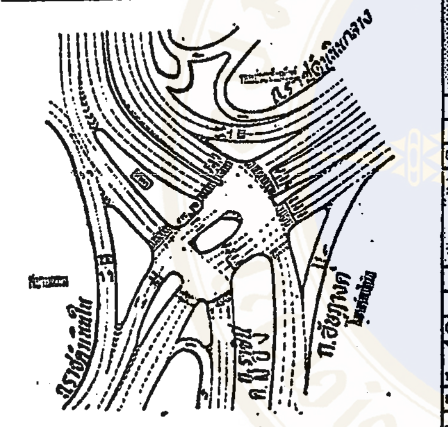
TRAFFIC VOLUME AT JUNCTION

ข้อมูลปริมาณการจราจรบริเวณทางแยก (ปี 2540)

ชื่อทางแยก ผ่านพิภพลีลา

ถนน ราชดำเนินกลาง-ราชดำเนินใน-ราชินี หมายเลข 13 วันที่ 13 มิถุนายน 2540 ปกติ





ผลิตและข้อมูล ฝ่ายการจราจรและวิศวกรรม
โดยกอง สำนักการจราจรและขนส่ง

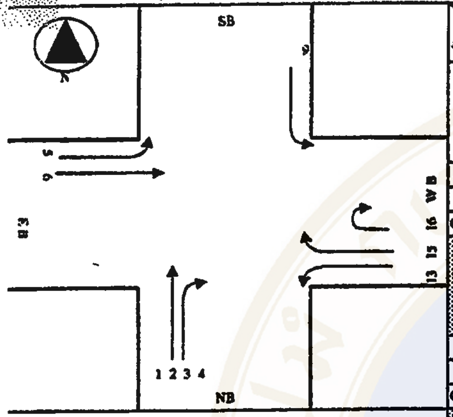
ทิศทาง		07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	รวม	เฉลี่ย ชม.	ปริมาณ รถ ต่ำสุด	ปริมาณ รถ สูงสุด
NB	1	16	11	42	45	35	50	35	32	24	34	13	15	352	29	11	50
	2	166	193	164	201	172	188	150	146	201	231	186	141	2139	178	141	231
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า NB		182	204	206	246	207	238	185	178	225	265	199	156	2491	206	156	265
ออก NB		111	157	191	297	342	337	298	253	261	191	219	126	2773	1406	111	342
QL (เมตร)		294	274	175	102	95	78	83	89	164	91	157	74				
EB	5	1021	1061	1100	1402	1415	1371	1494	1492	1503	1466	1228	1194	15747	1451	1021	1503
	6	387	401	543	742	787	710	690	689	718	656	306	158	6787	666	158	787
	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า EB		1408	1462	1643	2144	2202	2081	2184	2181	2221	2122	1534	1353	22534	2117	1352	2221
ออก EB		382	495	552	513	598	544	370	369	404	518	421	495	5661	1304	369	598
QL (เมตร)		162	138	111	138	131	111	114	106	129	437	105	117				
SB	9	2655	2627	2546	2721	2274	2208	2261	2279	2315	2213	1862	1764	27725	2467	1764	2721
	9ก	366	484	510	469	563	494	335	337	380	484	408	480	5309	477	335	563
	10	1489	1516	1614	1177	1074	889	810	865	1091	845	961	1096	12528	1164	845	1614
	12	501	399	253	249	222	213	258	270	315	356	341	252	3629	339	213	501
เข้า SB		5011	5026	4923	4615	4133	3804	3764	3752	4101	3898	3572	3592	50191	4447	3572	5026
ออก SB		2928	2813	2943	3546	3650	3649	3859	4020	4242	4413	4534	3925	44522	3959	2813	4534
QL (เมตร)		294	274	175	102	95	78	83	89	164	91	157	74				
WB	13	111	157	191	297	342	327	298	253	261	191	219	126	2773	242	111	342
	14	757	883	914	800	831	843	791	766	561	383	398	382	8209	798	382	883
	15	1249	1160	1426	1694	1841	1877	1957	2112	2223	2360	2879	2238	23107	1991	1160	2879
	15ก	574	568	513	496	506	589	564	558	673	535	550	538	6664	637	496	673
เข้า WB		2682	2768	2944	3287	3520	3636	3610	3689	3718	3469	4046	3384	40753	3668	2682	4046
ออก WB		3616	3596	3602	3949	3567	3507	3515	3526	3706	3404	2718	2460	41176	3769	2460	3949
QL (เมตร)		293	284	219	188	227	208	199	280	298	299	294	294				

ประเภท	NB 7-9	EB 7-9	SB 7-9	WB 7-9	รวม	NB 9-16	EB 9-16	SB 9-16	WB 9-16	รวม	NB 16-19	EB 16-19	SB 16-19	WB 16-19	รวม	ตลอดวัน
รถยนต์	265	7013	7013	3648	17879	825	7113	15934	14420	39302	390	3020	6991	6925	17326	74507
รถตู้,ปิคอัพ	138	735	2257	1147	4327	518	4342	9056	6607	20523	208	1332	3141	2597	7548	32398
รถบัสใหญ่	0	281	306	319	906	0	1413	921	1153	3487	0	321	333	499	1153	5546
รถบัสเล็ก	0	129	119	94	342	0	367	384	334	1085	0	88	157	163	408	1835
รถบรรทุก	0	10	94	9	113	0	284	720	598	1602	0	16	21	17	54	1769
สามล้อ	43	123	248	183	597	132	1137	1077	1284	3630	22	261	419	398	1100	5327
รวม	386	8291	10037	5450	24164	1455	14654	28092	24396	69629	620	5028	11062	10899	27589	121382
PCU	7.00-9.00				12730	9.00-16.00				18154	16.00-19.00				9658	126139

ข้อมูลปริมาณการจราจรบริเวณทางแยก (ปี 2540)

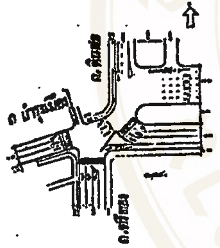
ชื่อทางแยก เสาชิงช้า

ถนน ตีทอง-บำรุงเมือง หมายเลข 147 วันที่ 7 กรกฎาคม 2540 สภาพอากาศ ปกติ



ทิศทาง	เวลา	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	รวม	เฉลี่ย PCU/ชม.	ปริมาณ รถ ค่าต่ำสุด	ปริมาณ รถ ค่าสูงสุด
NB	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	370	382	615	571	507	565	642	672	614	629	589	515	6671	577	370	672
	3	422	559	515	586	524	434	506	561	518	460	365	464	5914	502	365	586
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า NB		792	941	1130	1157	1031	999	1148	1233	1132	1089	954	979	12585	1079	792	1233
ออก NB		102	103	84	106	96	99	202	239	233	252	278	255	2039	188	84	278
QL (เมตร)		67	70	64	82	76	70	40	40	82	69	63	49				
EB	5	193	171	217	272	288	290	258	208	181	235	250	225	2788	240	171	290
	6	969	1200	1022	950	912	865	867	838	934	980	1023	969	11529	973	838	1200
	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	0	0	0	0	•0	0	0	0	0
เข้า EB		1162	1371	1239	1222	1200	1155	1125	1046	1115	1215	1273	1194	14317	1213	1046	1371
ออก EB		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
QL (เมตร)		58	63	64	63	83	68	69	62	59	63	57	50				
SB	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า SB		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ออก SB		706	689	990	977	985	989	1115	1099	1109	1153	1184	1151	12147	1050	689	1184
QL (เมตร)		0	0	0	0	0	0	0	0	0	0	0	0				
WB	13	102	103	84	106	96	99	202	239	233	252	278	255	2039	188	84	278
	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	143	136	158	134	190	134	215	219	314	289	345	411	2688	234	134	411
	16	71	61	82	78	85	80	88	92	109	78	64	57	945	80	57	109
เข้า WB		245	239	242	240	286	233	417	448	547	541	623	666	4727	502	233	666
ออก WB		1462	1820	1619	1614	1521	1379	1461	1491	1561	1518	1452	1490	18388	1555	1379	1820
QL (เมตร)		50	50	50	50	50	50	50	50	50	50	50	50				

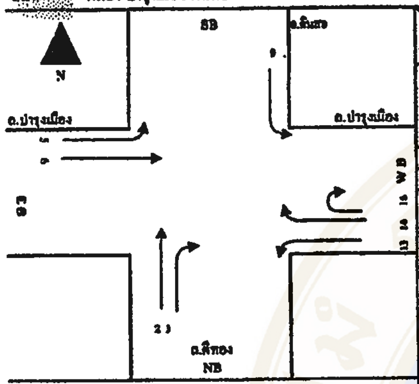
ประเภท	NB 7-9	EB 7-9	SB 7-9	WB 7-9	รวม	NB 9-16	EB 9-16	SB 9-16	WB 9-16	รวม	NB 16-19	EB 16-19	SB 16-19	WB 16-19	รวม	ตลอดวัน
รถยนต์	1022	0	0	296	1318	4066	4465	0	1391	9922	1696	2251	0	1109	5056	16296
รถตู้,ปิกอัพ	343	545	0	165	1053	2201	2070	0	825	5096	782	829	0	518	2129	8378
รถเมล์ใหญ่	78	5	0	38	121	167	50	0	160	377	49	34	0	79	162	660
รถเมล์เล็ก	25	0	0	15	40	69	0	0	55	124	23	0	0	33	56	220
รถบรรทุก	3	3	0	4	10	74	186	0	36	296	4	3	0	1	8	314
สามล้อ	262	286	0	98	646	1253	1331	0	560	3144	468	565	0	289	1322	5112
รวม	1733	839	0	616	3188	7830	8102	0	3027	18959	3022	3682	0	2029	8733	30880
PCU	7.00-9.00				1655	9.00-16.00				3754	16.00-19.00				2953	27471

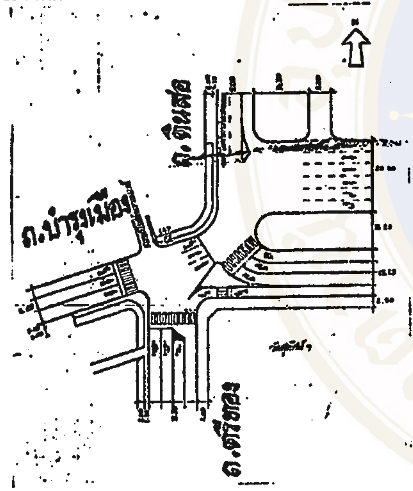


ที่มา: ข้อมูล ส่วนสำรวจและวิเคราะห์ วิศวกร สำนักการจราจรและขนส่ง

ข้อมูลปริมาณการจราจรบริเวณทางแยก (ปี 2541)

ชื่อทางแยก เสาชิงช้า
ถนน ตีทอง-บำรุงเมือง-ดินสอ หมายเลข 147 วันที่ 10 มิถุนายน 2541 สภาพอากาศ ปกติ





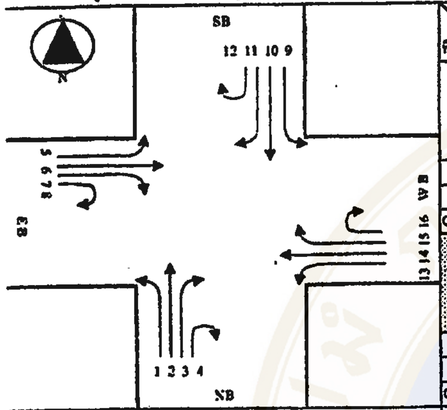
ทิศทาง / เวลา		07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	รวม	ปริมาณ รถ ต่ำสุด	ปริมาณ รถ สูงสุด	เฉลี่ย
		ปริมาณการจราจรแต่ละช่วงเวลา (คัน/ชม.)						(ไม่รวมรถจักรยานยนต์)									
NB	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	606	1027	490	616	612	632	637	605	744	691	577	656	7893	490	1027	687
	3	618	562	482	485	531	547	582	529	536	586	504	401	6363	401	618	532
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า		1224	1589	972	1101	1143	1179	1219	1134	1280	1377	1081	1057	14256	972	1589	
ออก		239	233	177	176	163	175	155	158	168	197	188	177	2206	155	239	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ต่ำสุด	สูงสุด	
	15	320	1266	1486	931	1140	1182	1148	1223	1153	1317	1236	1034	13456	320	1486	
	30	607	1365	1328	996	1138	1201	1161	1222	1165	1352	1103	1083	13721	607	1365	
	45	909	1499	1112	1065	1138	1198	1200	1155	1248	1345	1041	1090	14000	909	1499	
QL (เมตร)		112	100	65	90	117	130	76	98	95	75	78	72				
EB	5	275	247	238	254	275	284	277	280	330	282	261	245	3248	238	330	268
	6	757	994	869	924	802	871	838	871	1061	786	647	617	10057	617	1061	856
	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า		1032	1241	1107	1178	1077	1155	1135	1151	1391	1068	908	862	13305	862	1391	
ออก		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ต่ำสุด	สูงสุด	
	15	257	1101	1151	1179	1194	1044	1146	1136	1223	1307	1064	858	12660	257	1307	
	30	497	1163	1168	1147	1102	1124	1164	1123	1283	1256	1021	855	12903	497	1283	
	45	742	1232	1148	1149	1087	1148	1144	1138	1363	1150	971	838	13110	742	1363	
QL (เมตร)		183	136	57	59	61	61	64	53	77	69	77	60				
SB	9	124	97	63	67	65	56	48	73	53	51	53	49	799	48	124	103
	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า		124	97	63	67	65	56	48	73	53	51	53	49	799	48	124	
ออก		1062	1395	853	1018	1044	1035	1054	1118	1363	1157	975	1049	13123	853	1395	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ต่ำสุด	สูงสุด	
	15	35	121	79	67	71	56	56	55	64	53	51	56	766	35	121	
	30	65	119	69	66	68	53	57	58	63	60	45	53	776	45	119	
	45	95	110	64	69	65	55	51	67	59	56	45	50	786	45	110	
QL (เมตร)		0	0	0	0	0	0	0	0	0	0	0	0				
WB	13	239	233	177	176	163	175	155	158	168	197	188	177	2206	155	239	210
	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	181	121	125	148	157	119	140	233	289	184	137	148	1982	119	289	170
	16	142	53	7	57	52	65	44	66	93	33	28	25	667	7	142	55
เข้า		420	354	302	324	320	294	295	391	457	381	325	325	4188	294	457	
ออก		1641	1706	1421	1533	1450	1539	1532	1539	1745	1456	1232	1092	17886	1092	1745	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ต่ำสุด	สูงสุด	
	15	153	521	361	343	376	380	331	362	523	516	377	351	4594	153	523	
	30	303	481	339	334	387	374	337	390	533	490	365	337	4670	303	533	
	45	433	449	326	355	369	369	347	414	555	446	364	329	4756	326	555	
QL (เมตร)		53	50	-50	-50	-50	-50	-50	-50	55	55	56	50				

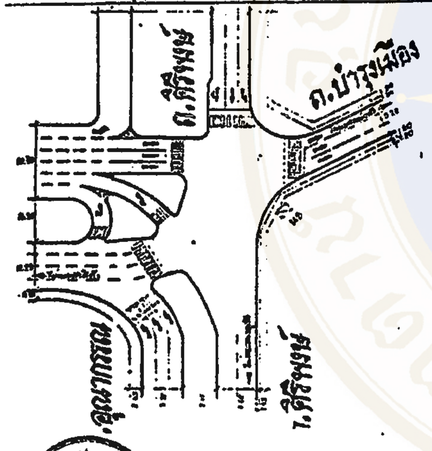
QL = 301 หมายถึง 300 เมตรขึ้นไป
QL = -50 หมายถึง น้อยกว่า 50 เมตร
งาน เก็บและข้อมูล ฝ่ายสำรวจและวิเคราะห์
กองวิศวกรรม สำนักการจราจรและขนส่ง

ข้อมูลปริมาณการจราจรบริเวณทางแยก (ปี 2540)

ชื่อทางแยก เสาชิงช้า 2

ถนน อุณากรรณ-ศิริพงษ์-บำรุงเมือง หมายเลข 148 วันที่ 7 ตุลาคม 2540 สภาพ .ท ปกติ





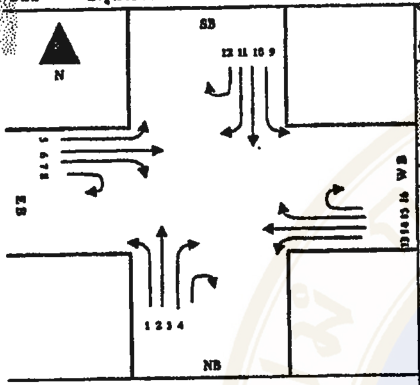
สถิติและข้อมูล ฝ่ายแผนงานและวิเคราะห์
วิศวกร สำนักการจราจรและขนส่ง

ทิศทาง \ เวลา		ปริมาณการจราจรแต่ละช่วงเวลา (คัน/ชม.)						(ไม่รวม รถจักรยานยนต์)							เฉลี่ย	ปริมาณ รถ	
		07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	รวม	ระหว่างวัน	ต่ำสุด	สูงสุด
NB	1	127	169	211	210	319	342	234	245	237	293	253	198	2838	251	127	342
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า NB		127	169	211	210	319	342	234	245	237	293	253	198	2838	251	127	342
ออก NB		479	505	553	684	773	816	627	596	633	626	573	566	7431	640	479	816
QL (เมตร)		-50	52	53	-50	57	51	-50	-50	-50	-50	-50	-50				
EB	5	57	31	28	28	32	33	55	49	44	59	40	21	477	40	21	59
	6	1367	1215	1184	1175	1503	1380	1183	1137	1170	1109	1239	1007	14669	1234	1007	1503
	7	163	176	245	251	252	318	256	206	195	198	166	150	2576	235	150	318
	8	45	53	66	83	102	142	51	36	48	43	43	62	774	84	36	142
เข้า EB		1587	1422	1457	1434	1787	1731	1494	1392	1409	1366	1445	1178	17722	1593	1178	1787
ออก EB		285	401	469	471	568	604	389	375	420	508	501	465	5456	483	285	604
QL (เมตร)		-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50				
SB	9	99	117	116	152	132	130	105	111	111	95	100	113	1381	114	95	152
	10	316	329	308	433	521	498	371	390	438	428	407	416	4855	405	308	521
	11	113	179	192	178	147	120	104	94	135	172	205	205	1844	148	94	205
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า SB		528	625	616	763	800	748	580	595	684	695	712	734	8080	667	528	800
ออก SB		57	31	28	28	32	33	55	49	44	59	40	21	477	40	21	59
QL (เมตร)		-50	52	53	-50	57	51	-50	-50	-50	-50	-50	-50				
WB	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า WB		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ออก WB		1466	1332	1300	1327	1635	1510	1288	1248	1281	1204	1339	1120	16050	1348	1120	1635
QL (เมตร)		0	0	0	0	0	0	0	0	0	0	0	0				

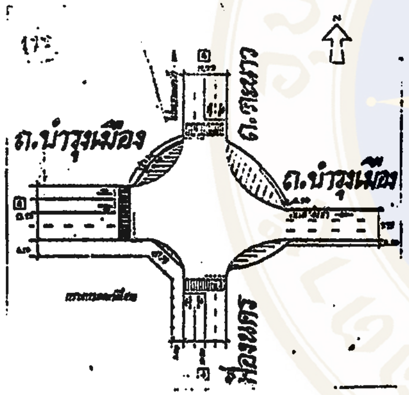
ประเภท	NB 7-9	EB 7-9	SB 7-9	WB 7-9	รวม	NB 9-16	EB 9-16	SB 9-16	WB 9-16	รวม	NB 16-19	EB 16-19	SB 16-19	WB 16-19	รวม	ตลอดวัน
รถยนต์	126	621	621	0	1368	852	5225	2548	0	8625	374	2056	1304	0	3734	13727
รถตู้,ปิคอัพ	72	563	281	0	916	493	3127	1413	0	5033	208	1230	542	0	1980	7929
รถเมล์ใหญ่	33	45	0	0	78	91	234	0	0	325	33	104	2	0	139	542
รถเมล์เล็ก	0	54	0	0	54	0	216	0	0	216	0	58	3	0	61	331
รถบรรทุก	2	2	0	0	4	22	184	41	0	247	1	3	4	0	8	259
สามล้อ	63	552	251	0	866	340	2266	757	0	3363	128	686	258	0	1072	5301
รวม	296	1837	1153	0	3286	1798	11252	4759	0	17809	744	4137	2113	0	6994	28089
PCU	07.00-09.00				1672	09.00-16.00				3585	16.00-19.00				2371	24319

ข้อมูลปริมาณการจราจรบริเวณทางแยก (ปี 2541)

ชื่อทางแยก สี่กั๊กเสาชิงช้า
ถนน บำรุงเมือง-ตะนาว-เฟื่องนคร หมายเลข 177 วันที่ 28 สิงหาคม 2541 สภาพอากาศ ปกติ



ทิศทาง	เวลา	ปริมาณการจราจรแต่ละช่วงเวลา (คันต่อชม.)						(ไม่รวมรถจักรยานยนต์)							ปริมาณ [illegible]		เฉลี่ย
		07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	รวม	ค่าต่ำสุด	ค่าสูงสุด	PCU/HOUR
NB	1	48	62	59	64	68	48	53	64	53	52	53	46	670	46	68	56
	2	385	341	350	383	403	403	360	394	404	427	384	297	4531	297	427	373
	3	94	69	56	59	97	93	85	70	85	91	91	85	975	56	97	81
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า		527	472	465	506	568	544	498	528	542	570	528	428	6176	428	570	
ออก		483	411	228	229	292	291	289	314	315	367	274	262	3755	228	483	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ค่าต่ำสุด	ค่าสูงสุด	
	15	135	518	454	483	524	560	538	489	545	551	552	502	5851	135	560	
	30	263	505	463	473	523	573	535	491	544	566	547	466	5953	263	573	
	45	391	495	472	488	538	562	518	502	540	581	539	440	6066	391	581	
QL (เมตร)		97	75	68	61	58	60	66	75	88	114	146	150				
EB	5	93	204	187	152	175	177	161	124	184	218	147	129	1951	93	218	160
	6	987	879	789	728	906	780	784	813	920	918	800	724	10028	724	987	857
	7	246	221	140	95	107	116	101	126	123	113	78	72	1538	72	246	126
	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า		1326	1304	1116	975	1188	1073	1046	1063	1227	1249	1025	925	13517	925	1326	
ออก		120	149	135	141	148	154	146	121	127	134	134	122	1631	120	154	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ค่าต่ำสุด	ค่าสูงสุด	
	15	279	1357	1296	1046	1012	1194	1045	1046	1095	1233	[illegible]	979	12826	279	1367	
	30	640	1323	1249	1014	1072	1163	1047	1041	1111	1321	1119	974	13074	643	1323	
	45	982	1304	1199	1013	1099	1125	1042	1050	1162	1283	1097	939	13295	939	1304	
QL (เมตร)		80	69	67	63	62	65	57	65	68	68	80	71				
SB	9	134	114	102	109	107	123	119	180	205	161	141	165	1660	102	205	138
	10	237	190	88	134	185	175	188	188	192	254	196	190	2217	88	254	184
	11	72	87	76	77	80	106	93	57	74	82	81	76	961	57	106	79
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า		443	391	266	320	372	404	400	425	471	497	418	431	4838	266	497	
ออก		478	545	537	535	578	580	521	518	588	645	531	426	6482	426	645	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ค่าต่ำสุด	ค่าสูงสุด	
	15	91	446	374	289	325	393	398	394	454	467	500	394	4505	91	500	
	30	210	434	334	288	326	413	395	395	463	481	479	391	4609	210	481	
	45	326	409	304	300	353	405	404	402	474	487	451	409	4724	300	487	
QL (เมตร)		84	67	59	58	66	75	70	71	70	67	67	68				
WB	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	0	0	0	0	0	C	0	0	0	0	0	0	0	0	0	0
	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
เข้า		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
ออก		1215	1062	947	896	1110	996	988	1063	1210	1170	1032	974	12663	896	1215	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ค่าต่ำสุด	ค่าสูงสุด	
	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
QL (เมตร)		0	0	0	0	0	0	0	0	0	0	0	0				



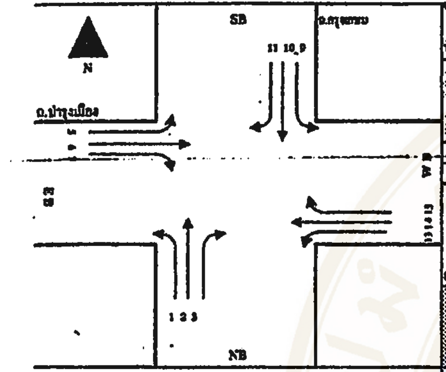
QL = 301 หมายถึง 300 เมตรขึ้นไป
QL = -50 หมายถึง น้อยกว่า 50 เมตร
งานสถิติและข้อมูล ส่วนสำรวจและวิเคราะห์
กองวิศวกรรม สำนักการจราจรและขนส่ง

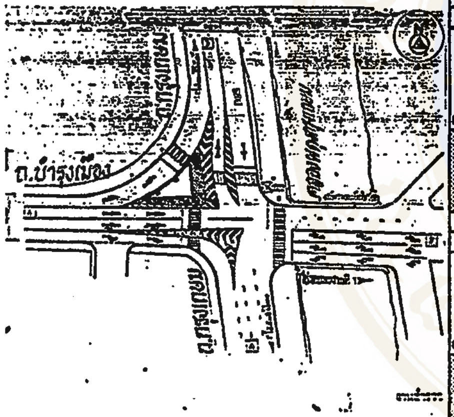
ข้อมูลปริมาณการจราจรบริเวณทางแยก (ปี 2541)

ชื่อทางแยก กษัตริย์ศึก

ถนน บำรุงเมือง - กรุงเกษม หมายเลข 2 วันที่ 10 ธันวาคม 2541 สภาพอากาศ ปกติ

47 1/65





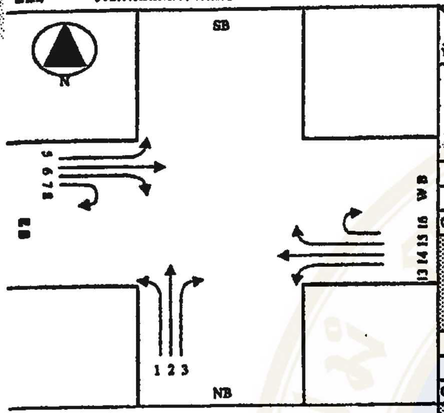
ทิศทาง	เวลา	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	รวม	ต่ำสุด	สูงสุด	เฉลี่ย PCU/HOUR
NB	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
ออก		2288	2614	2259	2093	2141	2200	2227	2188	2111	2465	2412	2073	27071	2073	2614	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ต่ำสุด	สูงสุด	
	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
QL (เมตร)		0	0	0	0	0	0	0	0	0	0	0	0				
EB	5	468	644	747	879	912	835	838	873	766	709	775	687	9133	468	912	769
	6	1834	1486	1140	1007	1159	1154	1224	1179	1151	1220	1199	1281	15034	1007	1834	1301
	7	1344	1498	1211	1165	1210	1167	1244	1274	1215	1474	1481	1218	15501	1165	1498	1319
	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า		3646	3628	3098	3051	3281	3156	3306	3326	3132	3403	3455	3186	39668	3051	3646	
ออก		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ต่ำสุด	สูงสุด	
	15	943	3623	3521	3040	3093	3346	3113	3321	3270	3224	3429	3465	37388	943	3623	
	30	1806	3657	3431	2986	3200	3285	3158	3312	3174	3339	3445	3414	38202	1806	3652	
	45	2696	3722	3249	2965	3244	3279	3197	3349	3093	3363	3478	3307	38942	2696	3722	
QL (เมตร)		152	181	98	125	175	169	156	172	144	160	149	140				
SB	9	222	85	32	16	11	18	7	12	16	44	40	7	510	7	222	42
	10	13	12	12	12	9	8	14	12	12	15	12	14	145	8	15	25
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า		235	97	44	28	20	26	21	24	28	59	52	21	655	20	235	
ออก		1281	1470	1550	1720	1784	1676	1644	1670	1600	1530	1588	1424	18937	1281	1784	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ต่ำสุด	สูงสุด	
	15	53	217	76	35	31	22	18	25	24	37	64	37	639	18	217	
	30	120	176	63	30	28	24	18	24	23	44	62	35	647	18	176	
	45	183	127	60	28	22	24	20	24	25	47	57	23	650	20	183	
QL (เมตร)		51	60	0	0	0	0	-50	0	58	57	55	-50				
WB	13	931	1104	1036	916	922	1025	969	902	884	976	919	841	11425	841	1104	1010
	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	813	826	803	841	872	841	854	797	834	821	813	737	9804	737	872	821
	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า		1744	1930	1839	1757	1794	1866	1775	1699	1718	1797	1732	1578	21229	1578	1930	
ออก		2036	1571	1172	1023	1170	1172	1231	1191	1167	1264	1239	1288	15344	1023	2036	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ต่ำสุด	สูงสุด	
	15	399	1818	1939	1818	1726	1857	1843	1730	1706	1729	1832	1638	20035	399	1939	
	30	885	1824	1892	1816	1712	1883	1831	1715	1670	1790	1811	1610	20441	885	1892	
	45	1286	1924	1913	1778	1724	1874	1823	1661	1699	1825	1754	1590	20831	1286	1913	
QL (เมตร)		80	180	180	180	180	180	180	180	180	180	180	180				

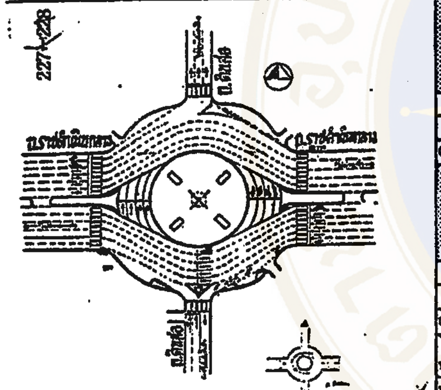
QL = 301 หมายถึง 300 เมตรขึ้นไป
QL = -50 หมายถึง น้อยกว่า 50 เมตร
งานสถิติและข้อมูล ฝ่ายสำรวจและวิเคราะห์
และวิจัยจราจร สำนักการจราจรและขนส่ง

ข้อมูลปริมาณการจราจรบริเวณทางแยก (ปี 2540)

ชื่อทางแยก ประชาธิปไตย

ถนน ราชดำเนินกลาง-ดินสอ หมายเลข 227 วันที่ 6 มิถุนายน 2540 สภาพอากาศ ปกติ





ทิศทาง		07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	รวม	เฉลี่ย pcu/hour	ปริมาณ รถ ต่ำสุด	ปริมาณ รถ สูงสุด
NB	1	149	216	204	284	278	319	276	254	275	303	347	311	3196	285	149	347
	2	720	601	509	569	510	517	534	510	555	593	675	706	6999	623	509	720
	3	376	314	336	362	363	336	428	557	555	629	504	504	5264	439	314	629
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า NB		1245	1131	1049	1195	1151	1172	1238	1321	1385	1525	1526	1521	15459	1345	1049	1526
ออก NB		45	42	47	47	51	46	47	42	59	65	61	56	608	83	42	65
QL (เมตร)		0	0	0	0	0	0	0	0	0	0	0	0				
EB	5	532	501	519	566	561	546	454	513	552	545	432	352	6073	516	352	566
	6	3035	3152	3291	3213	3065	3219	2621	2227	2505	2258	2258	1884	32728	2915	1884	3291
	7	15	11	14	14	14	13	17	19	21	19	22	22	201	25	11	22
	8	125	157	130	130	138	133	152	153	161	184	129	128	1720	217	125	184
เข้า EB		3582	3664	3824	3793	3640	3778	3092	2759	3078	2822	2712	2258	39002	3672	2258	3824
ออก EB		2906	3359	3600	4160	3989	3782	3853	4057	5124	4599	4043	3563	47035	4244	2906	5124
QL (เมตร)		96	101	107	111	158	175	190	190	193	193	192	181				
SB	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า SB		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ออก SB		1391	1229	1127	1266	1223	1233	1140	1159	1255	1301	1282	1240	14846	1291	1127	1391
QL (เมตร)		0	0	0	0	0	0	0	0	0	0	0	0				
WB	13	30	31	33	33	37	33	30	23	38	46	39	34	407	58	23	46
	14	2632	2986	3266	3766	3573	3330	3425	3650	4688	4112	3567	3124	42119	3743	2632	4688
	15	139	127	99	131	152	170	152	136	148	163	175	182	1774	154	99	182
	16	45	36	38	75	73	77	69	53	55	52	55	58	686	57	36	77
เข้า WB		2801	3144	3398	3930	3762	3533	3607	3809	4874	4321	3781	3340	44300	4012	2801	4874
ออก WB		3456	3502	3665	3650	3501	3632	3118	2837	3115	2939	2817	2446	38678	3411	2446	3665
QL (เมตร)		112	88	97	115	126	126	161	149	163	153	177	180				

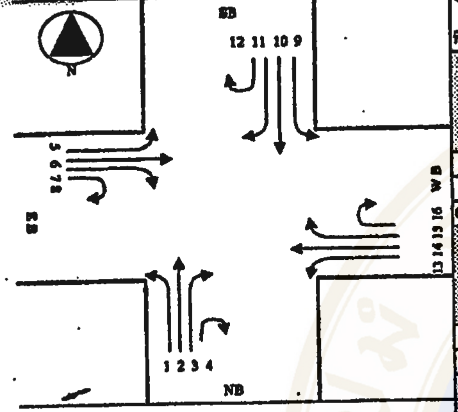
ประเภท	NB 7-9	EB 7-9	SB 7-9	WB 7-9	รวม	NB 9-16	EB 9-16	SB 9-16	WB 9-16	รวม	NB 16-19	EB 16-19	SB 16-19	WB 16-19	รวม	ตลอดวัน
✓ รถยนต์	1509	0	0	4186	5695	4834	14012	0	14794	33640	2748	4842	0	5404	12994	52329
✓ รถตู้,ปิคอัพ	449	1839	0	1162	3450	[illegible]	7742	0	9191	19106	1109	2241	0	5237	8587	31143
รถใหญ่	119	367	0	342	828	275	1321	0	1335	2931	161	481	0	456	1098	4857
รถเล็ก	32	129	0	79	240	78	476	0	349	903	44	272	0	146	462	1605
บรรทุก	3	8	0	10	21	73	404	0	423	900	9	10	0	6	25	946
รถเมล์	264	252	0	247	763	1078	1006	0	1261	3343	501	387	0	351	1239	5347
รวม	2376	2595	0	6026	10997	8511	24961	0	27353	60825	4572	8233	0	11600	24405	96227
PCU เฉลี่ย	7.00-9.00				6003	9.00-16.00				12804	16.00-19.00				8598	98859

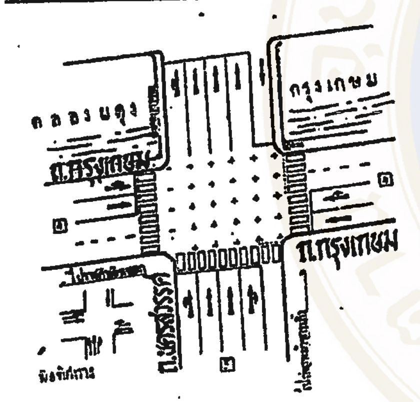
สถิติและข้อมูล ฝ่ายสำรวจและวิเคราะห์
วิจัยจราจร สำนักการจราจรและขนส่ง

ข้อมูลปริมาณการจราจรบริเวณทางแยก (ปี 2541)

ชื่อทางแยก สะพานเทวกรรม

ถนน กรุงเกษม-นครสวรรค์ หมายเลข 26 วันที่ 16 มกราคม 2541 สภาพอากาศ ปกติ





สถิติและข้อมูล ฝ่ายสำรวจและวิเคราะห์
ที่มา สำนักการจราจรและขนส่ง

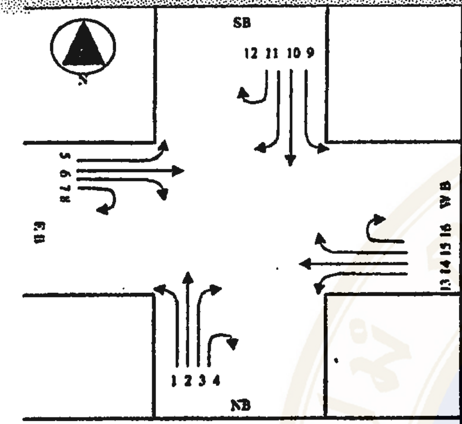
ทิศทาง / เวลา		07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	รวม	เฉลี่ย PCU/HOUR	ปริมาณ รถ ช่วงต่ำสุด	ช่วงสูงสุด
NB	1	19	20	34	27	59	42	35	31	33	26	23	44	413	35	19	59
	2	2221	2062	2060	2203	2286	2349	2233	2185	2354	1716	2126	1962	25757	2198	1716	2354
	3	59	44	54	71	79	62	49	45	62	26	13	19	583	54	13	79
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า NB		2299	2126	2148	2301	2424	2453	2337	2261	2449	1768	2162	2025	26753	2287	1768	2453
ออก NB		24	20	36	27	34	26	41	26	21	37	47	52	391	49	20	52
QL (เมตร)		50	50	50	50	50	50	50	50	50	50	50	50				
EB	5	124	101	107	108	154	155	110	138	175	146	137	154	1609	136	101	175
	6	299	237	181	165	176	169	112	117	89	123	118	87	1873	174	87	299
	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า EB		423	338	288	273	330	324	222	235	264	269	255	241	3482	310	222	423
ออก EB		636	565	514	413	598	543	503	594	453	585	845	842	7091	603	413	845
QL (เมตร)		51	55	50	56	50	52	50	50	50	50	50	50				
SB	9	3	5	0	4	2	1	2	4	2	5	7	5	40	3	0	7
	10	23	20	29	27	30	24	38	26	21	37	46	52	373	48	20	52
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า SB		26	25	29	31	32	25	40	30	23	42	53	57	413	51	23	57
ออก SB		2509	2346	2361	2500	2616	2711	2502	2491	2707	2092	2457	2316	29608	2523	2092	2711
QL (เมตร)		50	50	50	50	50	50	50	50	50	50	50	50				
WB	13	1	0	7	0	4	2	3	0	0	0	1	0	18	2	0	7
	14	617	545	480	386	539	501	448	563	420	559	822	798	6678	568	386	822
	15	164	183	194	189	176	207	159	168	178	230	194	200	2242	188	159	230
	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า WB		782	728	681	575	719	710	610	731	598	789	1017	998	8938	758	575	1017
ออก WB		361	286	235	240	257	232	163	166	153	154	138	111	2496	231	111	361
QL (เมตร)		68	66	79	54	91	198	165	194	121	153	130	162				

ประเภท	NB 7-9	EB 7-9	SB 7-9	WB 7-9	รวม	NB 9-16	EB 9-16	SB 9-16	WB 9-16	รวม	NB 16-19	EB 16-19	SB 16-19	WB 16-19	รวม	ตลอดวัน
รถยนต์	3430	10	10	990	4440	10514	961	47	2592	14114	4191	483	38	1758	6450	25004
รถตู้,ปิคอัพ	797	177	4	212	1190	4772	627	34	1173	6606	1523	173	22	458	2176	9972
รถเมล์ใหญ่	47	37	24	26	134	171	78	71	71	391	60	41	35	40	176	701
รถเมล์เล็ก	15	0	13	0	28	48	0	58	0	106	24	0	37	1	62	196
รถบรรทุก	18	3	0	2	23	244	52	0	72	368	10	2	0	3	15	406
สามล้อ	118	48	0	280	446	624	238	0	716	1578	187	66	0	544	797	2821
รวม	4425	275	51	1510	6261	16373	1956	210	4624	23163	5955	765	152	2804	9676	39100
PCU	7.00-9.00				3213	9.00-16.00				3441	16.00-19.00				3289	37976

ข้อมูลปริมาณการจราจรบริเวณทางแยก (ปี 2540)

ชื่อทางแยก จักรพรรดิพงษ์

ถนน จักรพรรดิพงษ์-นครสวรรค์ หมายเลข 32 วันที่ 26 สิงหาคม 2540 สภาพ [illegible] ปกติ



ทิศทาง		07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	รวม	เฉลี่ย ระดับชั่วโมง	ปริมาณ รถ ต่ำสุด	ปริมาณ รถ สูงสุด
NB	1	21	34	56	57	50	35	47	37	23	32	38	29	459	38	21	57
	2	1899	1884	1563	1373	1533	1324	1595	1553	1650	1650	1370	1265	18679	1584	1265	1899
	3	123	101	104	126	130	137	98	143	124	93	86	117	1382	124	86	143
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า NB		2043	2019	1743	1556	1713	1496	1740	1733	1797	1775	1494	1411	20520	1746	1411	2043
ออก NB		47	34	51	64	60	54	41	38	30	35	43	34	531	75	30	64
QL (เมตร)		50	50	50	50	50	50	50	50	50	50	50	50				
EB	5	242	206	187	192	177	192	242	250	259	393	256	288	2884	245	177	393
	6	874	903	645	555	609	662	665	629	658	775	707	687	8369	710	555	903
	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า EB		1116	1109	832	747	786	854	907	879	917	1168	963	975	11253	935	747	1168
ออก EB		714	621	507	451	544	525	517	467	462	447	630	619	6504	553	447	714
QL (เมตร)		61	60	64	79	91	75	81	98	87	90	54	50				
SB	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10	47	34	51	64	60	54	41	38	30	35	43	34	531	75	30	64
	11	6	4	3	3	6	4	5	5	5	5	5	4	55	10	3	6
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า SB		53	38	54	67	66	58	46	43	35	40	48	38	586	84	35	67
ออก SB		2365	2287	1987	1843	1958	1749	2163	2154	2279	2362	1942	1861	24950	2120	1749	2365
QL (เมตร)		50	50	50	50	50	50	50	50	50	50	50	50				
WB	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	14	687	583	448	391	488	486	465	425	434	410	587	586	5990	506	391	687
	15	224	197	217	278	248	233	326	351	370	319	316	328	3387	291	197	370
	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า WB		911	780	665	669	736	719	791	776	804	729	903	894	9377	797	665	911
ออก WB		997	1004	749	681	739	799	763	772	782	868	793	804	9751	834	681	1004
QL (เมตร)		69	90	84	66	56	59	53	54	54	59	57	57				

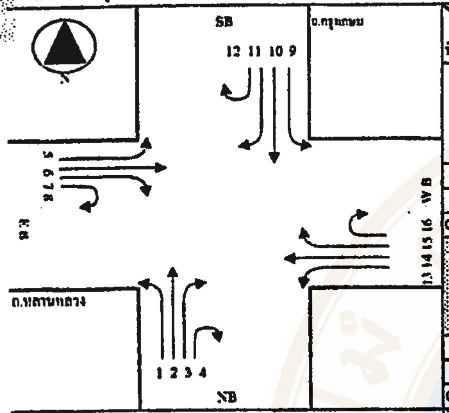
ปริมาณการจราจรแต่ละช่วงเวลา (คัน/ชม.) (ไม่รวม รถจักรยานยนต์)

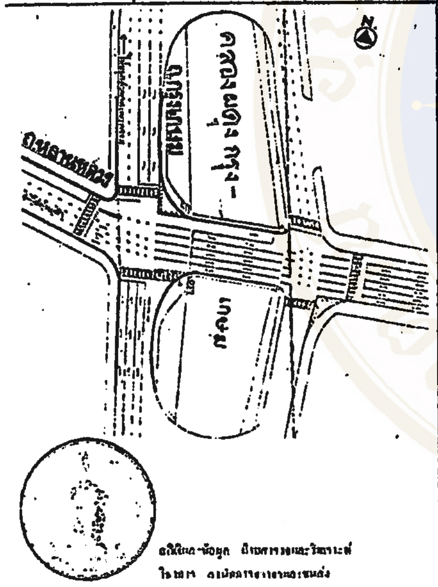
ประเภท	NB 7-9	EB 7-9	SB 7-9	WB 7-9	รวม	NB 9-16	EB 9-16	SB 9-16	WB 9-16	รวม	NB 16-19	EB 16-19	SB 16-19	WB 16-19	รวม	ตลอดวัน
รถยนต์	3065	18	18	1160	4261	7260	3391	47	2842	13540	2996	1963	6	1680	6645	24446
รถตู้,ปิคอัพ	823	323	5	311	1462	3619	1443	24	1457	6543	1389	678	3	543	2613	10648
รถเมล์ใหญ่	34	23	59	12	128	95	100	206	56	457	36	41	39	14	130	715
รถเมล์เล็ก	3	0	9	0	12	27	0	92	0	119	5	0	78	0	83	214
รถบรรทุก	0	3	0	2	5	193	75	0	112	380	5	11	0	5	21	406
สามล้อ	137	226	0	206	569	584	913	0	693	2190	249	413	0	284	946	3705
รวม	4062	623	91	1691	6467	11778	5922	369	5160	23229	4680	3106	126	2526	10438	40134
PCU	7.00-9.00				3291	9.00-16.00				5339	16.00-19.00				3529	38219

สถิติและข้อมูล ฝ่ายสำรวจและวิเคราะห์
วิศวกร สำนักการจราจรและขนส่ง

ข้อมูลปริมาณการจราจรบริเวณทางแยก (ปี 2540)

ชื่อทางแยก สะพานขาว
ถนน กรุงเกษม-หลานหลวง หมายเลข 37 วันที่ 31 ตุลาคม 2540 [illegible] ปกติ



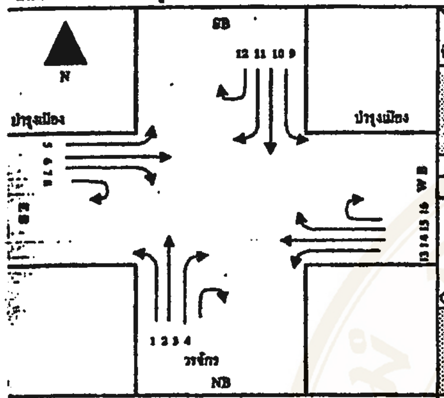


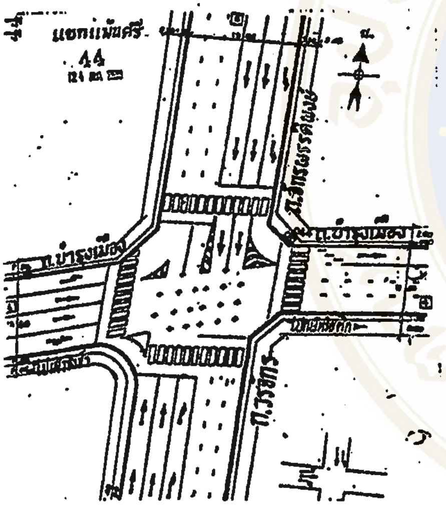
ทิศทาง	เวลา	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	รวม	เฉลี่ย	ปริมาณ รถ ต่ำสุด	ปริมาณ รถ สูงสุด
NB	1	667	768	708	787	727	708	738	941	916	761	833	857	9411	800	667	941
	2	575	540	505	559	640	577	628	639	658	686	635	588	7230	617	505	686
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า NB		1242	1308	1213	1346	1367	1285	1366	1580	1574	1447	1468	1445	16641	1417	1213	1580
ออก NB		291	193	113	116	75	74	53	64	88	52	38	43	1200	112	38	291
QL (เมตร)		-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50				
EB	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6	119	149	137	119	111	110	87	89	82	85	66	66	1220	199	66	149
	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า EB		119	149	137	119	111	110	87	89	82	85	66	66	1220	199	66	149
ออก EB		3779	3861	3283	3533	3291	2988	3655	3869	3733	3439	3480	3403	42313	3704	2988	3869
QL (เมตร)		-50	-50	-50	-50	-50	-50	-50	50	-50	-50	-50	-50				
SB	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10	178	107	57	58	44	43	49	54	66	33	21	30	740	74	21	178
	11	135	131	141	135	148	151	116	119	105	116	95	115	1507	129	95	151
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า SB		313	238	198	193	192	194	165	173	171	149	116	145	2247	203	116	313
ออก SB		771	683	630	653	727	708	790	791	799	861	777	686	8876	[illegible]	630	861
QL (เมตร)		-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50				
WB	13	113	86	56	58	31	31	4	10	22	19	17	13	460	38	4	113
	14	2977	2962	2433	2611	2416	2129	2801	2809	2712	2562	2552	2431	31395	2776	2129	2977
	15	196	143	125	94	87	131	162	152	141	175	142	98	1646	139	87	196
	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า WB		3286	3191	2614	2763	2534	2291	2967	2971	2875	2756	2711	2542	33501	2953	2291	3286
ออก WB		119	149	137	119	111	110	87	89	82	85	66	66	1220	199	66	149
QL (เมตร)		147	99	90	85	72	78	128	11	104	111	60	67				

ประเภท	NB 7-9	EB 7-9	SB 7-9	WB 7-9	รวม	NB 9-16	EB 9-16	SB 9-16	WB 9-16	รวม	NB 16-19	EB 16-19	SB 16-19	WB 16-19	รวม	ตลอดวัน
รถยนต์	1564	348	348	4093	6293	4984	0	619	10681	16284	2528	0	213	4987	7728	30313
รถตู้ ปิคอัพ	469	2	132	1507	2110	2915	17	487	6064	9483	1101	3	121	2180	3405	14998
รถใหญ่	49	212	27	246	534	130	556	61	757	1504	57	167	28	371	623	2661
ร.สิบล้อ	0	53	0	29	82	0	159	0	70	229	0	45	0	31	76	387
รถบรรทุก	3	1	10	8	22	194	3	34	326	557	0	2	4	12	18	597
สามล้อ	525	0	34	594	1153	1508	0	85	1117	2710	674	0	44	415	1133	4991
รวม	2610	616	551	6477	10194	9731	735	1286	19015	30767	4360	217	410	7996	12983	[illegible]
[illegible]	7.00-9.00				938	9.00-16.00				7819	16.00-19.00				[illegible]	[illegible]

ข้อมูลปริมาณการจราจรบริเวณทางแยก (ปี 2541)

ชื่อทางแยก เพ็ญศรี
ถนน วรจักร-บำรุงเมือง-จักรพรรดิพงษ์ หมายเลข 44 วันที่ 24 มีนาคม 2541 สภาพอากาศ ปกติ





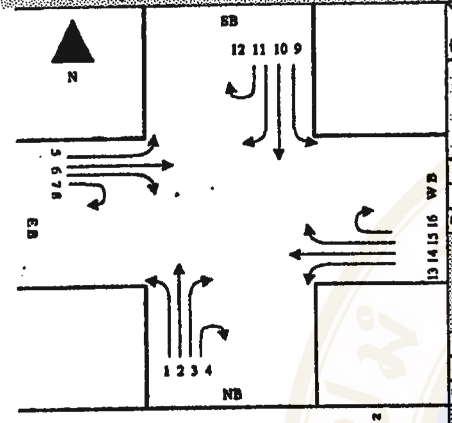
งานเก็บข้อมูล ส่วนสำรวจและวิเคราะห์
จราจร สำนักการจราจรและขนส่ง

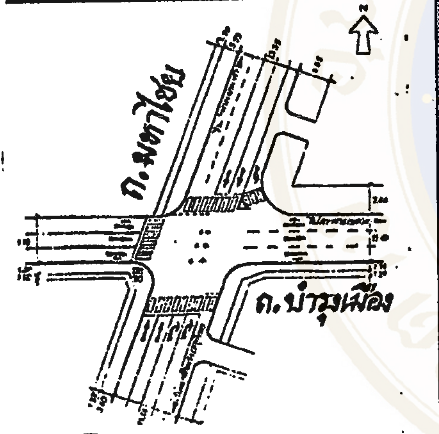
ทิศทาง \ เวลา		ปริมาณการจราจรเฉลี่ยต่อช่วงเวลา (คัน/ชม.)							(ไม่รวมรถจักรยานยนต์)						ปริมาณ 24		เฉลี่ย
		07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	รวม	ต่ำสุด	สูงสุด	PCU/HOUR
NB	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	475	572	574	588	508	499	474	573	619	684	680	551	6797	474	684	617
	3	156	152	196	179	166	207	184	189	171	213	190	196	2199	152	213	187
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า		631	724	770	767	674	706	658	762	790	897	870	747	8996	631	897	
ออก		898	917	952	1035	1108	1108	1255	1272	1169	1210	1167	1158	13249	898	1272	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ต่ำสุด	สูงสุด	
	15	154	654	730	775	761	674	678	681	779	820	887	853	8446	154	887	
	30	284	712	745	769	727	697	664	699	787	846	872	830	8632	284	872	
	45	457	716	770	763	701	696	655	734	790	877	871	787	8817	457	877	
QL (เมตร)		52	52	53	53	54	53	60	63	71	73	68	61				
EB	5	223	307	276	217	246	252	383	373	347	437	388	351	3800	217	437	320
	6	2332	2172	1908	1745	1673	1719	1994	2151	2254	1996	1780	1717	23441	1673	2332	1969
	7	142	143	177	171	180	169	292	302	291	272	218	193	2550	142	302	211
	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า		2697	2622	2361	2133	2099	2140	2669	2826	2892	2705	2386	2261	29791	2099	2892	
ออก		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ต่ำสุด	สูงสุด	
	15	681	2721	2522	2309	2086	2129	2287	2625	2913	2879	2624	2326	28102	681	2913	
	30	1333	2727	2451	2255	2072	2136	2417	2644	2966	2805	2589	2273	28668	1333	2966	
	45	2005	2690	2403	2204	2067	2146	2555	2715	2944	2746	2469	2298	29242	2005	2944	
QL (เมตร)		133	148	213	219	219	219	200	200	200	200	200	200				
SB	9	1141	1196	1043	923	928	988	970	955	890	838	905	1016	11793	838	1196	1001
	10	756	774	775	864	928	939	963	970	878	938	949	965	10699	756	970	932
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า		1897	1970	1818	1787	1856	1927	1933	1925	1768	1776	1854	1981	22492	1768	1981	
ออก		698	879	850	805	754	751	857	946	966	1121	1068	902	10597	698	1121	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ต่ำสุด	สูงสุด	
	15	425	1968	1938	1794	1814	1872	1935	1932	1884	1763	1769	1935	21029	425	1968	
	30	898	2002	1899	1772	1822	1903	1941	1900	1872	1787	1724	2007	21527	898	2007	
	45	1400	1988	1872	1762	1849	1901	1927	1925	1808	1802	1744	2041	22019	1400	2041	
QL (เมตร)		92	90	71	72	100	67	79	81	84	81	97	79				
WB	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
ออก		3629	3520	3147	2847	2767	2914	3148	3295	3315	3047	2875	2929	37433	2767	3629	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ต่ำสุด	สูงสุด	
	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
QL (เมตร)		0	0	0	0	0	0	0	0	0	0	0	0				

ข้อมูลปริมาณการจราจรบริเวณทางแยก (ปี 2541)

ชื่อทางแยก สำราญราษฎร์

ถนน บำรุงเมือง-มหาไชย หมายเลข 70 วันที่ 18 กุมภาพันธ์ 2541 สภาพอากาศ ปกติ





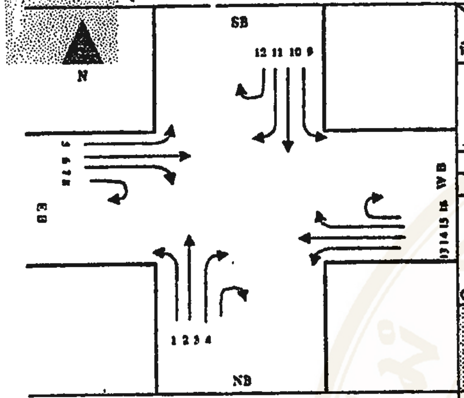
ผลิตและข้อมูล ส่วนสำรวจและวิเคราะห์
โดยกอง สำนักการจราจรและขนส่ง

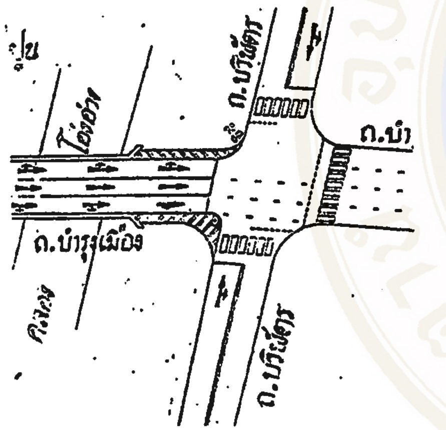
เวลา / ทิศทาง		ปริมาณการจราจรแต่ละช่วงเวลา (คัน/ชม.)								(ไม่รวม รถจักรยานยนต์)					เฉลี่ย	ปริมาณ รถ	
ทิศทาง		07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	รวม	ระหว่างวัน	ต่ำที่สุด	สูงที่สุด
NB	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	1208	1144	1078	965	1118	1120	1238	1214	1174	1159	1022	1153	13593	1185	965	1238
	3	582	537	501	435	527	508	477	372	441	394	327	240	5341	448	240	582
	4	203	217	275	299	376	368	235	210	145	147	194	156	2825	237	145	376
เข้า NB		1790	1681	1579	1400	1645	1628	1715	1586	1615	1553	1349	1393	18934	1869	1349	1790
ออก NB		595	538	585	673	779	748	567	571	508	469	534	485	7052	611	469	779
QL (เมตร)		55	56	50	53	55	50	50	62	50	50	50	50				
EB	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6	1490	1495	1270	1158	1228	1205	1335	1461	1377	1450	1364	874	15707	1327	874	1495
	7	65	61	55	70	57	39	50	27	25	23	29	28	529	44	23	70
	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า EB		1555	1556	1325	1228	1285	1244	1385	1488	1402	1473	1393	902	16236	1370	902	1556
ออก EB		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
QL (เมตร)		116	124	66	75	113	142	101	162	126	93	94	69				
SB	9	592	600	703	745	576	642	734	683	748	772	770	671	8236	688	576	772
	10	327	260	255	304	346	341	282	334	338	299	311	301	3698	331	255	346
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า SB		919	860	958	1049	922	983	1016	1017	1086	1071	1081	972	11934	1018	860	1086
ออก SB		1208	1144	1078	965	1118	1120	1238	1214	1174	1159	1022	1153	13593	1185	965	1238
QL (เมตร)		55	56	50	53	55	50	50	62	50	50	50	50				
WB	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า WB		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ออก WB		2664	2632	2474	2338	2331	2355	2546	2516	2566	2616	2461	1785	29284	2462	1785	2664
QL (เมตร)		0	0	0	0	0	0	0	0	0	0	0	0				

ประเภท	NB 7-9	SB 7-9	EB 7-9	WB 7-9	รวม	NB 9-16	SB 9-16	EB 9-16	WB 9-16	รวม	NB 16-19	SB 16-19	EB 16-19	WB 16-19	รวม	ตลอดวัน
รถยนต์	2628	1165	1165	0	4958	6718	4806	3531	0	15055	3051	2282	1628	0	6961	26974
รถตู้,ปิคอัพ	793	558	309	0	1660	4569	2599	2103	0	9231	1195	796	929	0	2920	13811
รถเมล์ใหญ่	82	14	27	0	123	175	46	116	0	337	70	37	36	0	143	603
รถเมล์เล็ก	36	0	25	0	61	76	1	80	0	157	34	0	34	0	68	286
รถบรรทุก	19	1	0	0	20	231	192	96	0	519	7	6	4	0	17	556
สามล้อ	333	448	253	0	1034	1307	1753	1105	0	4165	435	647	493	0	1575	6774
รวม	3891	2186	1779	0	7856	13076	9357	7031	0	29464	4792	3768	3124	0	11684	49004
PCU	7.00-9.00				3990	9.00-16.00				4343	16.00-19.00				3930	44395

ข้อมูลปริมาณการจราจรบริเวณทางแยก (ปี 2541)

ชื่อทางแยก ญี่ปุ่น
ถนน บำรุงเมือง-บริพัตร หมายเลข 73 วันที่[redacted] 25 พฤษภาคม 2541 สภาพอากาศ ปกติ





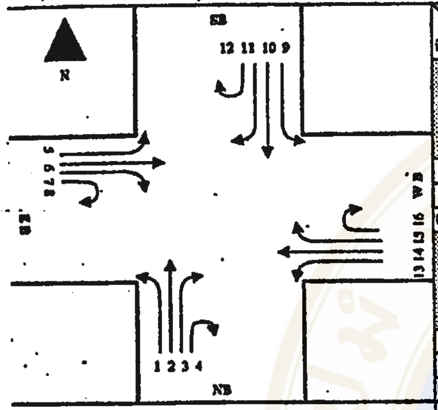
ทิศทาง	เวลา	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	รวม	ปริมาณ รถ ต่ำที่สุด	ปริมาณ รถ สูงที่สุด	เฉลี่ย PCU/HOUR
NB	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	3	6	3	6	3	3	4	3	3	4	5	3	46	3	6	4
	3	44	60	47	40	51	55	.108	122	76	57	54	35	749	35	122	63
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า		47	66	50	46	54	58	112	125	79	61	59	38	795	38	125	
ออก		4	5	1	10	10	13	16	6	6	8	7	7	93	1	16	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ต่ำที่สุด	สูงที่สุด	
	15	12	50	66	49	46	57	61	133	112	71	53	55	765	12	133	
	30	21	61	58	48	49	54	90	119	101	70	55	48	774	21	119	
	45	36	61	55	48	49	57	100	124	89	67	56	41	783	36	124	
QL (เมตร)		0	0	0	0	0	0	0	0	0	0	0	0				
EB	5	3	3	4	22	28	38	36	42	40	21	14	4	255	3	42	21
	6	2295	2248	2071	2239	2420	2384	2447	2590	2451	2021	2111	2125	27402	2021	2590	2304
	7	3	4	1	7	9	12	15	6	5	8	7	6	83	1	15	7
	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า		2301	2255	2076	2268	2457	2434	2498	2638	2496	2050	2132	2135	27740	2050	2638	
ออก		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ต่ำที่สุด	สูงที่สุด	
	15	554	2340	2209	2055	2340	2485	2407	2549	2630	2471	1966	2131	26136	554	2630	
	30	1105	2375	2138	2117	2398	2454	2447	2598	2573	2344	1973	2133	26654	1105	2598	
	45	1682	2346	2084	2189	2430	2472	2462	2622	2510	2206	2053	2133	27169	1682	2622	
QL (เมตร)		0	0	0	0	0	0	0	0	0	0	0	0				
SB	9	442	478	444	476	462	423	421	437	330	337	430	423	5103	330	478	431
	10	1	1	0	3	1	1	1	0	1	0	0	1	10	0	3	1
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า		443	479	444	479	463	424	422	437	331	337	430	424	5113	331	479	
ออก		6	9	7	28	31	41	40	45	43	35	19	7	301	6	45	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ต่ำที่สุด	สูงที่สุด	
	15	106	461	475	429	489	443	431	454	413	295	354	416	[illegible]	106	489	
	30	214	466	476	435	482	443	410	457	307	276	415	423	4804	214	482	
	45	326	479	458	452	470	435	453	465	352	319	420	419	[illegible]	219	480	
QL (เมตร)		0	0	0	0	0	0	0	0	0	0	0	0				
WB	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
เข้า		[illegible]	[illegible]	0	[illegible]	0	0	[illegible]	0	0	0	[illegible]	0	[illegible]	[illegible]	0	
ออก		[illegible]	[illegible]	[illegible]	2715	2523	2462	2576	[illegible]	2657	2415	[illegible]	2187	[illegible]	[illegible]	[illegible]	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ต่ำสุด	สูงสุด	
	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	0	0	[illegible]	0	[illegible]	[illegible]	0	
	45	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	0	0	0	[illegible]	[illegible]	0	0	0	0	
QL (เมตร)		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	[illegible]	[illegible]	[illegible]				

งานสถิติและข้อมูล [illegible]
[illegible]

ข้อมูลปริมาณการจราจรบริเวณทางแยก (ปี 2541)

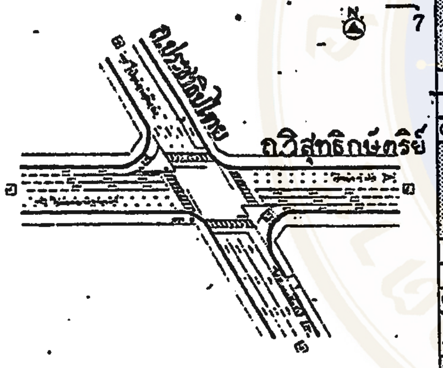
ชื่อทางแยก วิสุทธิกษัตริย์

ถนน ประชาธิปไตย-วิสุทธิกษัตริย์ หมายเลข 77 วันที่ 21 มกราคม 2541 สภาพอากาศ ปกติ



เวลา		[illegible]								(ไม่รวมรถจักรยานยนต์)					เฉลี่ย	ปริมาณ/ชม.	
ทิศทาง		07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	รวม	ระหว่างวัน	ต่ำสุด	สูงสุด
NB	1	448	269	262	261	287	253	129	162	257	249	234	213	3024	248	129	448
	2	1190	1221	1159	1120	1144	1246	965	1051	933	836	855	891	12631	1115	855	1246
	3	212	183	153	177	174	172	93	155	186	262	236	219	2222	189	93	262
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า NB		1850	1673	1574	1558	1605	1671	1187	1368	1376	1367	1325	1323	17877	1552	1187	1850
ออก NB		76	78	70	73	95	88	48	54	67	72	67	57	845	112	48	95
QL (เมตร)		50	50	50	50	50	50	50	50	50	50	50	50				
EB	5	312	343	343	321	376	401	385	386	337	262	281	252	3999	333	252	401
	6	770	601	574	616	702	689	340	422	475	655	590	394	6828	573	340	770
	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า EB		1082	944	917	937	1078	1090	725	808	812	917	871	646	10827	905	646	1090
ออก EB		1130	820	584	589	787	781	573	544	683	666	731	646	8534	713	544	1130
QL (เมตร)		60	60	60	60	60	60	51	50	50	51	50	50				
SB	9	23	26	25	25	28	25	9	4	16	18	8	6	213	18	4	28
	10	66	65	59	62	84	77	42	43	58	64	61	52	733	99	42	94
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า SB		89	91	84	87	112	102	51	47	74	82	69	58	946	117	47	112
ออก SB		1602	1671	1627	1565	1642	1781	1436	1546	1334	1159	1197	1188	17748	1541	1159	1781
QL (เมตร)		50	50	50	50	50	50	50	50	50	50	50	50				
WB	13	10	13	11	11	11	11	6	11	9	8	6	5	112	13	5	13
	14	682	551	322	328	500	528	444	382	426	417	497	433	5510	465	322	682
	15	100	107	125	124	122	134	86	109	64	41	61	45	1118	93	41	134
	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า WB		792	671	458	463	633	673	536	502	499	466	564	483	6740	571	458	792
ออก WB		1005	810	752	818	904	886	442	581	677	935	834	619	9263	779	442	1005
QL (เมตร)		61	63	55	56	55	60	50	50	50	50	50	50				

ประเภท	NB 7-9	EB 7-9	SB 7-9	WB 7-9	รวม	NB 9-16	EB 9-16	SB 9-16	WB 9-16	รวม	NB 16-19	EB 16-19	SB 16-19	WB 16-19	รวม	รวมทั้งวัน
รถยนต์	2328	31	31	951	3341	6132	3676	190	2215	12213	3641	1573	78	866	5158	20712
รถตู้,ปิคอัพ	615	258	31	220	1124	2393	1487	76	619	4675	591	366	22	278	1257	7056
รถบัสใหญ่	85	13	54	16	168	292	52	178	90	612	141	29	78	38	286	1066
รถบัสเล็ก	44	0	63	0	107	133	2	106	1	242	67	0	31	0	98	447
รถบรรทุก	6	3	1	2	12	141	43	7	22	213	2	1	0	2	5	230
สามล้อ	445	384	0	274	1103	1348	1107	0	617	3072	573	465	0	327	1365	5540
รวม	3523	689	180	1463	5855	10339	6367	557	3764	21027	4015	2434	209	1511	8169	35051
PCU	7.00-9.00				3017	9.00-16.00				3132	16.00-19.00				2815	31651



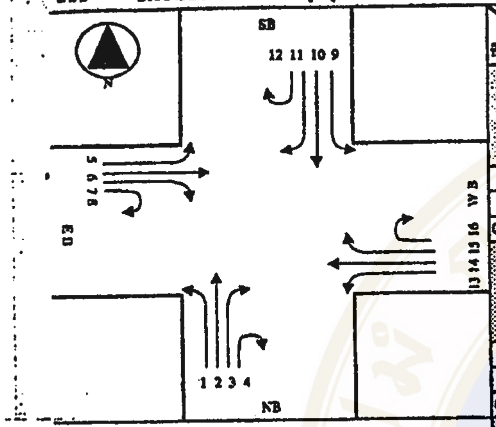
ฝ่ายสถิติและข้อมูล ส่วนสำรวจและวิเคราะห์
โครงการ สำนักการจราจรและขนส่ง

ข้อมูลปริมาณการจราจรบริเวณทางแยก (ปี 2540)

ชื่อทางแยก สะพานวันชาติ

ถนน ประชาธิปไตย-ดินสอ-พระสุเมรุ หมายเลข 78

วันที่ 12 กันยายน 2540 สภาพอากาศ ปกติ



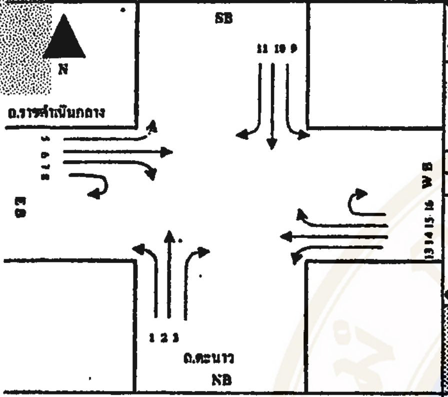
ทิศทาง \ เวลา		ปริมาณการจราจรแต่ละช่วงเวลา (คัน/ชม.)						(ไม่รวม รถจักรยานยนต์)							เฉลี่ย	ปริมาณ รถ	
		07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	รวม	ระหว่างวัน	ต่ำสุด	สูงสุด
NB	1	261	210	295	222	166	154	158	252	202	92	70	76	2158	203	70	295
	2	1040	1014	931	758	729	774	678	646	596	631	651	641	9089	784	596	1040
	3	47	63	56	72	68	73	83	67	68	96	90		359	71	47	96
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า NB		1348	1287	1282	1052	963	1003	919	965	866	819	811	791	12106	1059	791	1348
ออก NB		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
QL (เมตร)		-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50				
EB	5	894	805	826	819	788	890	542	657	669	504	453	419	8266	716	419	894
	6	472	466	432	461	455	448	606	602	657	719	705	774	6797	571	432	774
	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า EB		1366	1271	1258	1280	1243	1338	1148	1259	1326	1223	1158	1193	15063	1287	1148	1366
ออก EB		365	291	375	318	281	275	331	414	340	213	203	223	3629	348	203	414
QL (เมตร)		234	118	-50	34	51	34	47	48	41	55	96	35				
SB	9	90	62	46	59	60	49	23	20	50	38	58	43	598	75	20	90
	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11	38	35	21	18	32	33	22	19	11	8	11	9	257	39	8	38
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า SB		128	97	67	77	92	82	45	39	61	46	69	52	855	115	39	128
ออก SB		1995	1891	1850	1652	1630	1837	1312	1427	1355	1258	1217	1189	18643	1609	1189	1995
QL (เมตร)		-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50				
WB	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	14	66	46	59	78	83	88	151	143	127	113	122	138	1214	106	46	151
	15	61	72	93	105	113	173	92	124	90	123	113	129	1288	109	61	173
	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า WB		127	118	152	183	196	261	243	267	217	236	235	267	2502	215	118	267
ออก WB		609	591	534	592	583	572	712	689	775	853	853	891	8254	718	534	891
QL (เมตร)		-50	-50	-50	-50	-50	-50	0	0	0	0	0	0				

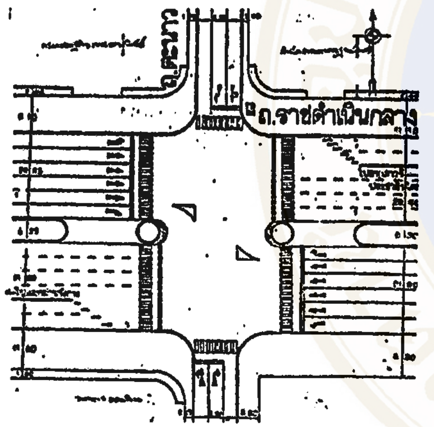
ประเภท	NB 7-9	EB 7-9	SB 7-9	WB 7-9	รวม	NB 9-16	EB 9-16	SB 9-16	WB 9-16	รวม	NB 16-19	EB 16-19	SB 16-19	WB 16-19	รวม	ตลอดวัน
รถยนต์	1614	66	66	147	1893	3990	5044	49	783	9865	1679	2166	39	397	4282	16021
รถตู้/ปิคอัพ	557	465	17	60	1099	1683	1637	58	418	3798	423	637	37	233	1330	6227
รถเมล์ใหญ่	113	70	84	4	271	287	268	215	28	798	70	74	63	17	224	1293
รถเมล์เล็ก	35	19	57	0	111	136	103	138	11	388	41	37	36	21	135	634
รถบรรทุก	5	3	1	0	9	48	32	3	20	103	0	0	1	0	1	113
สามล้อ	311	485	0	34	830	904	1768	0	259	2931	217	660	1	70	948	4709
รวม	2635	1108	225	245	4213	7050	8852	463	1519	17884	2421	3574	167	738	6900	28997
PCU	7.00-9.00				2261	9.00-16.00				3993	16.00-19.00				2383	26555

สถิติและข้อมูล ส่วนสำรวจและวิเคราะห์
วิศวกรรม สำนักการจราจรและขนส่ง

ข้อมูลปริมาณการจราจรบริเวณทางแยก (ปี 2541)

ชื่อทางแยก คอกวัว
ถนน ราชดำเนินกลาง-ตะนาว หมายเลข 79 วันที่ 26 กุมภาพันธ์ 2541 สภาพอากาศ ปกติ





ทิศทาง	เวลา	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	รวม	ค่าต่ำสุด	ค่าสูงสุด	เฉลี่ย PCU/HOUR
		ปริมาณการจราจรแต่ละช่วงเวลา (คัน/ชม.) (ไม่รวมรถจักรยานยนต์)													ปริมาณ รถ		
NB	1	80	90	87	98	122	138	82	71	96	201	166	163	1394	71	201	117
	2	124	152	117	170	208	218	135	84	150	121	110	117	1706	84	218	141
	3	123	225	188	177	158	289	299	316	221	193	209	203	2601	123	316	217
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า		327	467	392	445	488	645	516	471	467	515	485	483	5701	327	645	
ออก		620	596	631	598	583	569	581	501	544	454	366	348	6391	348	631	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ค่าต่ำสุด	ค่าสูงสุด	
	15	68	385	434	409	458	518	623	519	454	484	513	476	5341	68	623	
	30	138	440	406	428	457	559	602	504	459	486	506	472	5457	138	602	
	45	224	461	395	441	474	610	543	491	474	493	493	479	5578	224	610	
QL (เมตร)		58	60	98	69	67	67	156	193	181	285	281	297				
EB	5	266	263	268	255	245	196	155	73	73	64	94	99	2051	64	268	177
	6	2578	2133	2203	2213	2464	2551	2969	3165	3216	2796	2544	2825	31659	2133	3216	2902
	7	121	103	130	108	114	134	119	95	124	117	110	94	1369	94	134	114
	8	43	48	66	48	73	119	146	161	151	176	171	309	1511	43	309	127
เข้า		3008	2547	2669	2624	2896	3000	3389	3494	3564	3153	2919	3327	36590	2547	3564	
ออก		3677	2480	2728	2423	2991	3118	3432	3459	3514	3865	3954	3831	38472	2423	3954	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ค่าต่ำสุด	ค่าสูงสุด	
	15	746	2956	2561	2813	2660	2940	3095	3448	3492	3533	3081	2935	34060	746	3533	
	30	1490	2853	2603	2591	2709	2983	3199	3448	3481	3491	3312	3343	34905	1490	3491	
	45	2267	2690	2621	2604	2808	3005	3277	3456	3532	3325	2989	3209	35783	2267	3532	
QL (เมตร)		229	249	222	229	237	215	146	208	153	156	183	132				
SB	9	64	65	52	79	71	89	96	81	48	25	25	31	726	25	96	61
	10	216	216	235	243	221	173	166	140	128	129	148	137	2152	128	243	176
	11	329	296	297	321	291	299	374	365	357	387	402	316	4034	291	402	351
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า		609	577	584	643	583	561	636	586	533	541	575	484	6912	484	643	
ออก		537	541	520	582	618	569	565	413	480	408	341	365	5879	365	618	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ค่าต่ำสุด	ค่าสูงสุด	
	15	144	620	565	605	637	550	602	628	559	527	566	571	6574	144	637	
	30	281	617	555	622	634	548	631	619	538	532	570	553	6700	281	634	
	45	448	597	572	634	606	561	620	611	528	535	575	522	6809	448	634	
QL (เมตร)		62	62	54	78	80	143	159	220	216	220	217	220				
WB	13	283	277	266	247	248	262	296	266	292	208	108	117	2870	108	296	235
	14	2225	2045	2278	1956	2505	2562	2830	2862	2910	3101	3215	3043	31532	1956	3215	2531
	15	147	126	135	157	165	155	275	256	257	223	137	89	2123	89	275	192
	16	23	18	26	21	26	22	33	40	41	33	26	12	321	12	41	27
เข้า		2678	2467	2705	2381	2944	3001	3434	3424	3500	3565	3486	3261	36846	2381	3565	
ออก		2788	2441	2471	2492	2719	2951	3397	3602	3526	3047	2854	3071	35307	2441	3602	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ค่าต่ำสุด	ค่าสูงสุด	
	15	743	2589	2466	2696	2437	2985	3136	3362	3519	3475	3600	3455	34463	743	3600	
	30	1390	2511	2565	2534	2573	3002	3241	3343	3540	3493	3601	3394	35287	1390	3601	
	45	2012	2503	2656	2403	2644	3002	3238	3361	3548	3518	3529	3355	36069	2012	3548	
QL (เมตร)		74	60	102	180	172	251	164	173	192	165	220	154				

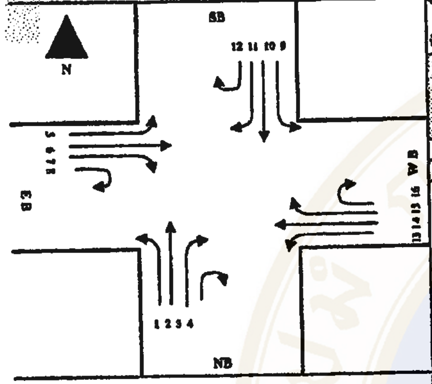
[illegible]
กองวิศวกรรม สำนักการจราจรและขนส่ง

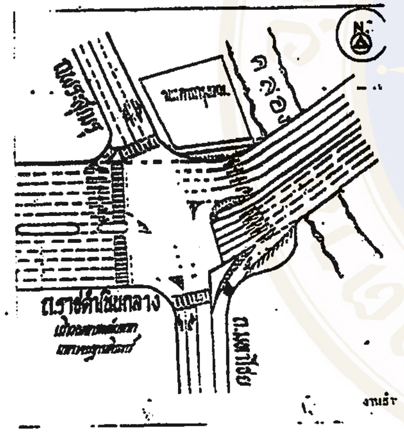
ข้อมูลปริมาณการจราจรบริเวณทางแยก (ปี 2541)

ชื่อทางแยก พระนั่งเกล้า

ถนน ราชดำเนินกลาง-พระสุเมรุ-มหาไชย หมายเลข 9

วันที่ 6 พฤษภาคม 2541 สภาพอากาศ ปกติ





ทิศทาง	เวลา	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	รวม	ต่ำสุด	สูงสุด	เฉลี่ย ความยาวแถวคอย
NB	1	301	365	483	566	586	499	523	523	507	628	701	463	6145	301	701	540
	2	101	153	169	175	135	177	150	120	83	89	157	127	1636	83	177	138
	3	562	665	619	585	516	437	370	462	540	619	570	633	6578	370	665	561
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า		964	1183	1271	1326	1237	1113	1043	1105	1130	1336	1428	1223	14359	964	1428	
ออก		1462	1397	1509	1687	1451	1373	1266	1326	1439	1405	1529	1366	17210	1266	1687	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ต่ำสุด	สูงสุด	
	15	237	1015	1197	1299	1313	1191	1103	1092	1095	1174	1342	1368	13426	237	1368	
	30	467	1080	1221	1324	1299	1147	1088	1097	1106	1224	1354	1326	13733	467	1354	
	45	717	1131	1233	1334	1268	1123	1072	1117	1121	1271	1382	1285	14054	717	1382	
QL (เมตร)		76	73	66	56	100	164	81	81	79	77	74	72				
EB	5	41	40	44	55	28	31	27	25	37	17	15	19	379	15	55	32
	6	3315	3531	2900	2504	2391	2534	2670	2478	2320	1616	2035	2272	30566	1616	3531	2711
	7	629	499	547	514	496	476	337	347	397	259	257	283	5041	257	629	437
	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า		3985	4070	3491	3073	2915	3041	3034	2850	2754	1892	2307	2574	35986	1892	4070	
ออก		2697	3023	2977	3712	4028	3421	3601	3658	3333	3235	3128	2894	39707	2697	4028	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ต่ำสุด	สูงสุด	
	15	958	4021	3881	3517	2863	3723	3049	2990	2802	2463	2049	2390	34036	958	4021	
	30	1964	4159	3709	3344	2831	3053	3055	2977	2779	2215	2139	2459	34684	1964	4159	
	45	2970	4150	3598	3176	2873	3061	3046	2922	2781	2010	2235	2510	35332	2010	4150	
QL (เมตร)		178	161	154	143	134	150	185	210	215	213	218	218				
SB	9	180	189	227	237	334	324	268	216	223	223	193	176	2790	176	334	235
	10	182	240	252	207	169	150	247	288	190	382	443	387	3109	150	443	268
	11	77	87	76	97	68	60	94	100	116	81	88	93	1035	60	116	112
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า		439	516	555	541	569	534	609	576	529	686	724	636	6934	439	724	
ออก		142	193	213	230	163	208	177	145	120	106	172	146	2015	106	230	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ต่ำสุด	สูงสุด	
	15	113	434	549	548	552	564	553	592	572	532	733	705	6447	113	733	
	30	214	458	556	558	548	568	556	582	568	562	747	693	6612	214	747	
	45	335	478	550	560	556	542	604	539	555	640	733	687	6779	335	733	
QL (เมตร)		63	69	62	59	77	158	211	225	207	193	153	144				
WB	13	651	658	710	966	786	747	682	719	852	764	829	696	9060	651	966	768
	14	2319	2571	2418	3049	3376	2862	2984	3035	2710	2526	2339	2338	32527	2319	3376	2903
	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
เข้า		2970	3229	3128	4015	4162	3609	3666	3734	3562	3290	3168	3034	41587	2970	4162	
ออก		4057	4385	3746	3326	3241	3295	3308	3156	3083	2458	2798	3081	39934	2458	4385	
	นาที	7.-	8.-	9.-	10.-	11.-	12.-	13.-	14.-	15.-	16.-	17.-	18.-	รวม	ต่ำสุด	สูงสุด	
	15	667	3116	3169	3390	4060	3982	3605	3737	3767	3310	3216	3284	39303	667	4060	
	30	1436	3098	3279	3651	4069	3763	3618	3749	3763	3223	3291	3116	40056	1436	4069	
	45	2161	3191	3208	3798	4195	3679	3615	3716	3842	2917	3441	3058	40821	2161	4195	

QL = 301 หมายถึง 300 เมตรขึ้นไป
QL = -50 หมายถึง น้อยกว่า 50 เมตร
งานสถิติและข้อมูล ส่วนสำรวจและวิเคราะห์

APPENDIX B

VISUAL BASIC PROGRAMMING

DATA DECLARATION FOR SINGLE JUNCTION SIMULATION

```
'Public Constant
Public Const maxJunc = 100
Public Const MAXROAD = 200
Public Const MAX_FN = 8
Public Const MAX_DIR = 16
Public Const MAX_SIM_TIME = 2000

'Public constant - Characteristics
Public Const AVG_NETWORK_SPEED = 10#
Public Const AVG_CAR_LENGTH = 2.4
Public Const MEAN_CAR_ARRIVAL = 60
Public Const STD_LANES = 2

'Public application path & system
Public Const APPLPATH = "c:\Thesis\Current Development\BkkTraffSim"

'Public Type declaration
Type Junction
  ID As String
  Name As String
  CurrX As Integer
  CurrY As Integer
End Type

Type road
  ID As String
  Name As String
  X As Integer
  Y As Integer
  FromJunc As String
  ToJunc As String
  Length As Double
  FromToLanes As Integer
  FromToSpeed As Double
  ToFromLanes As Integer
  ToFromSpeed As Double
  MeanCarArrival As Integer
End Type

Type TraffVolume
  JID As String              'Junction ID
  Vol(1 To 12, 1 To 16) As Integer     'Traffic Volume by Direction
  NB_In As Integer              'Sum of Direction 1..4
  NB_Out As Integer              'Direction 7 + 10 + 13
  EB_In As Integer              'Sum of Direction 5..8
  EB_Out As Integer              'Direction 1 + 11 + 14
  SB_In As Integer              'Sum of Direction 9..12
  SB_Out As Integer              'Direction 2 + 5 + 15
  WB_In As Integer              'Sum of Direction 12..16
  WB_Out As Integer              'Direction 3 + 6 + 9
End Type

Type JuncFnCtrl
  JID As String
  nFn As Integer
  CycleTime As Integer
  Dir_Allow(1 To 16) As Boolean
End Type

Type TimingCtrl
  JID As String
  CtrlType As String
  CycleTime As Integer
  Fn_DirAllow(1 To 8, 1 To 16) As Boolean
  Fn_CycleTime(1 To 8) As Integer
  Fn_Active(1 To 8) As Boolean
End Type

Type SingleSimRept
  CarGen(1 To 16) As Integer
  QLen(1 To 16) As Integer
End Type

'Public variables
Public Junction(1 To maxJunc) As Junction
Public tempJunction As Junction
Public road(1 To MAXROAD) As road
Public tempRoad As road

'Temporary traffic volumn 1 for 7-8,...,12 for 18-19
Public tempTraffVol As TraffVolume
Public tempTimeCtrl As TimingCtrl
Public currFn As JuncFnCtrl
Public CurrJunc As Integer
Public SimPeriod As Integer
Public tempSingleSim(1 To MAX_SIM_TIME) As SingleSimRept
Public nTimeSingleSim As Integer
```

DATA DECLARATION FOR NETWORK SIMULATION

```
Public Const GenNodeWidth = 100
Public Const MAXNODE = 30
Public Const MAXLINK = 100
Public Const MAXPATH = 100
Public Const MaxCars = 1000
Public Const Road_Height = 400
Public Const Road_Width = 400
Public Const Junc_Height = 800
Public Const Junc_Width = 800

Type Junc_Location
  Index As Integer
  X As Integer
  Y As Integer
  ID As String
End Type

Type FlowDirection
  Dir As Integer
  fromRoad As String
  toRoad As String
  Green As Boolean
End Type

Type JuncNode
  ID As String
  Left As Integer
  Top As Integer
  TraffFlow(1 To 16) As FlowDirection
End Type
```

```
Type RoadLink
  ID As String
  FromJunc As String
  ToJunc As String
  Left As Integer
  Top As Integer
  Length As Integer
  Speed As Double
End Type

Type CarInNetwork
  ID As String
  fromNode As String
  ToNode As String
  currNode As String
  toStopLine As Double
  PATH As String
  X As Integer
  Y As Integer
  Speed As Double
  TimeToNextJunc As Long
  GenTime As Integer
  ArrivalTime As Integer
  DepartureTime As Integer
  ExitTime As Integer
  Status As String
End Type

Public J_Node(1 To MAXNODE) As JuncNode
Public nJ_Node As Integer

Public R_Link(1 To MAXLINK) As RoadLink
Public nR_Link As Integer

Public Car(1 To MaxCars) As CarInNetwork
Public nCars As Integer

Public Paths(1 To MAXPATH) As String
Public nPaths As Integer

'Global condition variables
Public totCarsInNetwork As Integer      'vehicles
Public avgCarsArrival As Integer        'vehicles / sec
Public carMinSpeed As Double            'Minimum speed
Public carAvgSpeed As Double            'Average speed
Public carMaxSpeed As Double            'Maximum speed
Public updateTimes As Integer           'Update Network Cycle Time

'Timing control variable
Public J_Ctrl(1 To MAXNODE) As TimingCtrl
Public simClockTick As Integer          'Clock Tick Counter

'Log file
Public logfile As New Collection
```

BIOGRAPHY

NAME	Mr. Nipon Sriyen
DATE OF BIRTH	15 November 1972
PLACE OF BIRTH	Bangkok, Thailand

INSTITUTIONS ATTENDED

Mahidol University, 1989 – 1992:
Bachelor of Science (Mathematics)

POSITION & OFFICE

1993 – 1995, Sahaviriya Advanced Product,
Bangkok, Thailand.
Position: Programmer, Development Dept.

1995 – 1997, Shinawatra Computer and Communications, Bangkok, Thailand.
Position: Programmer Analyst, SAP Dept.

1997 – 1998, Shinawatra Information Technology, Bangkok, Thailand.
Position: Senior Consultant, SAP Dept.

1998 – Present, SAP Thailand
Bangkok, Thailand
Position: Software Developer, Development Dept.