

**MODELLING TOLL OPERATIONS IN
MALAYSIA**

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ABSTRACT

This thesis describes research carried out to investigate and model toll system operations on a closed toll highway network in Malaysia. The main objectives were to identify factors that influence toll operations and to investigate the effect of alternative layouts and strategies on toll system operations.

Field surveys were conducted at the Sungai Besi toll plaza near Kuala Lumpur and the Senai toll plaza near Johor Bahru. Field data included parameters such as traffic flow, composition, headway and speed distributions that are the demand elements to the toll system and the plaza layout, number of toll booths and service times distribution that are the supply components of the system. Drivers' booth selection behaviour and move-up times were also studied. The data showed that while drivers follow each other very closely on the highway they take a relatively long time to move-up into service when in queue at the toll booths.

A microscopic time scanning simulation model that describes traffic behaviour in a toll system has been developed. The model deals with the following toll operations strategies: closed and opened toll systems, different toll collection systems and multiple toll systems. The model has been calibrated and validated by comparing measures of delay and throughput with data obtained at the Sungai Besi toll plaza over several peak and off-peak periods.

The model has also been applied to examine the impact of introducing automatic vehicle identification (AVI) in the tolling system. The results show that the number of AVI booths provided should be limited to a certain number when the percentage of vehicles using the AVI system is less than or equal to sixty percent.

A multiple toll situation commonly found at border entries was also examined. The results show that buffer distances will affect vehicle delays and that an optimum buffer distance will result in minimum delays. A proposal has been forwarded for the construction of toll design charts by exploiting the advantages of simulation modelling embodied in the model developed.

ABSTRAK

Tesis ini menerangkan kajian yang telah dijalankan untuk menyelidik dan membangunkan model sistem operasi tol diatas rangkaian lebuh raya tol tertutup di Malaysia. Objektif-objektif utama kajian adalah untuk menyiasat kesan beberapa susunatur dan strategi keatas operasi sistem tol.

Tinjauan tapak telah dijalankan di plaza tol Sungai Besi di Kuala Lumpur dan plaza tol Senai di Johor Bahru. Data-data padang bagi unsur-unsur permintaan kepada sistem tol termasuklah aliran lalulintas, komposisi, ruang lolos dan taburan laju. Data-data komponen penawaran sistem pula adalah susunatur plaza, jumlah pondok tol dan taburan masa khidmat. Sifat pemilihan pondok tol oleh pemandu dan masa gerak depan juga telah dikaji. Data-data tersebut menunjukkan bahawa sementara pemandu mengekori sesama sendiri dengan begitu dekat diatas lebuh raya mereka mengambil masa yang agak lama untuk bergerak ke hadapan untuk perkhidmatan samasa berada didalam baris gilir di pondok-pondok tol.

Satu model simulasi kesan masa secara mikro yang menggambarkan sifat lalulintas didalam sistem tol telah dibentuk. Model berkenaan boleh menguruskan strategi-strategi operasi tol berikut: sistem tol tertutup dan terbuka, pelbagai sistem kutipan tol dan sistem tol berbilang. Model tersebut telah di tentu-ukur dan disahkan dengan membandingkan ukuran-ukuran masa lengah dan keluaran dengan data-data yang diperolehi di plaza tol Sungai Besi sepanjang beberapa waktu puncak dan tidak puncak.

Model tersebut telah digunakan untuk memeriksa kesan penggunaan 'Pengesanan Kenderaan Secara Otomatik' (AVI) didalam sistem tol. Keputusan menunjukkan bahawa jumlah pondok AVI mestilah dihadkan kepada sesuatu jumlah tertentu apabila peratusan kenderaan yang menggunakan sistem AVI adalah kurang atau sama dengan enam puluh peratus.

Satu situasi tol berbilang yang sering didapati dipintu-pintu masuk disempadan telah juga dikaji. Keputusan menunjukkan bahawa jarak pemisah akan memberi kesan kepada masa lengah dan jarak pemisah optimum akan memberikan lengah yang minimum. Satu cadangan telah dimajukan bagi pembentuk carta-carta rekabentuk tol dengan mengeksploitasikan kebaikan-kebaikan pemodelan simulasi yang terdapat didalam model yang telah dibangunkan.

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LIST OF SYMBOLS

a_n	-	Acceleration rate of vehicle n , m/s^2
b_n	-	Deceleration rate of vehicle n , m/s^2
Df	-	Deceleration factor
L_q	-	Average length of queue, m
L	-	Average number of vehicles in a system
P_0	-	Probability there are no vehicles in the system
P_h	-	Probability there are h number of vehicles in the system
$P(x)$	-	Probability of x vehicles arriving during counting time t
Q	-	Traffic flow, veh/hr
T	-	Mean headway, $sec.$
$t_{\alpha, n-1}$	-	student t statistics for level of significance ' α ' and degree of freedom $n-1$
v_a	-	Safe speed under acceleration conditions, km/hr
v_b	-	Safe speed under braking conditions, km/hr
V_n	-	Desired speed of driver of vehicle n , km/hr
W	-	Average time a vehicle spends in a system, $sec.$
W_q	-	Average time a vehicle spends in a queue, $sec.$
α	-	Arrival rate, veh/hr
$1/\mu$	-	Mean service time
Ω	-	Reciprocal of the mean of interbunch gap
ϵ	-	Sample error
σ	-	Standard deviation
τ	-	Minimum headway

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CHAPTER I

INTRODUCTION

1.1 History of toll roads

Owen and Dearing (1951) stated that ' the environment of the twentieth century now appears to hold more promise for the turnpike than the nineteenth century which rejected it'. Turnpike refers to the practice of levying a toll for the privilege of using a road or highway. The turnpike road system emerged in eighteenth century Britain in response to the tremendous growth in transport and commerce at the onset of the Industrial Revolution. Figures 1.1 to 1.3 show the growth in the turnpike road network in Britain in 1740, 1750 and 1770 respectively.

The concept of toll financing was revived with the opening of the Pennsylvania Turnpike in 1940 in the United States of America. By 1950 there were 424 miles of toll roads operating. The basic reason for introducing toll financing was the widening gap between available revenues and the cost of bringing highway facilities to adequate standards (Pawson, 1977).

1.2 Present day toll systems

A second revival of toll roads appeared to have started in the 1980's in Europe following economic difficulties provoked by the Energy Crisis of the 1970's

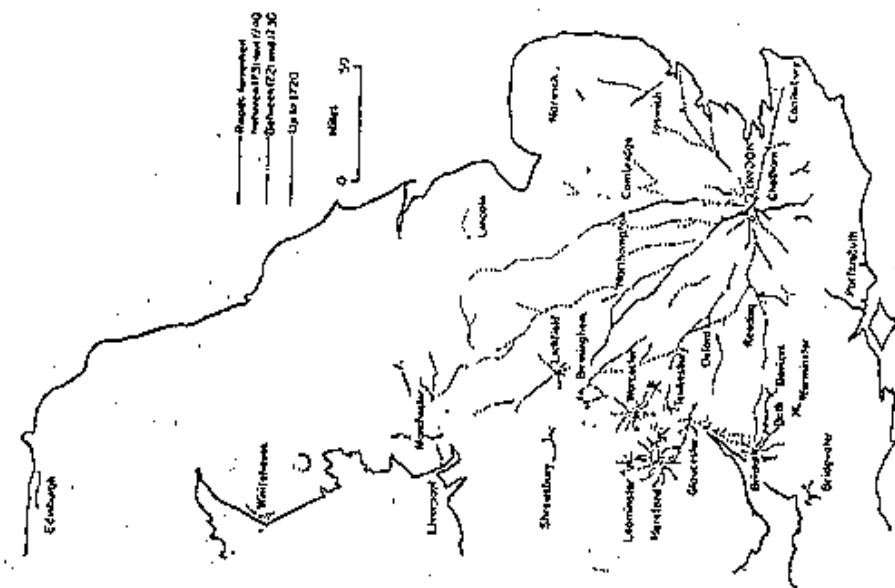


Figure 1.1 The British turnpike road network in 1740 *

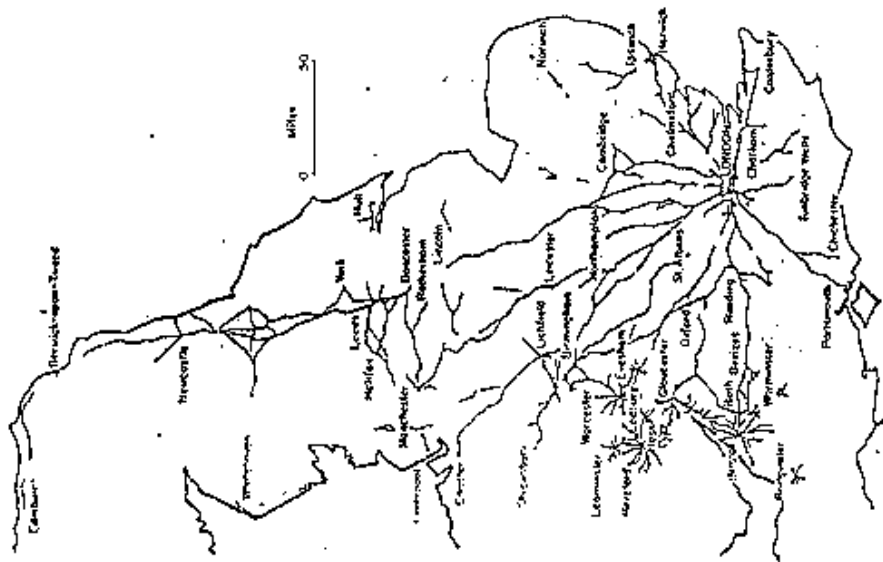


Figure 1.2 The British turnpike road network in 1750 *

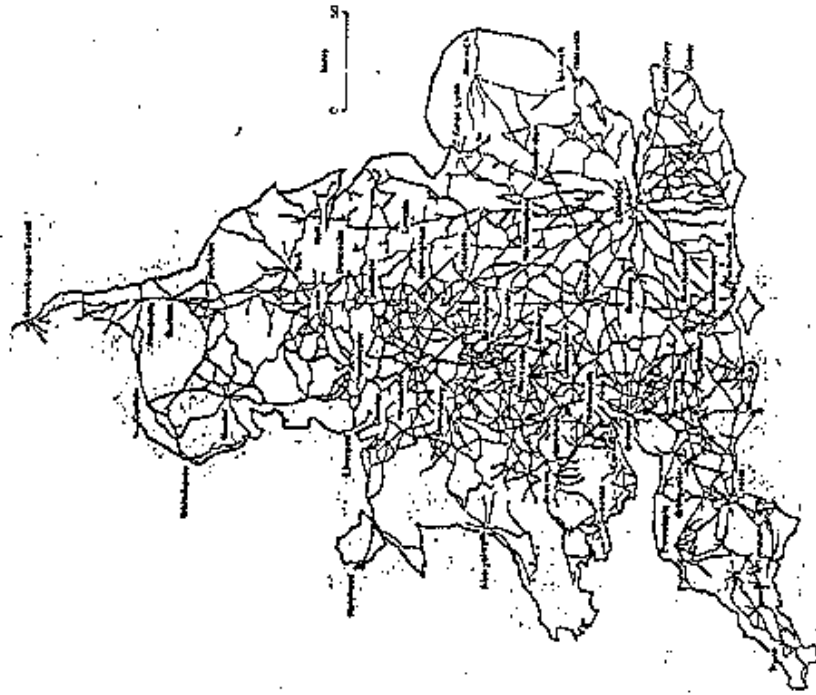


Figure 1.3 The British turnpike road network in 1770

[Source: Pawson, 1977]

(Roth, 1966). By the beginning of the 1990's, the pace of introducing toll roads almost throughout the world seemed to have quickened. In a report published in 1987, the Organisation for Economic Cooperation and Development (OECD) concluded that 'toll financing is a viable alternative to other methods of financing road construction and/or maintenance that should be considered by governments as a funding source for these vital improvements'.

In 1989, nine countries in Europe had tolled motorways in their overall motorway network. Of these countries, France, Italy and Spain accounted for 87 percent (some 15300 km) of the European tolled motorways. Table 1.1 lists the breakdown of the tolled motorways in Europe in 1989. Some of the other countries outside Europe that were also keen on toll roads are India, Thailand, Malaysia, Indonesia and Japan.

1.3 Toll roads in Malaysia

The first toll road in Malaysia was started in March 1966 on the Slim River to Tanjung Malim stretch of the Federal Route 1, the main trunk road at the time (Hunt et al, 1989). Toll was imposed after the original road was realigned with geometric design improvements. The main reason cited by the government for the toll collection was to obtain reimbursements for the cost of the new construction and to sustain a maintenance fund for the road. Toll is still being collected on the road

Table 1.1 Tolloed Motorways in Europe (1989)

Country	Motorway Network (km)	Length (km)	Percentage of Motorway Network (%)	Percentage of European Motorway (%)
Austria	1407	135	9.6	1
France	6940	4987	71.9	37.1
Greece	431	431	100	3.2
Italy	6171	5025	81.4	37.3
Norway	74	13	17.6	0.1
Portugal	196	177	90.3	1.3
Spain	2313	1839	79.5	13.7
Turkey	138	138	100	1
Yugoslavia	1019	716	70.3	5.3
Total	18689	13461	72	100

[Source: Munro-Lafon and Mussett, 1990]

to this day. The Kuala Lumpur-Seremban expressway became the second toll highway in the country when toll was collected for its use beginning in June 1980. The collection system that was used at the time was the open toll system. When the Seremban-Air Keroh stretch was completed, the government implemented the closed-toll system for the whole Kuala Lumpur to Air Keroh link. Under the closed-toll system users are charged according to the distance they travel and this is considered by most as a much fairer system than the open toll system which has a fixed toll regardless of the distance travelled.

At that same time, the government revealed plans for the construction of the biggest road building program ever to be implemented in Malaysia. The program was called the North-South Toll Expressway (NSTE) project. With a total length of approximately 900 kilometres linking Bukit Kayu Hitam near the Thai border to Johor Bahru at the southern tip of Peninsula Malaysia, the expressway will bring large scale tolling throughout the west coast of the Peninsula.

As of 1993, only about 60 percent of the expressway has been completed and is in operation. The remainder of the expressway will be constructed in several packages and is not expected to be completed until the end of 1994. This stage construction ensures that even as part of the NSTE was being constructed, the

completed links could serve the nation while gaining income for its operator. There were 32 toll plazas operating throughout the completed stretches of the expressway in 1993 and it is estimated that a total of 50 toll plazas will be in operation when the whole length of the expressway is completed. Figure 1.4 shows the proposed linkages of the NSTE project.

The estimated cost to complete the construction of the expressway is a hefty 3.45 billion Malaysian Ringgit. To fully finance the remaining stretches of the NSTE the government decided to privatise the construction program and awarded a thirty-years concessionary contract to construct, operate and maintain the NSTE to a private company, the Projek Lebuhraya Utara-Selatan (PLUS) Sdn. Bhd. The mechanism to ensure that the privatisation scheme will work was to allow PLUS to collect toll on the NSTE. The toll rate per kilometre is however set by the government rather than by the operators. As of 1993, the closed toll system, which began operation on 1st October 1987, is in use on all the completed links of the expressway and the system will be adopted for the whole of the expressway when it is completed.

Initially, the administration, construction and operation of the intercity toll expressways were the responsibility of the Malaysian Highway Authority (MHA) a specially formed government agency. Following the privatisation move, the MHA became a government watch

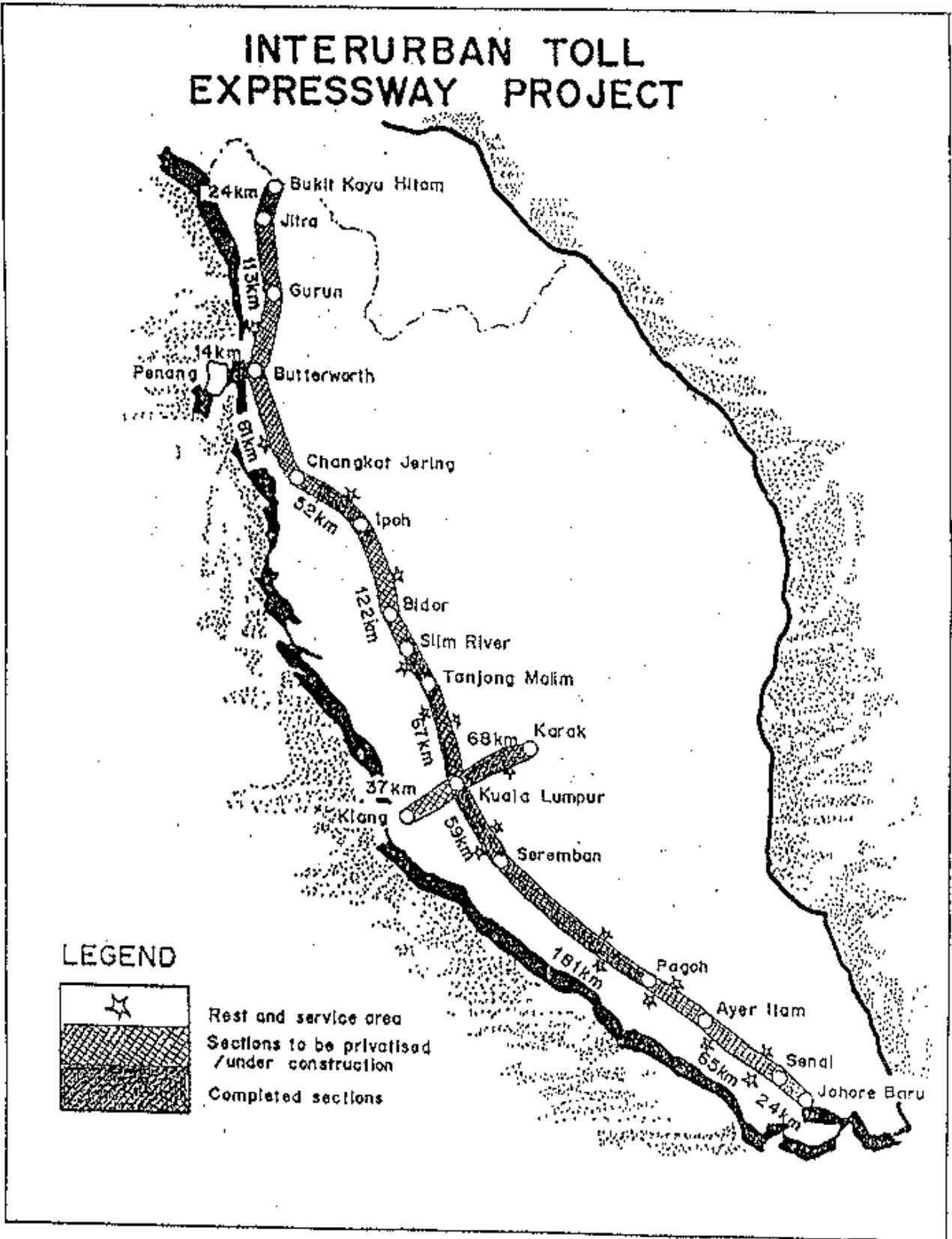


Figure 1.4 The North-South Toll Expressway

dog for the project and was charged with ensuring that the terms of the contract were implemented and adhered to. PLUS officially took over from the MHA on 30th November 1988.

With the present vehicle population standing at around 4.8 million and an annual growth rate of about 10.7 percent (Department of Statistics, 1991), the construction of the NSTE is very timely and appropriate. In addition, the privatisation of the construction and management of the NSTE, following similar government moves in other transportation sectors such as the airline and shipping industries, is an economic necessity for Malaysia. Previously, all road projects were funded by the States or the Federal government, i.e. using tax payers money.

1.4 Methodology of Study

When a new toll system is to be provided for a certain locality the following system components must be decided upon:

- i) the size of toll plaza including the number of booth,
- ii) the type of toll collection - manual or automatic,
- iii) the toll system to implement - closed or open system,
- iv) the number of booths to be opened at any particular time.

Often these issues are left to the discretion of the consulting engineers/designers to recommend. Currently, the only tool available is the use of the 'Steady state queueing' formula. In fact, real life toll operations are seldom under steady state conditions particularly during peak hour traffic demand.

For toll systems already in operation, the issue that often arise is that the toll plaza need to be expanded because of increasing traffic volume that often result in heavy congestion. The choices available to the toll operators are usually

- i) increase number of toll booths,
- ii) change the toll collection system to faster system. This maybe from manual to automatic or from automatic to nonstop prepaid system etc.,
- iii) Rearrange the toll booths alignment from single booths to tandem booths.

Again, none of the above changes can be made with great certainty. To test the new system, the toll operators need to do site testing, which is costly and may even be disruptive to the existing system, i.e. even worse congestion may occur. As such, any changes made are often only intuitive with little support of its efficiency whether it is better or worse than the earlier system. Generally, a bigger system would usually reduce

the existing congestion although it would only be for a limited period. The problem recurs when traffic volume again rises with time and development. The circle is quite vicious as bigger and better toll facilities attract more traffic which eventually will demand for bigger and better facilities.

1.4.1 Justification of Study

There were no in-depth studies made on the toll system operating in Malaysia or in the South East Asia region despite the fact that more and more toll roads were being built in countries in the region. As such, it was found that little comprehensive technical information regarding toll operations and its components is available within Malaysia or the Region. Furthermore, there is no tool available, either manual or computerised, which specifically caters for studying or analysing toll operations in the country. This study seeks to generate a simulation model of toll system operation, which will:

- i) help engineers/planners design a toll system that will cater for traffic demand at a particular location.
- ii) aid toll operators to make suitable changes to existing toll system according to the changes in traffic situation and/or operating policy.

- iii) provide a simulation tool for interested parties such as engineers, planners, researchers etc., to study the workings of a toll system for evaluating the system's feasibility or efficiency or for forecasting future conditions of the toll system.

1.4.2 Objectives of Study

The smooth running of the operations of a toll expressway is not only of interest to the road users but should also be of concern to the operator of the expressway. The main objectives of the study are:

- i) to identify the factors that influence toll system efficiency,
- ii) to develop a computer simulation model of toll systems for the Malaysian condition, and
- iii) to use the developed toll model to investigate the effect of alternative layouts and strategies on toll system operation.

1.4.3 Research Questions

The following are the questions asked in implementing the study:

1. What are the supply components for a toll system?
2. What are the demand components of a toll system?

3. What is the distribution to be used to represent
 - vehicle headways?
 - moveup times of vehicles in a queue?
 - service times of toll collectors?
4. Is the operation of the toll system similar during peak and off-peak periods?
5. Is the operation of the toll system similar for both the to and fro directions of travel?
6. What type of simulation modelling is suitable for representing toll operations?

1.4.4 Data Collection Techniques

1.4.4.1 Types of data required

The data types required and collected in this study covers the following items:

i) Traffic characteristics

- a) driver behaviour - on the highway
 - at the toll plaza area
- b) types of vehicles
- c) vehicle speeds

ii) Toll plaza characteristics

- a) service times of operators
- b) number of booths operating
- c) size of plaza

1.4.4.2 Study population

The study population comprises of the users of the toll systems and the toll operators providing the service at the toll plazas. As the system is an interactive system, i.e. a user will always be serviced by a toll operator then the data collection process can be made simultaneously regarding both the user and the server. For example, while measuring the move-up time of vehicles in a queue the service time provided by the toll operator can also be measured immediately after the move-up process.

1.4.4.3 Sample size

The total population using the toll system to be studied was obtained from PLUS Sdn.Bhd, the operators of the toll plazas studied. It was decided that the sample size to be collected was 10% of the total daily traffic which is the recommended sample size (O'Flaherty, 1974) for the population concerned.

The actual number of booths opened usually varies within a day and from day to day. This occurs for reasons such as booth maintenance, staff work schedule and managerial decisions. The collection of data was therefore made at booths that were operating during the survey periods. The number of vehicles actually surveyed, some 21957 vehicles, was accumulated over the various survey sessions in a total of 20 days of field survey.

1.4.4.4 Sampling procedure

Most of the data collected were made manually as there were no historical data available for the site studied. The researcher and seven university technicians and students were employed to do all the manual data collection. These students and technicians have prior training and ample experience to carry out the survey.

The following is a summary of the manual processes applied in obtaining information for the various data collected.

i) Headway and speed distribution studies

The study on headway and speed distribution used video recorders in association with the Event Recorder System (ERS). The arrival of vehicles along a selected stretch of road was video-taped using ordinary video cameras. Both peak and off-peak hour sessions were recorded. The tapes were reviewed at a convenient time later in the office. This was the most appropriate tool as it required minimal manpower during tape recording and data processing while allowing review of the recorded traffic as and when required.

ii) Booth Selection

An observer is placed some distance away from the toll plaza so as to allow him an overall view of the plaza. The plaza selected by an incoming vehicle is then marked using tally counting. Data was collected for an

hour during both the peak and off-peak periods. The process was repeated for several days until the minimum sample size was achieved.

iii) Service time

Several observers were placed near toll booths that were operating. Care was taken so as not to disturb or in any way influence the normal operation of the toll service. This meant that observers had to operate without being seen by the toll collectors. This usually meant staying behind the toll booths rather than in front. Stop watches were used to measure the amount of time taken to process a vehicle through the toll booth. The time taken from the moment a vehicle stops at the toll booth until the time it leaves the toll booth was considered the service time for the vehicle.

iv) Move-up time

The data collection process is similar to the service time collection process. In this case, the time taken by a vehicle immediately behind a vehicle in service to move-up into the service box from the time the front vehicle leaves the box is measured. Again, stop watches were employed to make the time measurements.

1.4.4.5 Time of study

All information required from the site was obtained during two sessions of field study namely during November 1989 and March 1990. These periods were selected

to coincide with the availability of university vehicles and technician and students to help with the field study. Each session lasted for 10 days and data were collected every day during the peak and off-peak periods. The typical time period studied was as follows:

	<u>Peak Periods</u>	<u>Off-peak Periods</u>
Morning	7.00-9.30 am	9.30-11.30 am
Afternoon	4.00-6.00 pm	2.00-4.00 pm

1.4.4.6 Data Analysis

i) Statistical technique used

The main statistical tool used was the Chi-squared test. This test is the oldest goodness-of-fit test which dates to the paper by K. Pearson in 1900. The Chi-squared test is more likely to reject the null hypothesis H_0 when it is false than when it is true. It is therefore the most appropriate tool to evaluate comparison between the distributions found in collected data and standard distributions commonly used in traffic engineering studies as only the distributions that do not match with the standard ones are more likely to be rejected. Most researchers had applied the Chi-squared test when seeking a match between observed and standard distributions.

The R^2 test was used to compare observed data and simulated data. This test is normally used for

indicating how far the simulated data deviated from the observed data.

ii) Computer packages

a) The LOTUS spreadsheet was most commonly used to evaluate headway distributions, service time distributions and move-up time distributions. The facility found in the package allowed the arrangement of data in a user-chosen order. The package also provided statistical information on the data set such as standard deviation and coefficient of deviation etc. Pictorial graphs are also provided in the package for display and printing.

b) Event Recorder System

This computer package was developed by the author to facilitate the measurement and collection of headway and speed data from video tape recordings. Full details on the system are provided in Appendix A.

1.4.5 Expected Contributions

Among the contributions expected from this study are the following main items:

i) To provide detailed information on the various elements of the toll system supply and demand components. Only when all the relevant elements

are known can the interactive mechanism of a toll system be studied and understood.

- ii) To provide a tool in the form of a computer model for planners and engineers to design, modify, investigate and study either new or existing toll systems without the risk of disrupting existing traffic or requiring expensive on-site experimentation.

1.4.6 Limitations of the Study

Despite attempts to provide a comprehensive and complete investigation, there still are limitations inherent in the study due to various reasons beyond the control of the researcher. These are mainly constraints from limited financial and manpower resources coupled with a set time-frame for the completion of the study. Amongst these limitations are:

- i) The number of highway lanes approaching the toll plaza is currently only two. The increase in traffic volume on the highways may require additional lanes to be provided in the future. An increased number of approach lanes will result in very small headways between vehicles arriving at the toll booths. The increase in demand for toll service will directly affect the overall performance of the toll system. To cater for the change in the traffic demand pattern, provisions

should be made to investigate the impact of increasing the number of highway lanes on toll operations.

- ii) It was assumed that all Malaysian drivers behave similarly wherever they are and the Sungai Besi toll plaza was used for sampling. If financial and time resources were available, all major toll plaza should be investigated to evaluate the appropriateness of the above assumption.
- iii) The samples collected were for a limited period of time only. Additional data should be collected to give a broader database to monitor more stringently the behaviour of toll collectors and users.

8.3.2 Other improvements

The following discussions deal with other general improvements that may be made to further enhance the capabilities of TOSS. While these suggestions do not involve any structural changes to the TOSS model they do require alterations and additions in computer programming particularly where graphical presentations are proposed.

1. Graphical input of toll area configuration

Currently a standard toll plaza layout is provided to TOSS users. All data inputs for the plaza dimensions are made through the keyboard. It is thought that a layout input made through a pointer device (such as a mouse) on the video screen would be less prone to errors. Since the layout would be presented pictorially, errors in dimensions during data input could easily be detected and corrected.

2. Animated toll operations

In an animation key elements of a system are represented on the video screen by icons that change colour or position when there is a change of state in the simulation. Providing an animation option in the TOSS model would greatly increase TOSS's credibility. This is because animation has the ability to communicate the essence of the simulation model (or simulation itself) to managers and other key project personnel pictorially. Other benefits of animation are

- i) debugging a simulation computer program,
- ii) suggesting improved operational procedures or control logic for a system,
- iii) understanding the dynamic behaviour of a system, and
- iv) training operational personnel.

Animating a simulation model increases model development time and associated personnel costs. However, rapid developments in both the hardware and software aspects of the computer industry may allow this suggestion to be achieved at relatively low cost in the future.

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