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The Distribution of Service Time at Bangi, Kajang, Sungai Besi and Universiti Pertanian Malaysia Closed System Toll Plazas

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ABSTRAK

Masa perkhidmatan pemandu pada waktu sesak di empat buah plaza tol sistem tertutup iaitu Bangi, Kajang, Sungai Besi dan Universiti Pertanian Malaysia (UPM) telah dikaji. Satu analisis awal telah dilakukan untuk melihat jika terdapat perbezaan di antara hari dan pondok plaza tol terhadap masa perkhidmatan. Ujian kebaikan penyesuaian telah digunakan untuk menentukan taburan yang sesuai bagi masa perkhidmatan. Hasil kajian menunjukkan bahawa tiada perbezaan yang bererti bagi masa perkhidmatan di antara hari dan di antara pondok di plaza-plaza tol yang dikaji. Masa perkhidmatan pada ke empat-empat plaza tol di dapati bertaburan log-normal. Anggaran min masa perkhidmatan bagi plaza tol Bangi, Kajang, Sungai Besi dan Universiti Pertanian Malaysia adalah masing-masing 13.87, 10.07, 13.87 dan 7.32 saat. Maklumat yang didapati adalah penting bagi menilai dan memperbaiki sistem pengangkutan yang telah direkabentuk di negara ini. Langkah-langkah yang sewajarnya boleh dibuat untuk mempastikan sistem tol di negara ini berjalan dengan lancar serta berkesan.

ABSTRACT

The driver's service time at Bangi, Kajang, Sungai Besi and Universiti Pertanian Malaysia (UPM) closed system toll plazas was studied. A preliminary analysis was made to see if different days as well as different booths are homogenous with respect to service time. The goodness of fit test was used to determine the distribution of the service time. The results of the study show that there is no significant difference between days and booths with respect to service time. The distribution of service time for the four plazas was found to be a log-normal. The estimated values of the mean service time at Bangi, Kajang, Sungai Besi and Universiti Pertanian Malaysia toll plazas are 13.87, 10.07, 13.87 and 7.32 seconds, respectively. This information is an important input in evaluating and improving the transportation system designed. Appropriate measures can be taken to ensure a more efficient toll plaza system in this country.

INTRODUCTION

A desirable goal of transportation engineers is to design and operate transport facilities that can minimise delay and improve safety for users. Delays resulting from congestion will not only increase the vehicle's operating cost but also increase the accident risk, worsen environmental standards, increase the driver's stress and frustration as well as affect this driving behaviour. In addition, queuing of outflowing vehicles at highway exits may create a dangerous situation as a result of differential speed occurrence at the exit.

In a given highway situation, it is necessary to know the system's arrival and service characteristics. Service characteristics of any system must be fully compatible with the arrival characteristics in order for the system to be in equilibrium. Increasing arrival rate together with longer service time may result in traffic congestion.

The introduction of closed system toll plazas along the expressway, unless designed and managed effectively, may create an undesirable situation and problems. Research on queuing characteristics for the above system is needed to ensure that the motto of "Safer, Easier and Faster" system ia achieved. (Picard 1989) Queuing models or simulation techniques can be developed and the system performance such as congestion cost can be evaluated. Appropriate measures can be suggested for a better and more efficient transportation system. This study stresses only the service characteristics of the typical closed system toll plazas along the Kuala Lumpur - Seremban expressway.

MATERIALS AND METHODS

Location of Sampling Sites

Four closed system toll plazas along the Kuala Lumpur-Seremban expressway were chosen for studying service characteristics of the system. The above plazas are located as shown in *Figure 1.* They are the Bangi, Kajang, Sungai Besi and Universiti Pertanian Malaysia toll plazas.

Sampling Techniques

A video camera equipped with stop-watch was used in determining service characteristics of the system. A total of 3730 vehicles were observed at eleven exit points: Bangi, Kajang, and Universiti Pertanian Malaysia toll plazas each consisting of two booths and five booths for Sungai Besi toll plaza. All observations were carried out during weekdays particularly during peak hours. The observations at Bangi, Kajang, Sungai Besi and Universiti Pertanian Malaysia toll plazas were done from 3:45-4:45 p.m, 3:45-5:00 p.m., 3:30-4:3 p.m. and 7:25-8:05 a.m., respectively.

In determining service characteristics it is very important to obtain a consistent result of the system's service time. For consistency, the times at which a vehicle crosses two reference lines, just before and just after the booth, were taken and the time difference between these reference lines was obtained and referred to as driver's service time. In this study the drivers's service time is preferred instead of booth operator's service time since, from observations, the driver contributes most of the time required for the given service.

Log Normal Distribution and Its Parameter Estimates

A random variable such that its logarithm has a normal distribution is called a log-normal distribution. The probability density function is given by

$$f(x)=\begin{cases} \dfrac{1}{\sqrt{2\pi\beta}}\, x^{-1}\, e^{\frac{-(\ln x-\alpha)^2}{2\beta^2}} & \text{, for } x > 0,\ \beta > 0 \\ 0 & \text{, elsewhere} \end{cases}$$

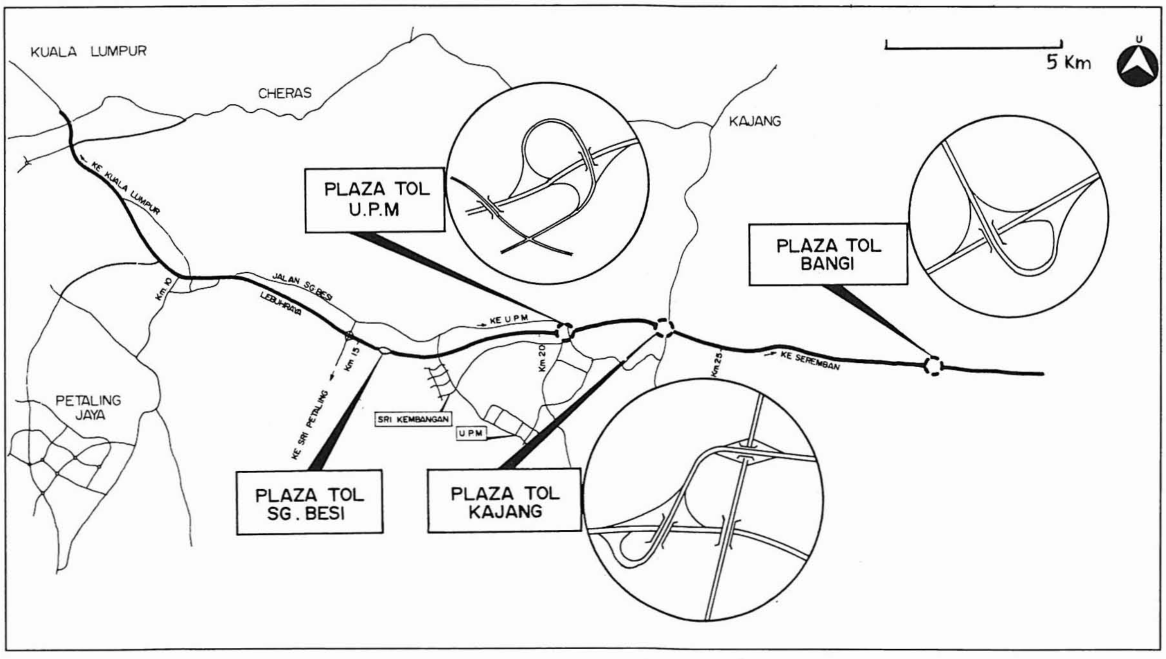

Figure 1: The location of sampling sites

where ln x stands for the natural logarithm of x

The mean and the variances of x are $\mu = e^{\alpha + \frac{1}{2}\beta^2}$ and $\sigma^2 = e^{2\alpha+\beta^2}(e^{\beta^2} - 1)$, respectively.

By using the maximum likelihood method, the unbiased estimates of α and β^2 are found to be

$$\hat{\alpha} = \sum_{1=1}^{n} \frac{\ln x_i}{n} \text{ and } \hat{\beta}^2 = \sum_{1=1}^{n} \frac{(\ln x_i - \hat{\alpha})^2}{(n-1)}$$

Tests of Homogeneity

It is very important to determine whether different days and booths are homogeneous with respect to service time before further analysis can be carried out. If there are no differences between days and booths, the mean service time of days and booths can be used for further analysis. When the situation is reversed, mean service time cannot be used and thus a separate analysis must be carried out. In order to test the null hypothesis that different days and booths are homogenous with respect to service time, a chi-square test of homogeneity is used.

Goodness of Fit Test

A chi-square goodness of fit test is used in order to determine whether sample data are compatible with the hypothesis that they were drawn from a population that follows a specified distribution. In goodness of fit tests of this type,

$$\chi^2 = \sum_{i=1}^{k} \frac{(0_i - e_i)^2}{e_i}$$ is distributed approximately as chi-square with (k-r-l) degreess of freedom, where r is the number of parameters being estimated and k is the number of categories, O_i is an observed frequency and e_i an expected frequency within each category. The expected frequency, e_i is found by multiplying sample size n with an appropriate distribution probability. In order to find the probability of x between values a and b (x from log-normal distribution)

$$p(a \le \mathbf{x} \le b) = \int_a^b \frac{1}{\sqrt{2\pi\beta}} x^{-1} e^{-(\ln x-\alpha)^2/2\beta^2} dx,$$

is equal to the probability that x is a normal distribution between ln a and ln b.

$$\text{Thus } p(a \le x \le b = p\left(z \le \frac{(\ln b - \alpha)}{\beta}\right) - p\left(z \le \frac{(\ln a - \alpha)}{\beta}\right)$$

RESULTS AND DISCUSSION

Data obtained from the above four toll plazas are used for the following analysis.

Homogeneous with Respect to Service Time

The frequency polygon for service time of different

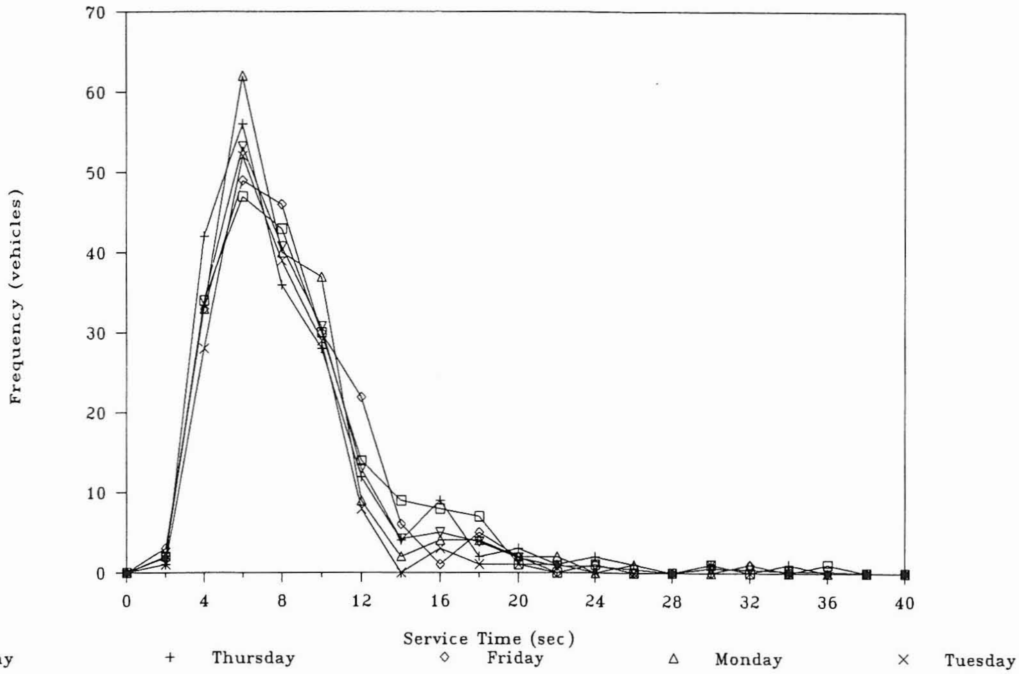

Fig. 2: Frequency polygon for service time of different days at UPM Toll Plaza

days for Universiti Pertanian Malaysia toll plaza is shown in *Figure 2.* The graph suggests that there is no significant difference between days with respect to service time. The computed value of χ^2 test of homogeneity is 19.24 with 16 degrees of freedom. From the chi-square table we conclude that the test supports the above suggestion ($p > 0.05$). A similar test was also carried out for the other toll plazas and the results are consistent with the earlier finding.

Figures 3, 4, 5, and *6* show the frequency polygon for service time of different booths at Bangi, Kajang, Sungai Besi and Universiti Pertanian Malaysia toll plazas, respectively. The graphs also suggest that there is no significant difference between booths with respect to service time. The results of the chi-square test of homogeneity also

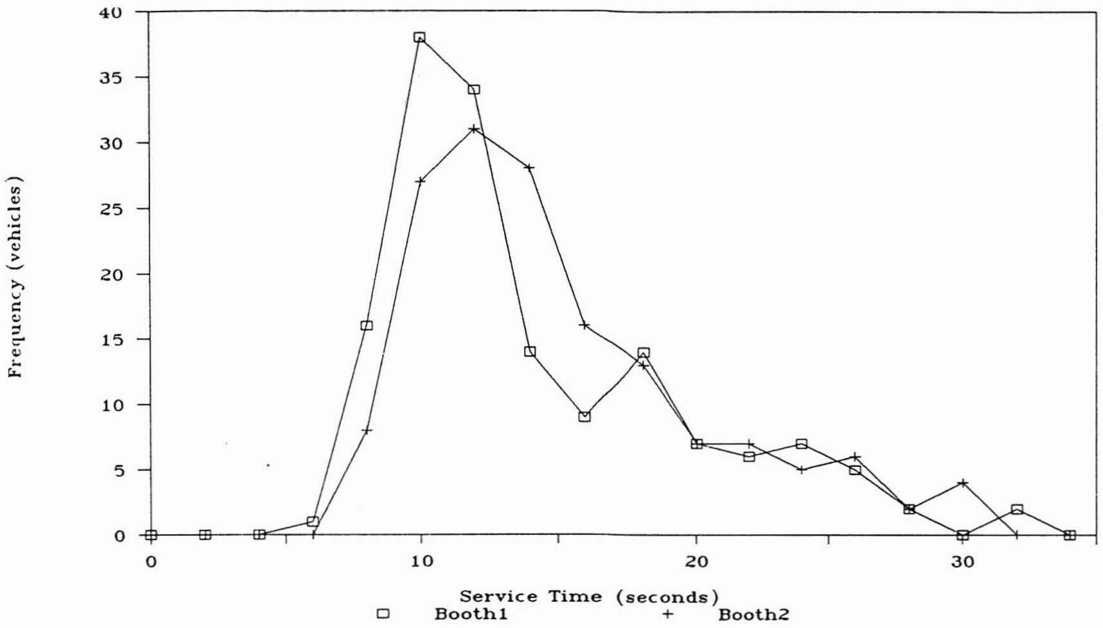

Fig. 3: Frequency polygon for service time of different booths at Bangi Toll Plaza

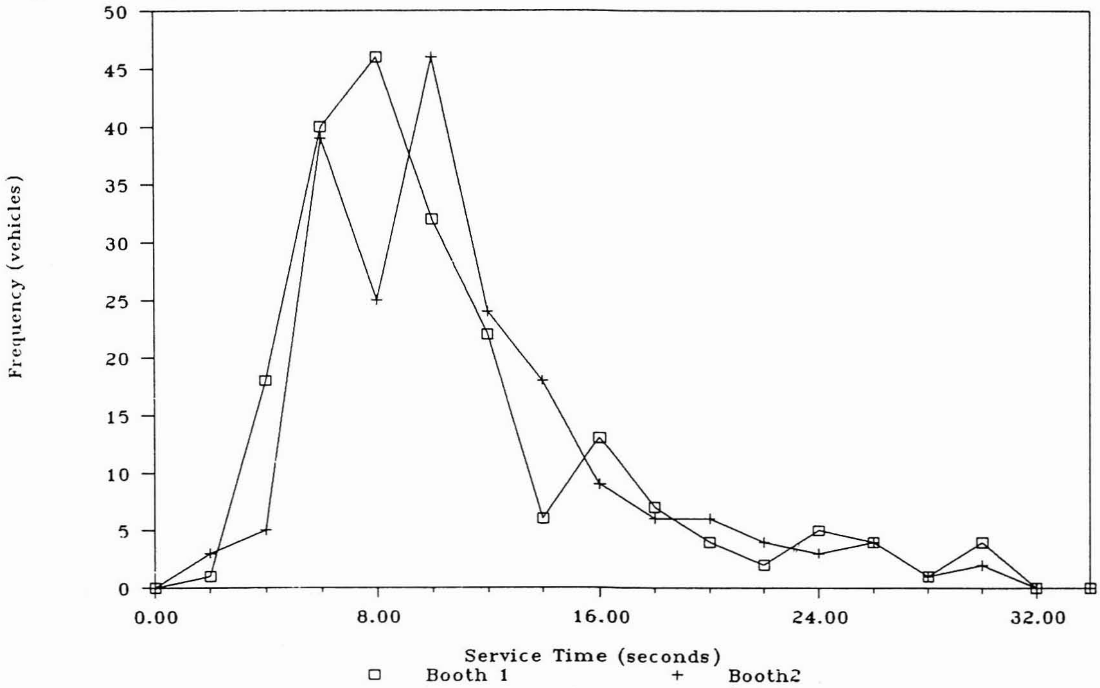

Fig. 4: Frequency polygon for service time of different booths at Kajang Toll Plaza

support the above conclusion ($p > 0.05$). Since different days and booths are homogeneous with respect to service time, further analysis was carried out based on the means of service time.

Service Time Distribution

The graphs of frequency polygon for service time in *Figures 3, 4, 5,* and *6* suggest a log-normal distribution. A log normal probability paper was used and the cumulative frequency distribution of the service time was plotted as shown in *Figure 7.* The straight line obtained suggests strong evidence of no major departure from normality and thus supports further the previous suggestion. It is observed that the service times at Bangi and Sungai

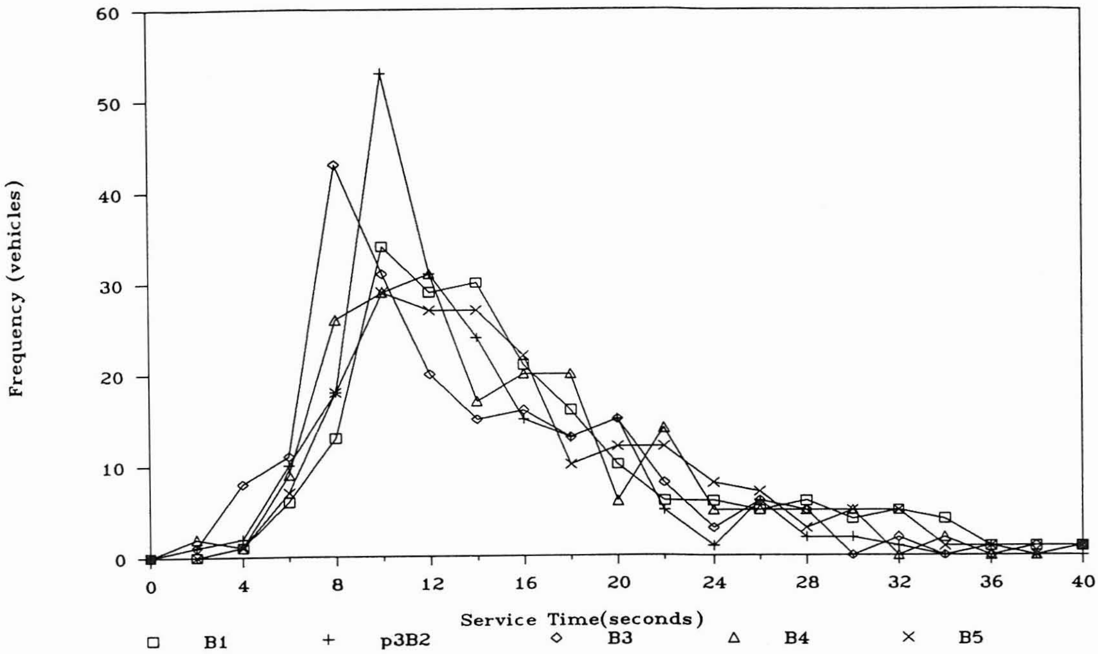

Fig. 5: Frequency polygon for service time of different booths at Sungai Besi Toll Plaza

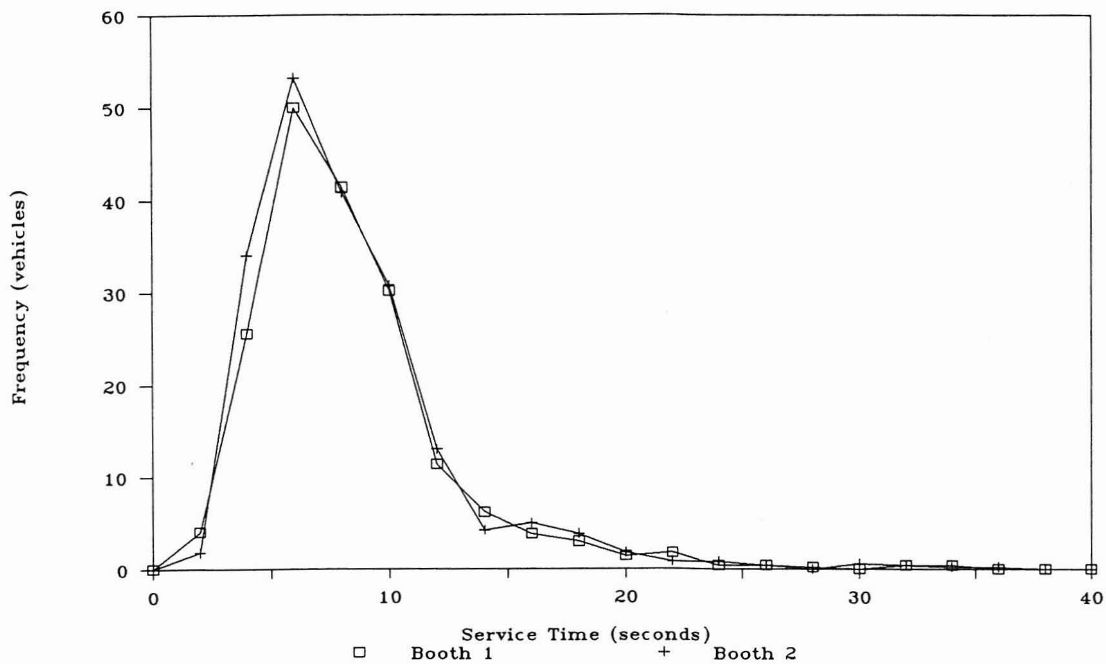

Fig. 6: Frequency polygon for service time of different booths at UPM Toll Plaza

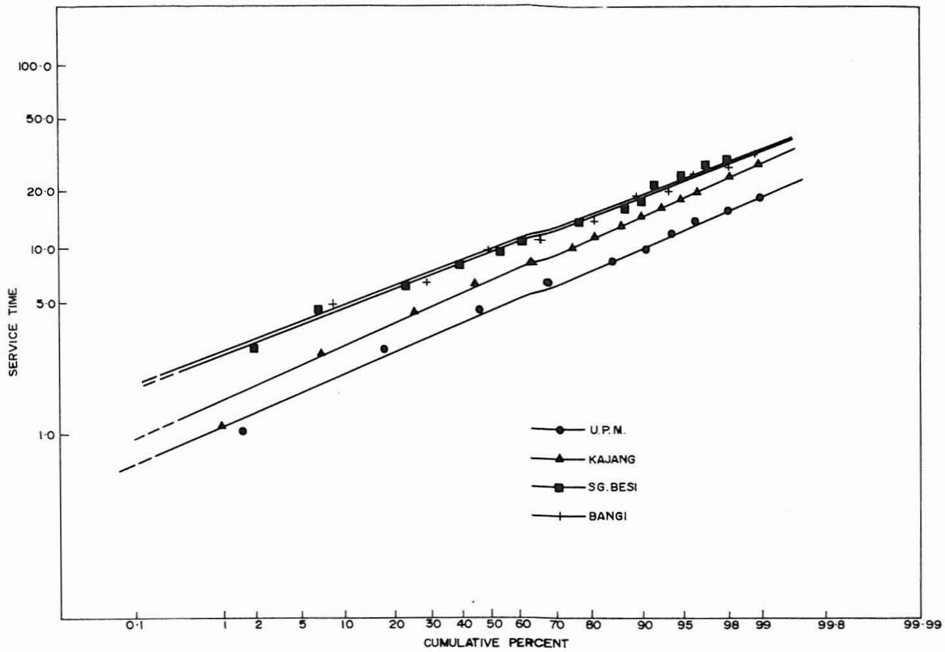

Fig. 7: Service time distribution on a log normal probability paper

Besi toll plazas are rather close to each other. The service time at Universiti Pertanian Malaysia toll plaza seems to be the lowest followed by Kajang toll plaza.

The goodness of fit test was conducted to confirm the hypothesis that the data of services times come from a log-normal distribution. The parameter estimates of α and β^2 for each toll plaza are shown in Table 1. Tables 2, 3, 4, and 5 show the class interval, expected frequency, observed frequency and $\frac{(O_i e_i)^2}{e_i}$ at Bangi, Kajang, Sungai Besi Universiti Pertanian Malaysia toll plazas, respectively.

The summary of results of goodness of fit test is shown in Table 6. The results conclude that the data of the driver's service time at each toll plaza come from a log-normal distribution. The unbiased estimates of the means and variances of service times at Bangi, Kajang, Sungai Besi and Universiti Pertanian Malaysia toll plazas are 13.87 and 30.49 seconds, 10.07 and 39.19 seconds, 13.87 and 59.08 seconds and 7.32 and 18.01 seconds, respectively. The mean service time at Universiti Pertanian Malaysia toll plaza is found to be the shortest, followed by Kajang, Bangi and Sungai Besi.

TABLE 1
The parameter estimates of α and β^2.

Toll Plaza	$\hat{\alpha}$	$\hat{\beta}^2$
Bangi	2.55	0.15
Kajang	2.14	0.33
Sungai Besi	2.49	0.27
UPM	1.84	0.29

CONCLUSION

The above study deals only with the service characteristics of the closed-system toll plazas. These characteristics lead to the establishment of some important congestion parameters and serve as primary input in evaluating the present design.

Homogeneity of different days and booths with respect to service time was observed in this study. The mean service time of days and booths was used for the analysis and a log-normal distribution of the service time was obtained.

Identification of appropriate distribution is crucial since incorrect assumptions on the service characteristics may lead to wrong interpretations, analysis and conclusions. Further study will concentrate on the system's arrival characteristics. Determination of accurate arrival and service characteristics is essential in evaluating, modifying, improving or changing the system's performance. Congestion parameters such as vehicle delay time and queue length can be obtained by developing

TABLE 2
Observed frequencies, probabilities and expected frequencies for data on service time (seconds) at Bangi Toll Plaza.

Class Intervals	Observed Frequency, O_i	Probability (Assuming a log-Normal Distribution)	Expected Frequency, e_i	$\frac{(O_i - e_i)^2}{e_i}$
4-6	1 }13	0.0222	3.51 } 17.10	0.9830
6-8	12	0.0860	13.59	
8-10	33	0.1485	23.46	3.8794
10-12	33	0.1747	27.60	1.0565
12-14	21	0.1585	25.04	0.6518
14-16	13	0.1314	20.76	2.9000
16-18	14	0.0935	14.70	0.0333
18-20	7	0.0631	9.97	0.8847
20-22	7	0.0432	6.83	0.0042
22-24	6 }12	0.0283	4.47 } 7.33	2.9753
24-26	6	0.0181	2.86	
26-28	2 } 5	0.0117	1.85 } 5.14	0.0038
28-30	2	0.0072	1.14	
Greater than 30	1	0.0136	2.15	
	158	1.0000		13.3720

TABLE 3
Observed frequencies, probabilities and expected frequencies for data on service time (seconds) at Kajang Toll Plaza.

Class Intervals	Observed frequency, O_i	Probability (Assuming a log-Normal Distribution)	Expected frequency, e_i	$\frac{(O_i - e_i)^2}{e_i}$
Less than 2	2 } 14	0.0055	1.11 } 18.87	1.2569
2-4	12	0.0879	17.76	
4-6	40	0.1775	35.86	0.4780
6-8	36	0.1853	37.43	0.0546
8-10	39	0.1579	31.90	1.5803
10-12	23	0.1150	23.23	0.0022
12-14	12	0.0815	16.46	1.2085
14-16	11	0.0559	11.29	0.0074
16-18	7	0.0401	8.10	0.1494
18-20	5	0.0266	5.37	0.0255
20-22	3 } 7	0.0193	3.90 } 6.55	0.0309
22-24	4	0.0131	2.65	
24-26	4 } 8	0.0094	1.90 } 6.95	0.1586
Greater than 26	4	0.0250	5.05	
	202	1.0000		4.9523

TABLE 4
Observed frequencies, probabilities and expected frequencies for data on service time (seconds) at Sungai Besi Toll Plaza.

Class Intervals	Observed Frequency, O_i	Probabiltiy (Assuming a log-Normal Distribution)	Expected Frequency, e_i	$\frac{(O_i - e_i)^2}{e_i}$
Less than 2	1 } 4	0.0003	0.06 } 3.48	0.0777
2-4	3	0.0170	3.42	
4-6	9	0.0730	14.67	2.1915
6-8	24	0.1200	24.12	0.0006
8-10	35	0.1446	29.06	1.2142
10-12	28	0.1366	27.46	0.0106
12-14	23	0.1180	23.72	0.0219
14-16	19	0.0913	18.35	0.0230
16-18	14	0.0740	14.87	0.0509
18-20	12	0.0546	10.97	0.0967
20-22	9	0.0430	8.64	0.0150
22-24	5	0.0296	5.95	0.1517
24-26	6 } 10	0.0240	4.82 } 8.20	0.3951
26-28	4	0.0168	3.38	
28-30	3 } 7	0.0125	2.51 } 5.89	0.2092
30-32	3	0.0100	2.01	
32-34	1	0.0068	1.37	
Greater than 34	2	0.0279	5.61	2.3230
	201	1.0000		6.7828

TABLE 5
Observed frequencies, probabilities and expected frequencies for data on service time (seconds) at Universiti Pertanian Malaysia Toll Plaza.

Class Intervals	Observed Frequency, O_i	Probability (Assuming a log-Normal Distribution)	Expected Frequency, e_i	$\frac{(O_i - e_i)^2}{e_i}$
Less than 2	2 } 36	0.0170	3.26 } 38.49	0.1610
2-4	34	0.1835	35.23	
4-6	53	0.2676	51.37	0.0517
6-8	41	0.2019	38.76	0.1295
8-10	31	0.1351	25.93	0.9913
10-12	13	0.0779	14.95	0.2543
12-14	4	0.0476	9.13	2.8825
14-16	5	0.0267	5.12	0.0028
16-18	4 } 9	0.0165	3.16 } 8.18	0.0822
18-20	2	0.0100	1.92	
20-22	1	0.0058	1.11	
Greater than 22	2	0.0104	1.99	
	192	1.0000		4.5553

TABLE 6
The results of goodness of fit test.

Toll Plaza	Value of x^2	degrees of freedom	p-value
Bangi	13.3720	7	> 0.05
Kajang	4.9523	8	> 0.05
Sungai Besi	6.7828	11	> 0.05
UPM	4.5553	5	> 0.05

queuing models or simulation techniques. Appropriate measures can then be taken to ensure a better and more efficient toll plaza system.

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