DETERMINING THE PARKING NEED AND TRAFFIC GENERATION OF SHOPPING FACILITIES

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ABSTRACT: *Shopping centres are large generators of traffic and require the provision of considerable parking. Inaccurate estimation of parking needs and traffic generation can lead to many problems. Under-provision leads to congestion and frustration, while over provision results in the under-utilisation of an asset. Parking and traffic demands vary throughout the day, week, month and year. The variations result from changes in the arrival of cars and the duration of parking. Many studies of shopping facility parking do not recognise these temporal variations. This paper presents a general framework which aids the planning of parking facilities and road networks at shopping centres and multi-use facilities. It includes a detailed analysis of shoppers arrival patterns and parking durations taken from surveys conducted in the Melbourne metropolitan area. In particular, the duration patterns, arrival rates of shoppers and their variation throughout the day are investigated and modelled. Using these results, a method of estimating the temporal variations in the accumulation of parkers that only requires knowledge of arrival rates is described.*

INTRODUCTION

Shopping centres are large generators of traffic that require the provision of considerable parking. Inaccurate estimation of parking need and traffic generation can lead to many problems. Under provision leads to congestion and frustration, while over provision results in the under utilization of an asset.

Parking and traffic demands vary throughout the day, week, month and year. The variations result from changes in the arrival of cars and the duration of parking. Many studies of shopping facilities parking do not recognise these temporal variations. However, understanding these trip characteristics is critical for planning parking facilities For instance, knowledge of the temporal distribution of parking durations and arrival rates enables, the return from pay parking lots, the accumulation of parking vehicles and the traffic load on the surrounding road system to be calculated. They are therefore important pieces of information for parking lot design.

This paper addresses two aspects of the parking durations of shoppers; their statistical distribution and variation over time. As well, a detailed investigation of the arrival rates of shoppers is presented. It also presents a general framework which aids the planning of parking facilities and road networks at shopping centres and multi-use facilities.

Before illustrating a model that can be used to study parking lot accumulations and traffic flows, in multi-use and shopping facilities, it is necessary to study the character of parking accumulation data. To carry out this task two data sets are investigated. The first study involved an input/output survey, performed in a moderate sized off-street car park in Mountain Gate, Melbourne. The second study was a large home interview survey, conducted throughout the Melbourne metropolitan area in 1979.

MOUNTAIN GATE SURVEY

The Mountain Gate shopping centre contains 308 parking spaces, with three entrance/exit points (Figure 1). The shops abutting the car park meet a wide range of needs and include a large supermarket, furniture store, real estate agents, launderette, milk bars, chemists and newsagents. The main shopping hours were 9.00 till 13.00. However, the supermarket opened at 8.00 and closed at 13.00.

A input/output or cordon survey (Taylor and Young, 1988) of vehicles entering the Mountain Gate lower car park was undertaken on a Saturday morning in June 1987 between 8.00 and 13.30 (all day Saturday shopping was not available in Melbourne at the time of the study). The input/output survey consisted of placing observers at each of the three entrance/exits,

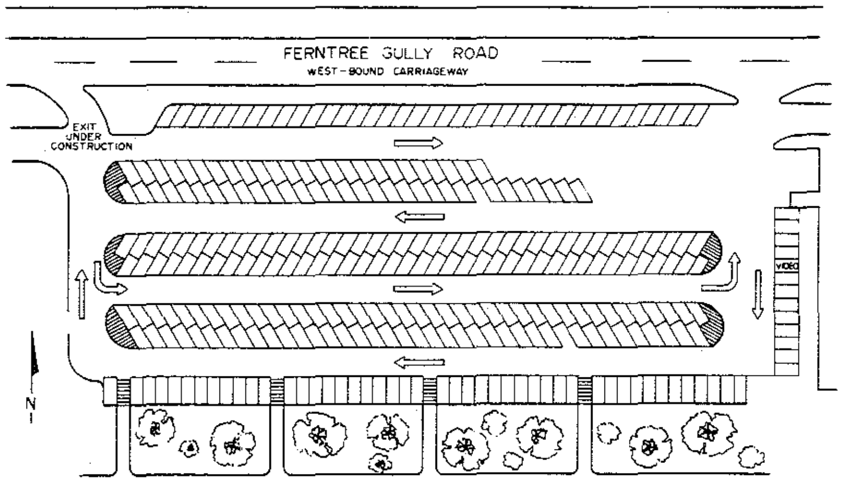

Figure 1 Mountain Gate parking lot layout

recording number plates for each vehicle entering and exiting every one minute throughout the survey period. The number plates were matched and the parking duration calculated. This survey technique also allowed the total number of vehicles, arrival rates, departure rates, composition of vehicles and parking accumulation to be obtained.

The input/output survey estimated the time vehicles spent inside the car park. This approach therefore results in a small over-estimation of parking durations, since the search and delay times experienced by drivers are included in the duration measure. Errors in this approach could also result from difficulty in reading coders hand writing, mis-coding, mis-timing and not recording all letters/numbers of the number plate. Therefore, this method also tends to underestimate the total parking population. It is however, a commonly used approach.

Overall Duration Distribution

The analysis of the data was compiled using a number of microcomputer packages DBASE III and LOTUS 123 were used to arrange the data and prepare some of the plots. TRANSTAT (Thompson and Young, 1988; Thompson, Taylor and Young 1988) was used to produce the exploratory data analysis plots, summary statistics and fit statistical distributions to the parking durations. Figure 2 shows that the durations are highly skewed. This finding is reinforced by the descriptive statistics presented in Table 1. The minimum observation of 0, is due to the recording of entry and exit times to the nearest minute. The numerous large observations (greater than 180 minutes) were staff parkers arriving in the first hour and were deleted from subsequent analysis.

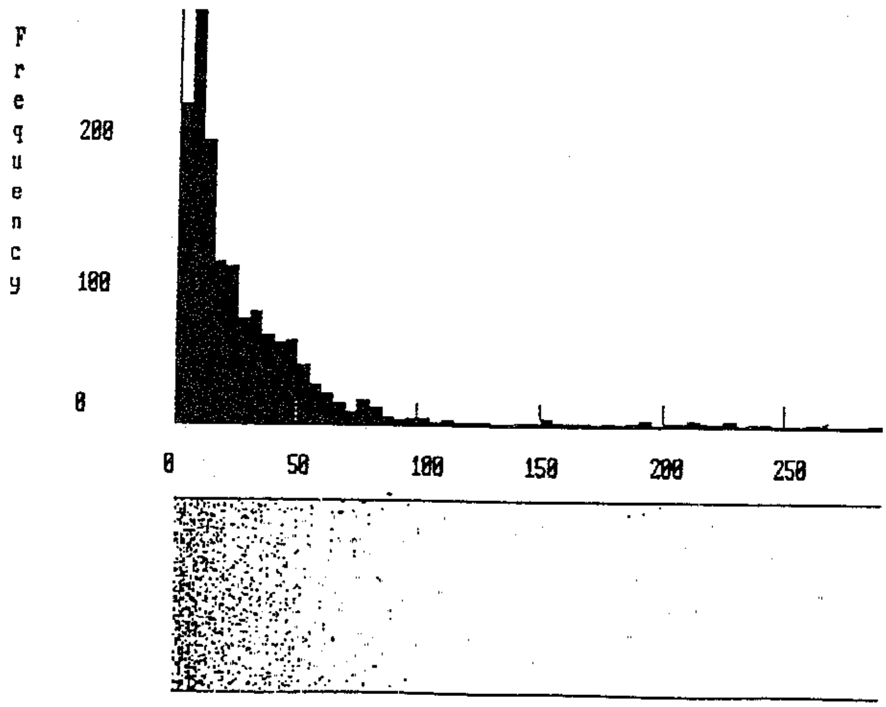

Figure 2. Histogram and Jitterplot of All Durations

The statistical distribution of the overall shopping durations was investigated using TRANSTAT. Neither the Exponential, Shifted Exponential, Erlang or Log-Normal models adequately represented the data. The Exponential model (Figure 3) performed better than the other models, however, there was still a significant difference at the 10 % level.

Table 1 Summary Statistics of Durations (Hours)

STATISTIC	ALL VEHICLES	SHOPPERS
DURATIONS MEASURES	1443.00	1422.00
MINIMUM	0.00	0.00
MAXIMUM	4.75	2.93
MEAN	0.44	0.39
5 % TRIMMED MEAN	0.38	0.36
BROADENED MEAN	0.20	0.25
MEDIAN	0.25	0.25
LOWER FOURTH	0.10	0.10
UPPER FOURTH	0.58	0.57
STANDARD DEVIATION	0.57	0.41
MODE	0.07	0.07
SKEWNESS	3.49	2.16
KURTOSIS	19.07	9.67
COEFF. OF VARIATION	1.29	1.05

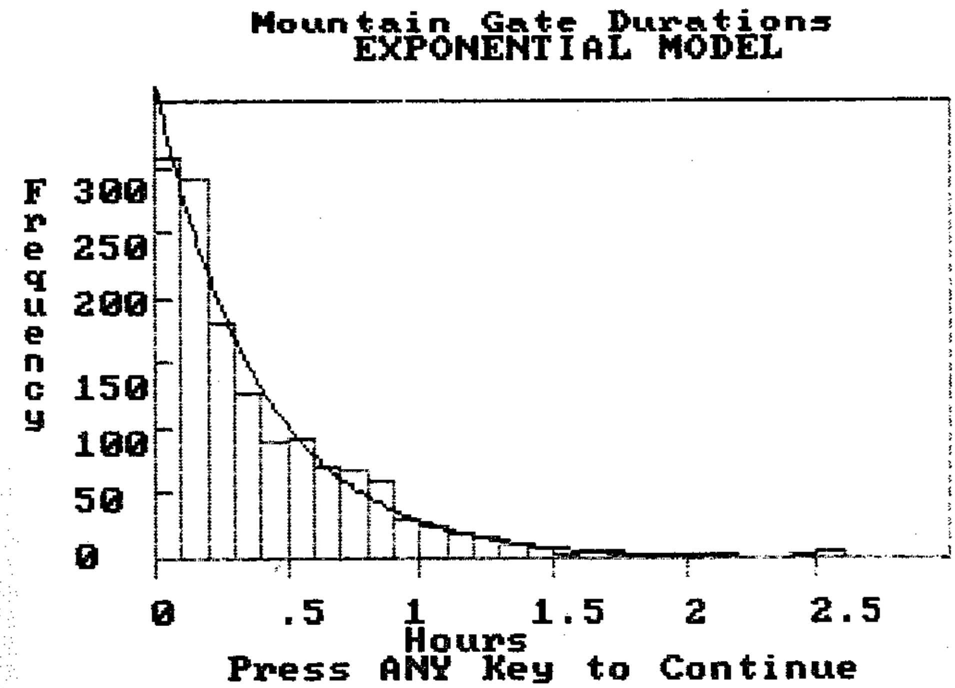

Figure 3 Exponential Model of Overall Shopping Durations

Temporal Variation of Durations and Arrivals

There can be many reasons why the data from the overall survey is not replicated by a theoretical distribution. Previous research (Cleveland 1963, Richardson 1974), however, suggests that the data can be represented by a distribution. To fully understand why these distributions do not fit the data, it is necessary to look closely at the character of the approaches used in their determination. Studies of the distribution of parking durations have tended to determine one duration distribution for each parking situation (Richardson 1974). They collect continuous data over the period that the facility is open and use this as a basis for determining the parking duration distribution. There are, however, many constraints influencing the distribution of parking durations. These include the closing of the parking station, the closing of adjacent landuses and the length of the working day. These constraints of the parking systems are likely to introduce variations in the character of the distribution over time. To investigate the influence of these constraints the data was divided into half hour intervals and the duration of parking for the people arriving during these periods studied (Table 2).

Table 2 Duration Summary Statistics (Hours)

1/2 HOUR BEGINNING	N	MAX.	MIN.	MEAN	MEDIAN	STDVN.	SKEW.	KURT.
8.00	47	2.67	0.00	0.53	0.48	0.54	1.70	7.00
8.30	79	2.48	0.00	0.48	0.33	0.51	1.80	6.70
9.00	143	2.75	0.00	0.42	0.27	0.47	2.70	11.90
9.30	160	2.58	0.00	0.42	0.28	0.40	1.90	8.60
10.00	181	2.58	0.00	0.61	0.25	0.50	2.20	8.60
10.30	219	1.70	0.00	0.42	0.32	0.36	1.30	4.30
11.00	193	1.93	0.00	0.46	0.33	0.40	1.30	4.40
11.30	171	1.35	0.00	0.37	0.27	0.32	1.30	3.90
12.00	104	1.25	0.00	0.30	0.23	0.27	1.40	4.80
12.30	63	.78	0.00	0.19	0.13	0.17	1.50	4.70
13.00	38	.25	0.00	0.08	0.07	0.06	1.50	5.00

Firstly, consider the arrival rate, Figure 4 presents the distribution of the arrival rates in each half hour. It can be seen that the arrival rate in the first hour is relatively small. Once all the shops opened the arrival rate picked up to 300 vph. The maximum arrival rate was 438 vph during the half hour 10.30 till 11.00. It dropped sharply after 12.00 to 126 vph. The arrival distribution therefore appears to consist of three parts. The first is the low arrival rate for the period when only the supermarket is open. The second is the period between 9.00 and 12.00 when the bulk of the people arrived. The arrival rate then decreases continually until the shops closed.

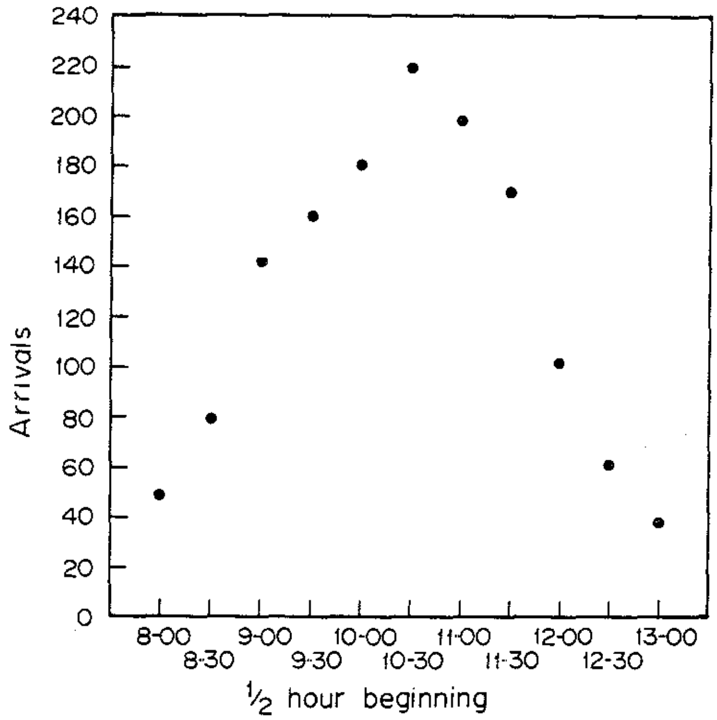

Figure 4 Distribution of vehicles arrivals

The arrival rate can be convoluted with the parking duration to determine the total accumulation. Figure 5 shows the average parking duration for the parkers by time of day. Like the arrival rate it appears to consist of three parts. The first part is during the period 8.00 till 9.00. Shoppers arriving during this period have longer than average parking times; where possible employees of the shopping centre were removed from the sample. During the second period, 9.00 till 12.00 the average duration appears to oscillate about an average of 0.42 hours (24.50 minutes). The final period is after 12.00 where there is a marked decrease in the average duration to 0.3 hours (18.1 minutes), between 12.00 and 12.30, and 0.08 hours (11.5 minutes), between 12.30 and 13.00.

Associated with the variations in the average parking duration for each time interval is the possibility of variations in the distribution. Figure 6 indicates the general character of the data for each time interval. The next step in the analysis was, therefore, to determine the type of distribution for each time period. To do this a Kolmogorov-Smirnov (KS) test was used. The study of the total data set for the study indicated that only the Exponential, Erlang and Lognormal models could possibly represent the data at an acceptable level. Table 3 presents the results of fitting these distributions to the data set for each half hour time interval. The KS test results showed all samples bar the intervals that start at 10.30 and 13.00 fitted the Exponential distribution. The Log-Normal also provided quite a good fit of the data. The Erlang distribution provided a poor fit.

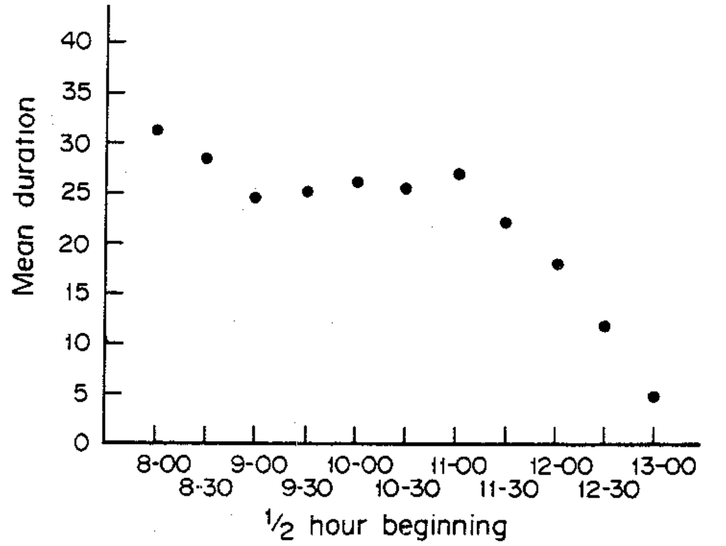

Figure 5 Distribution of mean parking durations

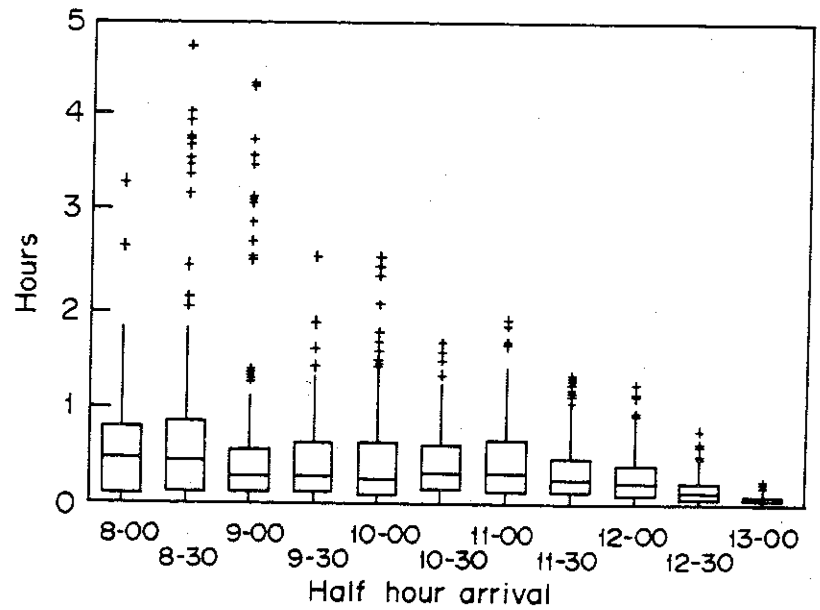

Figure 6 Multiple Box Plot of Parking Durations

Table 3 Goodness of Fit Test Results for Interval Durations

Model type	Interval Beginning										
	8.0	8.3	9.0	9.3	10.0	10.3	11.0	11.3	12.0	12.3	13.0
Exponential	*	**	NS	NS	*	***	NS	NS	NS	NS	***
Erlang	NS	***	NS	NS	***	***	***	***	***	***	***
Log Normal	***	***	NS	*	NS	NS	*	NS	**	NS	***

* - significant at 10 % ** - significant at 5 %
*** - significant at 1 % NS -Not Significant at 10%

Thompson (1988) developed a relationship between the interval number and the mean duration of:

MEAN DURATION = 1.1021 - 0.0694 * (1/2 HOUR OF ARRIVAL)

Where, 1/2 Hour of Arrival = 8.0, 8.5, 9.0,... ,13.00

This relationship had an R squared of 78.4 percent and when generalised could be used in conjunction with the Exponential distribution and variation in the arrival rate to determine temporal variations in accumulations and traffic flows for shopping centres and multi-use facilities. This will be discussed later in the paper.

Remarks

This section of the paper has shown that there is a variation in the mean of the duration of parking throughout a day but that the distribution is relatively stable. The distribution of durations of the total data set should therefore be seen as a combination of the a number of distributions with different means. The realisation that there is a temporal variation in the mean arrival rate and parking duration is important since the parking maximum parking accumulation and traffic flows are sensitive to these variations (Young and Le 1989). Use of the distribution for the entire day as a basis for calculating these parameters will underestimate their magnitude.

QUESTIONNAIRE DATA

The above discussion concentrates on an observational method of collecting duration data. This approach is commonly used and provides the opportunity to related parking accumulations and traffic generation to particular landuses. The encouragement of multi-use facilities is, however, complicating the interpretation of this approach to data collection. A more general data set, capable of investigating the overall character of parking durations, is the home interview questionnaire. A comprehensive questionnaire survey of travel patterns was undertaken by the Ministry of Transport in Melbourne during 1978 and 1979 (Ministry of Transport 1981a,b). This data set forms the basis of the second study of shopping parking characteristics.

One consideration that should be kept in mind when using this data set in the estimation of shopping durations is that peoples perceptions of travel details are what is recorded. This perception may differ slightly from the actual times. Several studies (O'Farrell and Markham 1974, Levin et al 1979 and Burnett 1976) indicate that individuals tend to overestimate travel times. Further, respondents tend to think in times units other than minutes (eg in 5, 10 or 15 minute groupings). This tendency was found in this data set. The estimation of parking durations will be affected by this discreteness effect. Notwithstanding these considerations, this data set is extremely useful and even though it is relatively old, it still provides guidance on the generality of the above findings. Further, many of the trip attributes surveyed are relevant to parking analysis. These included details of trip purpose, origins, destinations, arrival times, departure times and parking costs.

The Melbourne Home Interview Survey (HIS) contains travel patterns of individuals from over 11,000 households. This resulted in over 100,000 trips throughout the metropolitan region being surveyed. Analysis of this data allowed a detailed investigation of parking durations and arrival rates for shopping trips by car. To determine parking durations it is necessary to look at the respondents trips and determine the amount of time the vehicle was parked. A trip was defined as an individual person travelling from one place to another without changing the method of travel and without changing the number of persons in a motor vehicle. Trip details were recorded for individuals over a whole day, allowing consecutive trips to be linked and parking durations extracted.

Overall Duration Distribution

A total of 5553 car shopping durations were selected from the total trip file. There were a further 1135 public transport shopping trips. The public transport trips were not analyzed. Summary statistics relating to the parking durations (in hours) are presented in Table 4. These statistics combined with the exploratory plots (Figure 7) illustrate the significant skewness and large number of outliers contained in this data.

Like the previous study, the exploratory plots and summary statistics indicated that the Erlang, Exponential or Log Normal distributions had potential for representing the data. The determination of the specific statistical distribution representing this data was investigated using the TRANSTAT package. Due to the 'lumpiness' of the data (grouped in 5 minute intervals) the chi-square test was the only test which was appropriate. The only distribution that could be accepted at the 10 % level was the Exponential distribution.

Table 4 Overall Duration Summary Statistics (Hours)

No. of Observations	5553
Minimum	0.010
Maximum	12.830
Mean	0.884
Median	0.670
Standard Deviation	0.898
Lower Fourth	0.280
Upper Fourth	1.170
Coefficient of Skewness	2.717
Coefficient of Kurtosis	12.560

Temporal Variation of Durations and Arrivals

An important parameter in parking analysis is the arrival rate of vehicles at centres. Table 5 presents arrival patterns of shopping trips, by time of day and destination type, in 1 hour intervals.

Table 5. Arrivals by Time of Day and Destination Type

ARRIVAL HOUR ENDING	ALL METRO	REGIONAL CENTRE	DISTRICT CENTRE	CBD
		(PERCENTAGES)		
< 7	.11	0.00	0.10	0.00
8	.45	0.19	0.42	0.00
9	1.91	0.78	2.19	0.94
10	7.65	8.33	9.06	4.72
11	12.52	13.37	13.54	14.15
12	10.35	8.33	9.58	9.43
13	8.39	11.43	8.23	11.32
14	7.92	9.30	7.92	11.32
15	8.12	9.50	8.54	5.66
16	10.19	6.01	9.69	7.55
17	12.08	6.98	14.17	8.49
18	7.46	8.33	6.04	12.26
19	5.65	9.11	4.79	1.89
>19	7.19	8.33	5.73	12.26
TOTAL	100.00	100.00	100.00	100.00

For all shopping trips by car little trading occurred before 9.00 am. For all metropolitan trips most shopping was performed between 10.00 am - 12.00 pm and 15.00 pm - 17.00 pm. Figure 11 illustrates these arrival patterns. Shopping arrival percentages by time of day and day revealed a relatively uniform pattern for most days, with Friday evening shopping being significantly higher.

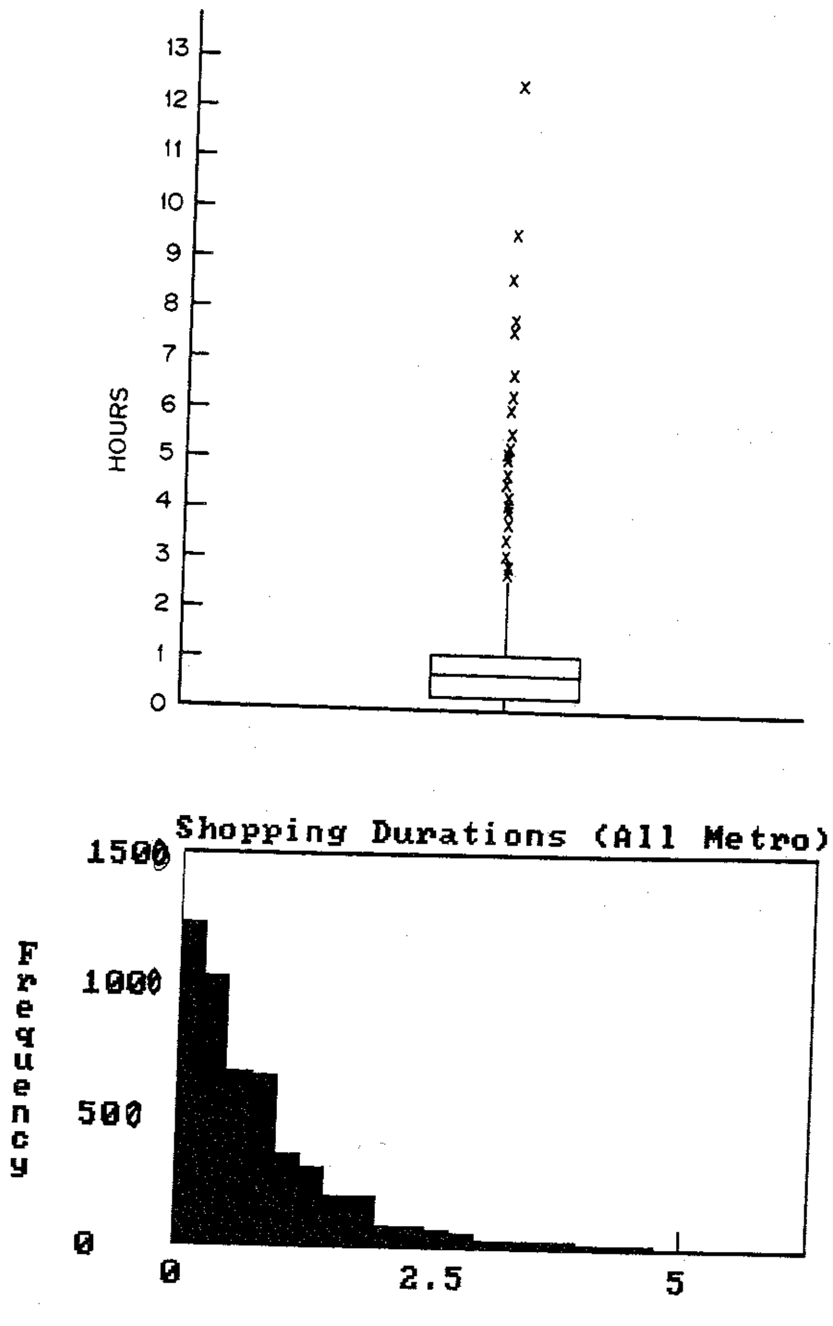

Figure 7 Exploratory Plots of All Shopping Durations by Car

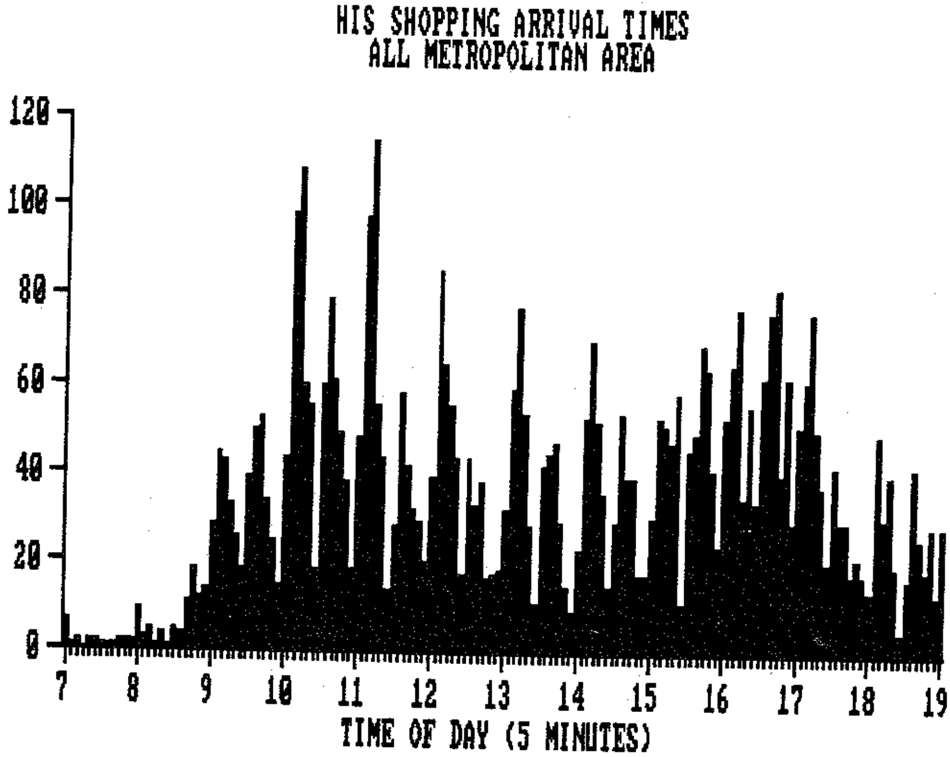

Figure 8 Shopping Arrivals By Car (All Metropolitan Area)

To investigate the temporal variation in shopping durations for car drivers the original data set was partitioned into one hour intervals, by time of arrival. The summary statistics for each interval are presented in Table 5. The multiple box plot in Figure 9 highlights the variation of durations between the arrival hours.

It can be seen that there is considerable variation between durations for each hour interval. The mean and median of the durations increase from the first hour to 10.00 am, and decrease there after. Further, the durations of the morning trips have a larger range and spread than their mean.

Figure 9 also shows a large number of outliers. The hour 7.00am -8.00am contains the largest number of outliers. Two outliers which were of particular concern relate to observations from the first two intervals 7 - 8 am and 8 - 9 am. Due to their unrepresentativeness, their considerable impact on the relatively small number of points in each interval and since they were for periods outside normal trading hours, these durations were not included in the analysis.

Table 6 Summary Statistics by Hour of Arrival (Hours)

ARRIVAL INTERVAL (Hours)	N	MIN.	MAX.	MEAN	MED.	STDVN	LF	UF	MODE	SKEW. COEFF.	KURT. COEFF.
7 - 8	18	0.01	8.83	1.18	0.24	2.63	0.08	0.50	0.02	2.41	7.01
8 - 9	88	0.03	12.83	1.38	0.39	2.45	0.15	1.17	0.08	2.85	11.19
9 - 10	407	0.01	9.58	1.24	1.00	1.10	0.45	1.73	0.92	2.29	13.02
10 - 11	691	0.01	7.75	1.22	0.92	1.05	0.50	1.75	0.50	1.79	7.83
11 - 12	583	0.01	5.67	1.02	0.83	0.90	0.42	1.33	0.83	1.73	6.50
12 - 13	473	0.01	6.00	0.93	0.67	0.90	0.33	1.25	0.25	1.81	7.03
13 - 14	450	0.01	4.00	0.83	0.83	0.77	0.33	1.42	0.17	1.08	3.77
14 - 15	443	0.01	7.83	0.84	0.67	0.71	0.42	1.08	0.50	3.25	25.57
15 - 16	543	0.01	7.67	0.71	0.50	0.79	0.25	0.92	0.17	3.61	22.45
16 - 17	673	0.01	5.00	0.60	0.50	0.58	0.25	0.83	0.50	3.18	18.81
17 - 18	452	0.01	6.75	0.63	0.42	0.81	0.17	0.75	0.08	3.82	23.07
18 - 19	299	0.01	3.08	0.70	0.45	0.61	0.25	0.92	0.17	1.40	4.92

STDVN - Standard Deviation
LF - Lower Fourth (25th Percentile)
SKEW. - Skewness
MED. - Median
UF - Upper Fourth (75th Percentile)
KURT. - Kurtosis

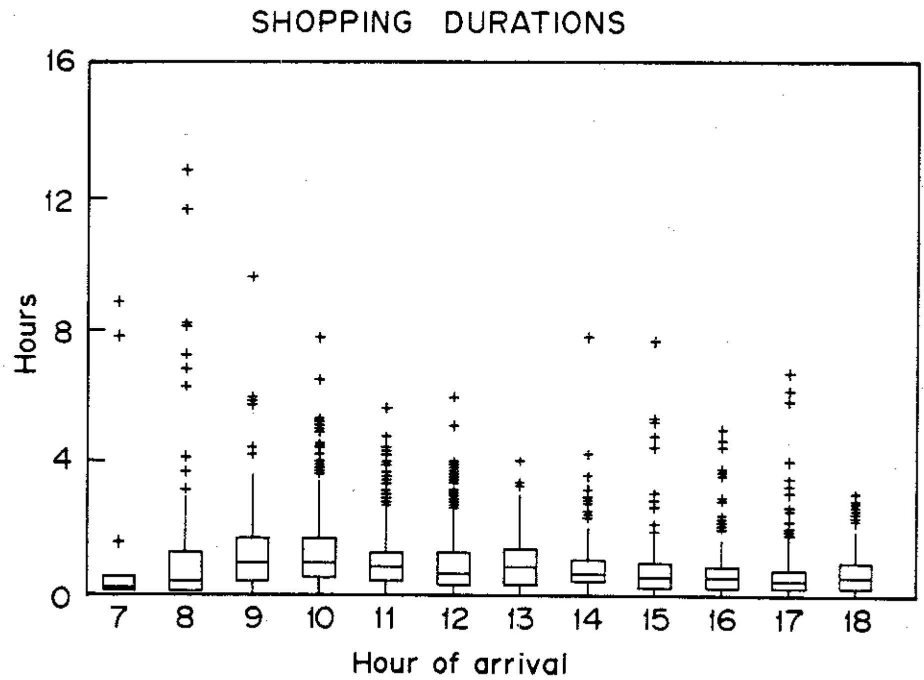

Figure 9 Durations by Hour of Arrival

The duration distribution for each hour interval was investigated using the chi-squared test. Table 7 shows that the Exponential distribution adequately represents the data for the majority of time periods. Both the Log-Normal and Erlang models failed to adequately represent the data for any of the time intervals.

Table 7 Distribution Fitting Results

ARRIVAL INTERVAL	MODEL		
	EXPONENTIAL	LOGNORMAL	ERLANG
9 - 10	**	***	***
10 - 11	**	***	***
11 - 12	NS	***	***
12 - 13	NS	**	***
13 - 14	***	***	***
14 - 15	***	***	***
15 - 16	**	***	***
16 - 17	NS	**	**
17 - 18	NS	***	***
18 - 19	NS	***	***

* - Significant at 10 % ** - Significant at 5 %
*** - Significant at 1 % NS - Not Significant at 10 %

To further investigate the Exponential models suitability for representing shopping durations by interval of arrival, the relationship between the mean and the standard deviation for each time interval (9.00 am - 7.00 pm) was modelled. A least squares regression equation was determined and takes the form:

MEAN = -0.1151 + 1.2009*(STDVN), R Squared = 0.7969

The standard error of the regression coefficient was 0.2143 indicating that the 95% confidence interval for this coefficient includes 1.0, signifying the closeness to unity between the two parameters. This provides further evidence that the Exponential distribution represents the durations by time of arrival intervals. The fact that the Exponential model fitted data for individual time intervals is consistent with the Mountain Gate study outlined above.

Relationships between the mean durations, standard deviations of durations and the interval of arrival were also investigated. Linear regression relationships were determined and are presented below:

MEAN = 1.8325 - 0.0712*(HOUR OF ARRIVAL),
R Squared = 0.8831

STDVN = 1.4831 - 0.0490*(HOUR OF ARRIVAL),
R Squared = 0.7570

Both equations have reasonable fits with both regression coefficients being significantly different than zero at the 1 percent level. These results illustrate the decreasing relationship between both the mean and standard deviation and the interval of arrival. These relationships could be used for predictive purposes in modelling shopping durations, throughout the day.

The magnitude and breadth of the questionnaire data set allowed the impact of many data disaggregations to be investigated. The effect of weekday type on shopping durations was investigated. The results of this study are presented in Young and Thompson 1989. It showed that Thursdays and Fridays have marginally longer durations and larger variations, but overall, there was little difference in shopping durations between weekdays. More shopping trips were observed on Thursdays and Fridays, which are the traditional days for household shopping trips.

Shopping durations were also disaggregated by type of destination shopping area (Young and Thompson 1989). The specific types of shopping trips examined were district centres (MMBW 1982), Melbourne's Central Business District (CBD) and regional shopping centres. There was a significant difference in the nature of shopping durations between regional, district centre, central business district and total metropolitan shopping trips. Durations are much larger for shopping trips to regional and district centres. The mean durations for trips to regional centres, district centres and the CBD were 70, 60 and 120 minutes respectively.

Remarks

The Melbourne Home Interview Survey data set provided further evidence of the temporal variation in parking durations. The impact of this variation on parking accumulation and traffic generation modelling is considerable and requires further investigation.

The Melbourne Home Interview Survey also provides the opportunity to investigate work, recreational and residential parking duration, accumulation and arrival characteristics. This information is essential for determining the parking accumulation characteristics of multi-use facilities and is presented in Young and Thompson (1989).

MODELLING ACCUMULATION

Models of parking systems can be used to generalise the results of field studies (Young 1987; Young, Taylor and Gipps 1989). Both the presence of temporal parking durations as well as their distribution (Exponential) were identified for the Mountain Gate study and the Melbourne Home Interview Survey data. These results can be helpful in the modelling of parking accumulation.

The accumulation of vehicles in a parking lot is usually determined by subtracting the total departures from the total arrivals. It can be shown that the accumulation of vehicles within a parking lot can be estimated with only knowledge of parking duration distributions and arrival rates (Young and Thompson 1989). More specifically, if the survey period is partitioned into N equal intervals (eg. 1/2 hours), which are also partitioned into M equal sub-intervals (eg. minutes), the accumulation of vehicles after the J th sub-interval, of the I th interval, can be written in the closed form:

$$ACC_{IJ} = ACC_{I,J-1} + ARR_{IJ} - DEP_{IJ}$$

$$\text{for, } J = 2, \ldots, M \qquad I = 1, \ldots, N$$

where,

ACC_{IJ} - is the accumulation after subinterval J, of interval I.

ARR_{IJ} - is the number of arrivals during subinterval J, of interval I.

DEP_{IJ} - is the departures during subinterval J, of interval I.

and,

$$ACC_{I1} = ACC_{I-1,M} + ARR_{I1} - DEP_{I1}$$

$$\text{for, } J = 1 \qquad I = 1, \ldots N$$

where,

$$DEP_{IJ} = \sum_{K=1}^{J} ARR_{IJ} * [\, F_I(J-K+1) - F_I(J-K) \,] + \sum_{R=1}^{I-1} \sum_{K=1}^{M} [\, ARR_{I-R,K} * \{F_{I-R}(RM+J-K+1) - F_{I-R}(RM+J-K)\} \,]$$

and,

$F_I(T)$ - is the cumulative distribution function of vehicle durations, after T sub-intervals, having arrived in interval I.

To indicate the accuracy of this relationships they were used to replicate the Mountain Gate data, under a variety of assumptions relating to the level of knowledge of the arrivals and duration distributions.

Three scenarios were investigated. The first scenario (Scenario 1) uses as input the actual arrivals of vehicles (in minutes) and Exponential distributions of durations in half hour intervals. The means presented in Table 2 were also used. The second scenario tested (Scenario 2) assumes only knowledge of the arrival rates by interval (half hour). To replicate vehicles arriving in minutes, the total arrivals for each hour were assumed to arrive uniformly within half hour intervals. This scenario also used Exponential models based on arrival interval and associated mean durations to estimate vehicle departures. The final scenario (Scenario 3), used the actual vehicle arrivals (in minutes) obtained from the input/output survey, but used only a single Exponential model for the whole survey to replicate parking durations. This duration function used the overall mean durations of shoppers of 0.39 hours (21.82 minutes) for the whole survey.

The resulting accumulations estimated by the models were compared with the observed accumulation calculated from the input/output (I/O) survey (Figure 10 and 11).

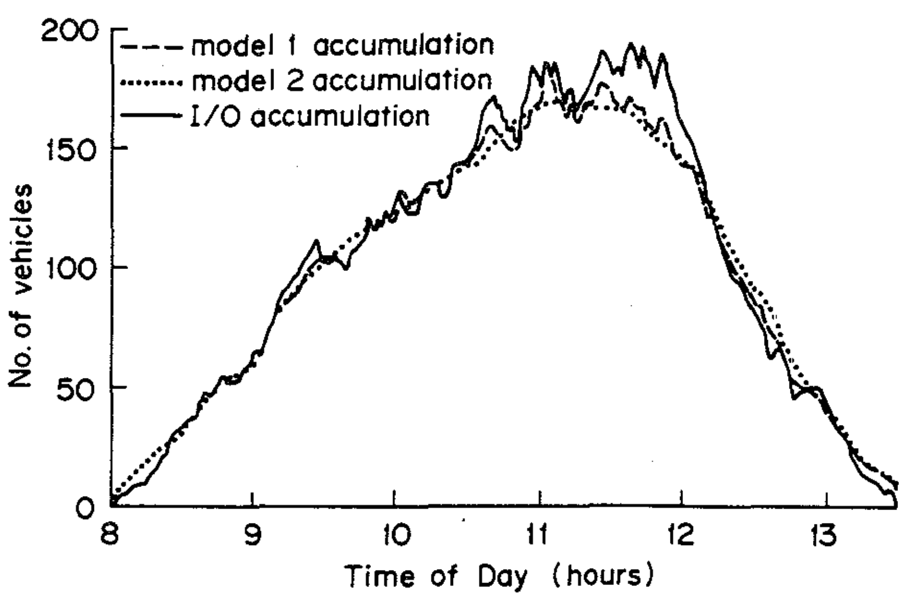

Figure 10 Comparison of I/O survey and Scenarios 1 and 2 Parking Accumulations

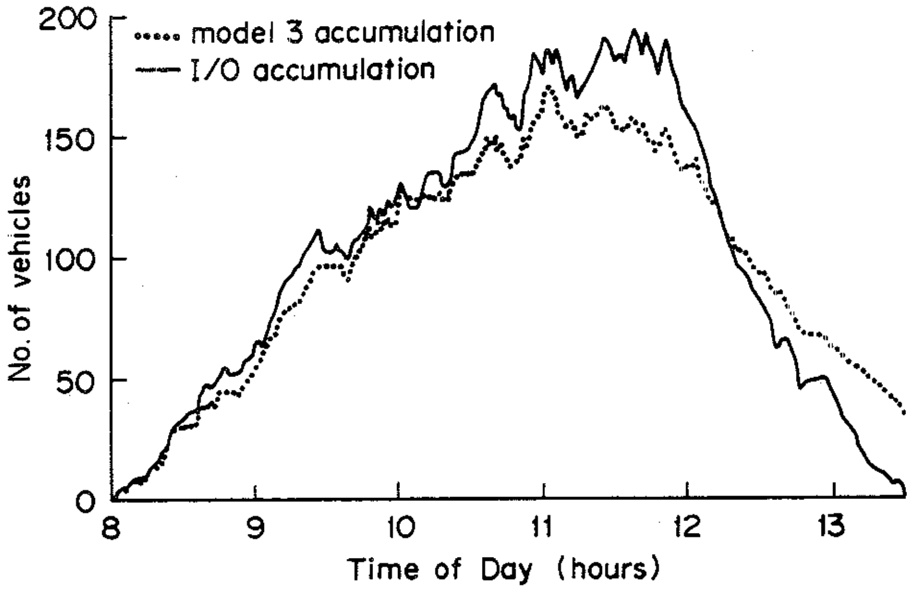

Figure 11 Comparison of I/O survey and Scenario 2 Parking Accumulations

All the scenarios provide a reasonable replication of the original data. Interestingly, all scenarios appear to perform poorly in the 11.30 - 12.30 intervals. It can be seen that Scenario 1 provides the best replication of the input/output accumulation. Scenario 2 is a smooth function due to the statistical assumptions relating to both vehicle arrivals and departures. It does not therefore follow the accumulation levels as well as Scenario 1 which uses actual the minute by minute arrivals. Scenario 3 substantially underestimates accumulation in the first part of the study period, while during 12.00 - 13.30 it tends to overestimate the accumulation. This is due to the use of the constant mean duration. This mean is low compared to the durations of arrivals in the early periods but is significantly higher than the durations of the arrivals in the last periods (Table 2).

The performance of the various scenarios is presented in Table 8. The input/output surveys accumulation was used for comparing the models performance and determining errors. Scenario 3 has the largest error (-39). This occurred at the end of the study period and was mainly due to the small durations of vehicles arriving in the last few intervals. Scenarios 1 and 2 maximum errors occurred in the period 11.30 - 12.00. These difference are quite small and are most probably due to unusually long durations from the previous 3 or 4 intervals. The mean absolute error ranking of the scenarios performance is consistent with the maximum error. Scenario 1's performance of an average error of around 6 vehicles per subinterval, highlights the good performance of the model. It therefore, appears that using Exponential duration distribution functions with parameters based on arrival interval leads to the better modelling of accumulation levels than using the same mean parking duration for the entire period. The presence of actual vehicle arrival information in subintervals (minutes) provided the most accurate model of accumulations.

Additional measures of the usage of the car park can also be determined once accumulation levels have been estimated. Utilization is the percentage of stalls that are occupied at any one time. The maximum and average of these measures are the most important. These statistics were calculated for the input/output survey and the 3 scenarios defined above (Table 8). The performance of the scenarios for the maximum utilization follow that of the maximum accumulation since, the only extra parameter is that of the capacity of the lot. For the average utilization however, scenario 2 more accurately models the input/output data, although only marginally. This is due to the overestimation of the accumulation levels by scenario 2 for the last 3 intervals.

As well, total occupancy levels were calculated for the input/output survey and the 3 scenarios. Occupancy measures the proportion of space hours that are utilized throughout the whole period. Scenario 2 again provided a marginally better estimate of this measure than scenario 1.

Scenarios 1 and 2, therefore, illustrated that using only information on vehicle arrivals and assumptions relating to distribution type and parameters for durations based on arrival interval, accumulations can be modelled accurately This also allows other measures of car park usage (eg. average utilization and occupancy) to be accurately estimated.

Table 8 Modelled and Input/Output Comparison

	ACCUMULATION			**UTILIZATION**		**OCCUPANCY**
	MAX.	**MAX. ERROR**	**MAE**	**MAX.**	**MEAN**	
I/O SURVEY	195	-	-	63.3	32.9	0.151
SCENARIO 1	183	28	5.6	59.4	31.8	0.146
SCENARIO 2	172	36	7.7	55.8	32.3	0.149
SCENARIO 3	172	-39	14.8	55.8	31.3	0.144

MAE - Mean Absolute Error

CONCLUSIONS

The parking duration data for the Mountain Gate and HIS duration data, were both accurately represented by the Exponential distribution once the durations were partitioned into intervals based on arrivals. The mean durations by arrival intervals varied considerably throughout the day, and were modelled using linear regression.

A technique was introduced for estimating parking accumulations based on duration distributions and arrival rates. The effect on the aggregation of input volumes and duration distribution functions were compared with actual accumulation levels observed in the Mountain Gate Survey. The most accurate model in predicting the peak accumulation was the Exponential durations based on interval of arrival, using arrival volumes in 1 minute sub-intervals.

The previous discussion has illustrated that the arrival rate and parking duration of vehicles vary with time. It has also illustrated that a model incorporating these variations provides a better estimate of vehicle accumulation than one that uses the same duration for the entire study period. This study however only considered shopping parking. Multi-use facilities in urban areas present many new problems for traffic planners, among these being estimating the provision of adequate parking facilities. Unfortunately, many of the existing methods for planning parking facilities within urban areas are unsuitable for multi-use centres. Trips generation rates (ITE 1983, Traffic Authority of NSW, 1981) relate to one type of complex. Using individual estimates of peak demand for the various components of a complex and combining these to estimate peak demand, generally results in an overestimate of parking demand, because the peaks for different land uses generally occur at different times of the day. The need for a new approach to planning parking facilities for these centres is urgent. A crucial component of this research, involves a detailed study of the important parking parameters like arrival rates, parking durations and accumulations for various trip types associated with trips to these centres. The next step is therefore to incorporate information on the arrival rates and parking durations of workers, shoppers and residents in the model introduced in this paper.

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