A MODEL OF PARKING VEHICLE MOVEMENTS

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ABSTRACT

Considerable effort has been directed at the design of the individual components of parking facilities. Similar effort has not however been directed at the study of how these components combine together into a traffic system. Consequently, advise as to the most appropriate layout for parking facilities is often contradictory. This paper presents the results of a study into the developing of a model for determining the efficiency of particular parking lot layouts. The paper first reviews existing procedures for determining these layouts. It then discusses a model (PARKSIM/1) developed for this purpose. Application of the PARKSIM/1 to parking facilities with and without parking on the major circulation routes provides a mechanism for investigating the appropriateness of the approach. The paper closes with a indication of the viability of the approach and discussion of directions for future research.

INTRODUCTION

Recommended practices for the design of parking lots are plentiful. In Australia, the National Association of Australian State Road Authorities (NAASRA) published the Guide to Traffic Engineering Practice (1982) to aid in the design of parking facilities. Other useful references include Brierley (1972), the Transportation and Traffic Handbook (ITE 1982), Forschunggesellschaft fur das Strassenwesen (1975) and Ogden and Bennett (1984). These references provide useful information on survey and design procedures for the various components of a parking system. Procedures for gathering these components into an overall systems design are, however, not so clearly described. For instance, it has been suggested (Ogden and Bennett 1984, p. 240), that the efficient flow of vehicles in a parking facility ".... can be achieved by a design which prevents direct access to parking bays from circulation paths providing for longer movements within the site and by careful consideration of potential conflicts in the vicinity of entrance and exits.". That is to say, by the development of a hierarchy of roads within the facility and the design of the parking lot to enhance this hierarchy. On the other hand the Highway Research Board (HRB 1971) recommend "The most desirable internal circulation is one in which each potentially vacant parking stall within a small lot or segment of a larger lot is passed once by incoming patrons seeking a space" (p. 102). Assessment of such suggestions can, at present, only be quantified by constructing the facility and observing its operation. Existing numerical models can only analyse simple interactions and cannot investigate the performance of a complex parking facility. Surveys of various parking layouts are expensive and time consuming.

Design procedures that provide concrete guidelines for the components of the system but lack such concrete procedures for investigating its overall performance can encourage a design that attempts to extract the maximum number of parking places from a given area. Such a process can often lead to a reduction in the overall manoeuvrability of vehicles in the facility and considerable frustration to the people using it. They should therefore be avoided (Carlisle and Searles 1983).

Research into the development of design tools to estimate the overall performance of particular parking layouts is limited (Farrow 1984). Creation of tools has been hindered by the difficulty in developing mathematical models of complex networks. The considerable developments in computers, both micro and macro, and associated computer graphics may, however, provide a solution to this problem and enable useful design models of parking facilities to be developed. This paper presents a study into the feasibility of developing such a tool. The model is called PARKSIM/1.

A MODEL OF PARKING VEHICLE MOVEMENTS

REVIEW OF PARKING LOT DESIGN MODELS

Numerical models based on simple assumptions have been used to analyse parking situations. The simplest model assumes that vehicles arrive at regular intervals (Lautso 1981). Lautso defines the supply of parking (S) as the product of the number of parking places (P) and the time interval (T) considered. That is

$$S=P.T \tag{1}$$

The total parking time (W) is the product of the accumulation of vehicles in the parking facility (A) and the time interval considered:

$$W=A.T \tag{2}$$

The average utilisation (U) is the total parking time divided by the supply of parking spaces:

$$U=W/S=A/P \tag{3}$$

The ratio of the arrival of vehicles and the supply of parking spaces is also a measure of the demand/supply relationship.

The total need for parking (N) is calculated by the product of the average arrival rate (Q) and the average duration of stay (pd):

$$N=Q.pd \tag{4}$$

This approach, although useful, is rather simplistic and does not take into account the random nature of traffic. The incorporation of a Poisson distribution of vehicle arrivals and a Poisson or Erlang distribution of parking duration was introduced by Droste (1971). This refinement enables the accumulation of vehicles over different time intervals to be calculated. Further, to gain an indication of the proportion of people who cannot find a parking place it is possible to use queueing theory (Gipps 1984). The utilisation of the parking facility can be used as a measure of the utilisation factor in queueing models. The number of people not finding parking spaces (nq) can be calculated using the formulae:

$$nq=(U)/(1-U)-1/U \tag{5}$$

The proportion of people finding a parking place (p) is then given by the ratio of the number of people finding parking place and the average flow into the system:

$$p=(Q-np)/Q \tag{6}$$

This approach is appropriate for utilisations less than 0.75. However the erlang loss function is a more appropriate method for studying the parking situation over all utilisation factors. It is however computationally more involved.

Estimates of the travel time through parking facilities are not so easily calculated. The delay to unparking vehicles has been estimated using Adam's formulae (Westland 1967). However this approach has only been applied to simple strip parking situations where the arrivals of vehicles can be described by a negative exponential distribution. The total delay resulting from the interaction between parking and through vehicles, gap acceptance at intersections in the parking network and queueing behind delayed vehicles is not as amenable to numerical analysis.

The application of computer simulation techniques to parking situations is also limited. Farrow (1984) presented a microscopic discrete event simulation model to study of parking behaviour along a length of road. He adopted a discrete event simulation approach since this enabled him to trace the movement of each vehicle along the road and incorporate some of the complexities present in parking situations. The approach was shown to be a considerable development on the simple numerical models discussed in the previous paragraph when applied to strip parking. It also appeared to have potential for being extended but was not extended to the network situation.

The effort that has been directed at the study of parking does not appear to have formalised itself into accredited modelling procedures for the study of vehicle movements inside parking facilities. Numerical models of parking systems provide approximations to some of the measures of the performance of parking facilities but are not able to aid the design of complex parking networks. Knowledge of the workings of such microscopic systems is however in need of attention. Determining appropriate layouts to obtain the maximum number of parking spaces while enabling a reasonably free flow of vehicles through the parking lot is important to both the developer and the user of parking facilities. The investigation of a procedure for quantifying the inconvenience experienced by drivers in parking facilities is the main thrust of the study reported here.

A MODEL OF PARKING VEHICLE MOVEMENTS

MODEL DESCRIPTION

The development of the PARKSIM/1 began with a very simple system and progressively introduced new dimensions. This process of developing simulation models from the "bottom-up" enables the model builder to develop his thoughts with the development of the model. It also enables detailed investigation of each of the components as they are developed. The first step in the model construction process was the building of a model to simulate the movement of vehicles along a link. Parking was then introduced. These two parts are outlined in Young and Farrow (1986). The model was then extended to consider a network. In order to facilitate a network it was necessary to introduce movement from one link to another. An intersection simulation model was needed for this task. The final stage of model construction was the introduction of the algorithm for searching for a parking place.

This section concentrates on the description of the network model. The link model has been described in Young and Farrow (1986). This paper will introduce the network description, the search algorithm and the intersection submodel.

Description of network

A parking lot is an open space. Movement in this space can be in any direction. There are no legal requirements for the vehicles to take particular routes. However, to develop the simulation model of vehicle movements it was necessary to develop a network on which the vehicles move. This may not represent actual movements in partly filled parking stations but will become more realistic as the parking facility approaches capacity. Since the parking facility which is near capacity is likely to be more critical with respect to vehicle movements this restriction was not considered a limitation.

The description of the network is an integral part of the model development process. It basic components are the link and the node. A link is considered a length of road with or without parking spaces connecting two nodes. Links can be considered as either primary, secondary or local. Primary links provide the major movements throughout the system while secondary links allow movement to parking spaces and the opportunity for through movement. Local links only provide movement to parking spaces. A node is a point where two or more links meet. Entrance and exit nodes provide connection with the traffic network outside the parking lot.

Intersection simulation

The intersection algorithm moves vehicles from one link to another. It consists of first determining which link the vehicles wishes to move to and then whether it can move onto this link.

Determining the link out of the intersection

A major component of the modelling process is the development of the process of searching for a parking space. As with the link simulation this process consists of the driver making decisions at a number of points in the network. This section takes the components of the individual decision making process and discusses how these can be treated in the model. A general view of the transport decision making process is presented in Figure 3.1. The overall objective of the process is for the decision maker to make a choice after consideration of the alternatives available to him. Before the final choice can be made, however, it is postulated that there are a number of discrete steps through which the choice process moves. Each of these steps and how they relate to the parking model will be discussed in this section.

Constraints. The most obvious constraint in a parking facility is the availability of a parking place. Parking spaces reserved for particular people are not readily available to everyone. Areas where parking restriction are in force may not be available to all people all of the time. The existence of parking meters may constrain the time a vehicle can stay at a particular location. Such constraints can be input into the model exogenously.

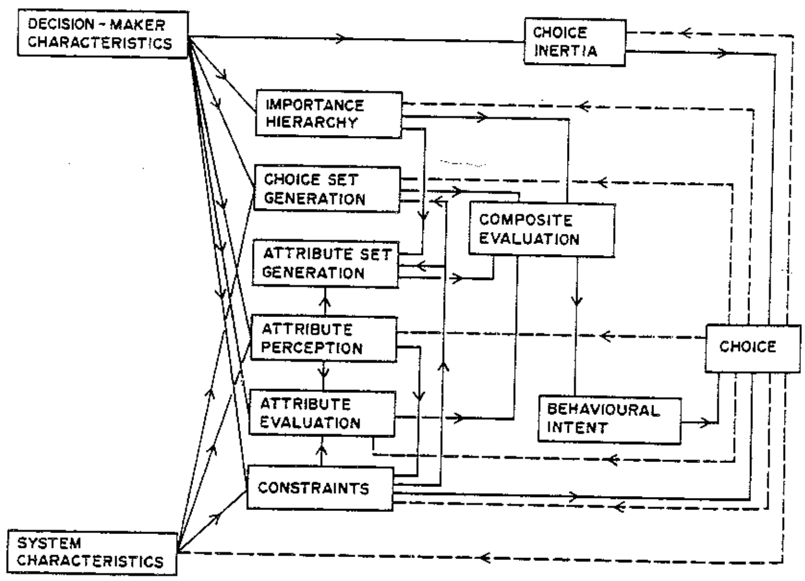

Figure 1 Transport decision process
(Richardson and Young 1979)

A MODEL OF PARKING VEHICLE MOVEMENTS

A more dynamic process that constraints the parking of people relates to the stock of available places. When a vehicle parks, a parking space becomes unavailable to another vehicles searching for a parking place. The drivers reaction to this dynamic process is the central part of the search process.

Attribute set generation. The set of attributes that influence the decision to travel to and choose a particular parking place are considerable. They could include:

Travel time to the parking place
Walk time from parking place to desired destination
Ease of parking
Ease of exit from parking facility
Ease of exit from vehicle
Availability of shade, etc.

The inclusion of any these attributes cannot, as yet, be supported by empirical evidence since their is none. The program, therefore, only considers travel time to parking place and walk time to the desired location as attributes in the choice.

Importance rating. The importance people associate with particular attributes has been assumed to equal 1 for the travel time variables and 0 for all other variables.

Choice set generation. The set of alternatives open to a parker is continually changing. Similarly, his perception of the available spaces is also changing. Information about the status of the parking facility is provided throughout the driver's trip and may even be influenced by information gained on previous trips to the facility. To simulate this change in knowledge, in the model, each driver is provided with a matrix of knowledge. This matrix includes the perceived availability of a parking place, the minimum travel time to each available parking place and the perceived number of vehicles between the driver's present position and the parking place. This matrix can be created prior to the vehicles entry into the system and updated as the vehicle moves through the parking facility.

The updating process occurs throughout the drivers trip within the parking facility. The program however limits the updating procedure to the times the vehicle reaches an intersection point. The updating procedure consists of the driver scanning the parking lot, one parking place at a time, and noting the availability of spaces and the position of vehicles the driver can see. This is carried out by drawing a line between the drivers eye and each parking place and investigating the parking places that fall along this line to see if they are empty or not.

This information, on the availability of parking places, is used to update the knowledge matrix. Obviously, parking places and vehicles that cannot be seen cannot be updated. If the driver is aware of the existence of these parking places from a previous scan of the parking facility they can be assumed to be in their previous state of being or to not exist at all. Perceived travel times and perceived number of parking vehicles can also be revised from this visual view and previous information.

Attribute perception. The perception of attributes is influenced by the persons knowledge of the system and his accuracy in measuring the attribute. Errors in the measurement of attributes are often assumed to be normally distributed about the minimum travel time (Taylor 1977). Drivers perceived attributes can be randomly transformed into a perceived value using the normal distribution. This study assumed that the driver is able to determine the exact travel time and the effect of parking and unparking vehicles on the travel time. This was justified by the relatively small parking lots analysed in this paper. The effect of introducing drivers perception into the model will be investigated at a later date.

Attribute evaluation. The attribute evaluation can be filtered through an individuals value structure (Young 1985). The presence of thresholds of acceptance may influence individuals evaluation of attributes. This study assumes that people rank the parking places they can see in order of their closeness to their final destination.

Composite evaluation. The composite evaluation of the choice process is simplified since it is only necessary to consider the travel time to each parking place or the exit. The parking space perceived as best is determined by considering the best parking place that will not be taken by a vehicle in front of the searching vehicle. This is calculated by considering each available parking space that can be seen in order. The best parking place first. Vehicles between the parking place and the searching vehicle are allocated to the spaces. Once there are no more vehicles to be allocated the next parking spot is considered the best available.

Behavioural intention. The choice of the appropriate route at each intersection is determined by the driver choosing the minimum travel time route to the parking place perceived as best. The link that enables the driver to follow this route is the link the driver will take out of the intersection.

Choice inertia. The choice inertia process may represent the drivers preconceived ideas of what parking places are available in the facility. The applications of the model outlined in this paper assumed that the drivers had no preconceived ideas about the availability of parking places.

Reverse process. The reverse linkages are representative of the choice to park or not to park and the influence these have on other vehicles decisions.

Movement onto the selected link

The previous section has described the process involved in choosing the link out of the intersection. The modelling of the movement of vehicles onto the selected link consists of two parts: the queueing model and a gap acceptance model. The discussion of movement onto the selected link will consider the ordering and priority of links in the system, the gap acceptance and the presence of vehicles on the exiting link.

Link ordering. The basic philosophy behind the consideration of each vehicle in the network is related to the vehicles position on a link, the link type and the position of the link in the network. First, all the major links are considered in order. The link closest to the exit with the highest priority is considered first. The order in which the exits are considered is chosen by the user and is related to their importance in the parking system. Once all the major links associated with the first exit are updated, the next exit is considered. Once all the major links and the exits have been updated, the minor links are considered.

Vehicles on exit link. One situation that may result in queueing occurs when a vehicle tries to move from a one link to another link in search of a parking place. If there is a vehicle queued, too close to the intersection, on the exit link the searching vehicle cannot enter the link. The searching vehicle must queue, on the entry link, until the blockage clears. Vehicles following the blocked vehicle must also queue.

Gap acceptance. Queueing can also take place when a vehicle attempts to exit from a minor link. This can occur as a result of the existing vehicle looking for a gap in the major flow of vehicles. Major road vehicles are given priority in this simulation. If a appropriate gap is not present the vehicle exiting the minor road must queue until there is an appropriate gap.

Exiting from the facility

The route taken, by a vehicle, to the desired exit is assumed to be the quickest available. The route is updated when the vehicle reaches each intersection. The calculation of the quickest time takes into account the existence of parking and unparking vehicles and the effect these will have on travel to the exit.

PROGRAM OPERATION

This section describes briefly the operation of the model as seen by the user. The section covers the inputs required by the model and the outputs produced by the model.

Inputs into the model

Input into the model can be either by interactive mode or through a disk file. In the interactive mode, the simulation model asks particular questions and the user provides the answers. The input can be divided into four groups: the description of the system, the traffic conditions, simulation options and the output options. The description of parking system involves the creation and numbering of the primary network. The links are numbered in increasing order from the exit points to the first change in direction of a link. The exit points are considered in order of priority. The secondary network is also numbered from the exit point. The position of parking spaces is denoted by the position of the centre of the parking space on the link. Numbering of nodes enables the connectivity of the parking system to be determined but does not have to occur in any particular order. For convenience, it is advisable to number the nodes in a manner consistent with the link numbering system. The traffic conditions required are the average traffic flow, vehicle spacing, acceptable gap, parking time, unparking time and parking duration. The simulation information required is the random number seed to start the simulation, the type of update procedure to be used and the times the simulation is to record vehicle information. The program output options relate to the type of output and the simulation times where information is to be output by the program.

Measures of performance

To determine the performance of a system a simulation model can be run in two different modes. These have been termed the "terminating" simulation and the "steady state" simulation. The "terminating" simulation determines the measures of performance after a specific event occurs. In the simulation of a parking lot at a shopping centre the terminating event may be the closing of the shops at the end of trading. The "steady state" simulation prescribes particular steady state conditions and runs the model until an estimate of the overall performance of the system can be determined. Both approaches have their application. The "steady state" situation can be used to estimate what is likely to occur in peak load conditions. The results of "steady state" simulation models are also the only method of comparison of the model output with the results of numerical models. The "terminating" situation may be used to investigate normal flow conditions. The model developed here can be run in both modes.

Specific measures of the performance for a parking facility can take several forms. Some suggested measures include:

Travel time through the system (not including parking time)
Travel time through the system (including parking time)
Delay in the system
Time to find parking place
Time to exit parking facility
Average number of parking places used
Maximum number of parking places used
Minimum number of parking places used
Average queue length at exits
Maximum queue length at exits
Number of stops while in parking lot
Utilisation of the parking facility
Occupancy of parking facility
Proportion of people not able to find a parking place
etc.

Obviously, the incorporation of all these measures into the model could result in a considerable increase in run time without necessarily increasing the understanding provided. The program therefore does not attempt this task. It rather outputs only a few measures of performance but also allows the information concerning each vehicles movements to be output to a computer file at each update point. The individual vehicle information can be accessed by an analysis program and the required performance measures calculated.

The performance measures output by the program are:

* The average vehicle travel time for all vehicles exiting the system. This measure provides an estimate of the efficiency of the system in terms of vehicle travel time and delay.

* The average travel time for vehicles that have parked and have exited the system. This measure enables the vehicle fleet to be broken down into vehicles that have parked and those that have not. The relative break up of the delays between these vehicle types can be calculated.

* The proportion of vehicles leaving the parking lot that had found a parking place. This measure provides an indication of the probability of a person finding a parking place.

* The proportion of time that vehicles are parked in the parking space. This measure is referred to as the utilisation of the facility and provides an indication of the efficiency of the parking facility.

VERIFICATION OF THE MODEL

The previous section introduced the model components and their combination into a computer program. This section considers the verification of the model.

Verification of the simulation model can occur in many ways (Young 1984). For the purposes of this study, verification was limited to the consideration of the model's components, observation of the movement of vehicles through the parking lot, comparison of the results obtained when using different program update options, using interpreted and compiled computer languages, comparison of the model results with existing analytical models and observation of overall measures of the systems performance.

Many of these verification procedures cannot be presented in this report. The results presented in this section aim at providing the reader with an indication of the accuracy of the model. The model was run in a "steady state" mode since it was possible to compare the results with the numerical models.

To study the performance of this model a small parking problem will be considered. This application will be the study of short term parking. Short term parking may be required at an airport, shopping centre or business premises. The parking bays are 6 meters in length. Parking times for this situation vary around a mean of 10 seconds while unparking times have a mean of 3 seconds. The average parking duration used was 15 minutes. The provision of 10, 20 and 30 parking places was considered. The traffic flows used were 30, 60, 90 and 120 vph.

The following sections will compare several performance measures with some similar measures obtained from analytical models .

In the determination of the measures of performance discussed in the following sections a warm-up-period of 20,000 seconds was used. The sampling of values was taken over 5,000 second intervals with 500 second gaps in between each interval.

Utilisation of parking places

The first aspect of the simulation model to be discussed is the utilisation of the parking spaces. Table 1 presents the results from the simulation model. It can be seen that the utilisation increases with increased traffic flow. The utilisation factors vary from a low of 0.26 for 30 parking places and 30 vehicles per hour to a high of 0.95 for 10 parking places and a flow of 120 vehicles per hour. Interestingly, the utilisation factor does not reach 100% even though, as will be seen in the next section, many vehicles are not able to find a parking place.

TABLE 1 UTILISATION OF PARKING PLACES

NO. OF PARKING PLACES	TRAFFIC FLOW (vph) 30	60	90	120
10	0.66 (0.07)	0.87 (0.04)	0.92 (0.02)	0.95 (0.01)
20	0.39 (0.09)	0.71 (0.09)	0.87 (0.03)	0.93 (0.02)
30	0.26 (0.06)	0.53 (0.07)	0.74 (0.07)	0.89 (0.03)

( ) standard deviation of sample means

The utilisation factor determined in the simulation model can be compared to the utilisation factor determined in queueing models (eqn 3). Table 2 shows the results of this calculation for the situation studied in this section. Comparison of the theoretical values in Table 2 and the simulation values in Table 1 shows a close correspondence for utilisation factors less than or equal to 0.75. However, for utilisation factors greater than 0.75 there is little or no correspondence. This lack of correspondence for high utilisation factors is to be expected since the analogy between the parking and queueing theory situation breaks down for these conditions. The correspondence for the lower utilisation factors indicates that the simulation models components are grouped together in the correct fashion.

Proportion of drivers finding a parking place

The second measure of performance to be discussed is the proportion of drivers finding a parking place. Table 3 presents the results. It can be seen that the number of drivers who can find a parking place decreases with increasing traffic flow and decreasing availability of parking places. This is as would be expected. All vehicles were able to find a parking place for the combinations 30 park places and flow rates of 30 and 60 vehicles per hour, and 20 park places and 30 vehicles per hour. The worst condition was the 10 park places and a flow rate of 120 vehicles per hour where only 31% of the vehicles found a parking place.

TABLE 2 THEORETICAL UTILISATION AND SUPPLY/DEMAND MEASURES

NO. OF PARKING PLACES	TRAFFIC FLOW (vph) 30	60	90	120
10	0.75 *	1.50 -	2.25 -	3.00 -
20	0.38 ns	0.75 ns	1.13 -	1.50 -
30	0.25 ns	0.50 ns	0.75 ns	1.00 -

ns - no significant difference at 5% level between utilisations given by the simulation model and the queueing model
* - significant difference at the 5% level

TABLE 3 PROPORTION OF PARKERS FINDING A PARKING PLACE

NO. OF PARKING PLACES	TRAFFIC FLOW (vph) 30	60	90	120
10	0.94 (0.05)	0.60 (0.09)	0.45 (0.05)	0.31 (0.04)
20	1.00 (0.00)	0.92 (0.06)	0.80 (0.08)	0.60 (0.07)
30	1.00 (0.00)	1.00 (0.00)	0.98 (0.02)	0.81 (0.07)

( ) standard deviation of sample means

Another approach to calculating the proportion of drivers not able to find a parking place is to use a simple queueing model that assumes random arrival and service rates (eqn 5). Table 4 shows the results of the above calculation for each of the parking conditions considered. It can be seen, that there is a considerable degree of correspondence between the analytical results (Table 4) and the simulation modes results (Table 3) for utilisation factors less than 0.75. The analogy between the queueing model and the parking situation breaks down as the utilisation factor increases above 0.75. The correspondence between the theoretical and the simulation model for low utilisation factors provides some evidence that the components of the simulation model are combined in a appropriate fashion.

TABLE 4 THEORETICAL PROPORTION OF PARKERS WHO CAN FIND A PARKING PLACE

NO. OF PARKING PLACES	TRAFFIC FLOW (vph) 30	60	90	120
10	0.93 ns	- -	- -	- -
20	0.99 -	0.96 ns	- -	- -
30	1.00 -	0.99 -	0.98 ns	- -

ns - no significant difference between simulation and numerical model results

Delay while unparking

The delay to vehicles travelling through the system consists of several parts. These are the delay due to following slower vehicles, the delay due to waiting for a cars to park and the delay when finding a gap to unpark. Unfortunately, all of these components can not be calculated by analytical models. It is however possible to approximate one of these components using an analytical model. This is the delay while unparking.

Unparking can be seen as a gap acceptance problem where the unparking vehicle is looking for a gap in a passing stream of traffic. The delay to vehicles accepting a gap in a random flow of traffic can be estimated using Adam's formulae. This formulae states that the delay (Del) to vehicles waiting for a gap t in a random flow of traffic can be given by:

$$\text{Del} = (\exp(Q.t) - Q.t - 1)/Q \qquad (7)$$

Westland (1967) argued that this formulae can be used to justify the provision of manoeuvreing lanes adjacent to strip parking centres by estimating the through volume that can be accommodated whilst maintaining delays to unparking vehicles within a tolerable limit. To replicate this formulae in the simulation model it is necessary to make the following adjustments:

Generate the arrival of vehicles using a negative exponential distribution.
Set the average parking manoeuvre time to a low value (1 second) so that parking vehicles have little influence on the flow of through vehicles.
Introduce vehicles that will not park.
Use a constant acceptable gap

The results of Adam's formulae and the simulation model were then compared for unparking times (or acceptable gaps) of 5, 10 and 15 seconds, and total vehicle flows of 250 and 500 vph..

Table 5 presents the results of the application of the simulation model to these conditions and the predictions made by Adam's formulae. Comparison of the results shows that the simulation model replicates the analytical model reasonably well. Slight overestimates of delay for the 5 second gap and underestimates of delay for the 15 second gap, each with a flow of 500 vehicles per hour, were present. These discrepancies could be due to a difficulty in replicating the desired conditions exactly. The problems with this replication were:

* Although the initial vehicle gaps are generated by a negative exponential distribution the distribution of vehicles adjacent to each parking place is unlikely to be representative of a negative exponential distribution. This is due to the complication of vehicles parking and unparking upstream of the parking place, the different speeds and car-following gaps in the traffic.
* The delay calculated by Adam's formulae did not take into account that 30 vehicles per hour were parking and the remainder were through vehicles
* The small parking time could have an influence on the flow of traffic

TABLE 5 DELAY TO UNPARKING VEHICLES (SECONDS)

UNPARKING TIMES (sec)	TRAFFIC FLOW (vph) 250		500	
	ADAM'S EQN.	SIMULATION	ADAM'S EQN.	SIMULATION
5	0.98	1.51 (0.72) ns	2.22	4.04 (1.57) *
10	4.44	4.55 (2.12) ns	11.67	10.08 (4.45) ns
15	11.41	11.38 (4.61) ns	35.62	27.01 (8.05) *

( ) standard deviation of sample means

ns - no significant difference at 5% level between theoretical and simulated measures

* - Significant difference between theoretical and simulated measure

TESTING THE MODELS SENSITIVITY

Each successful application of the model provides the user with more confidence in its ability. The applications of the parking simulation model considered in this section is the comparison of the performance of a number of parking networks. Three layouts were chosen for this comparison. They are presented in Figures 2, 3 and 4. Network 1 (Figure 2) has all its parking places positioned on each side on the north/south roads. The road through the parking lot is continuous and passes each parking place. This layout is consistent with the desires of the Highway Research Boards (HRB 1971) report for drivers to pass each parking place in their trip through the parking lot. Network 2 (Figure 3) has a major east/west road with no parking. All the parking stalls are in the north/south direction as in network 1. The parking roads exit from and enter onto this road. This approach is more in line with that suggested by Ogden and Bennett (1984). Network 3 (Figure 4) is similar to the second system but parking is provided along the major east/west route. The three systems were constrained to have 56 car parking places for comparison purposes. More parking places can be fitted into network 1 (Figure 2) and network 3 (Figure 4) layout.

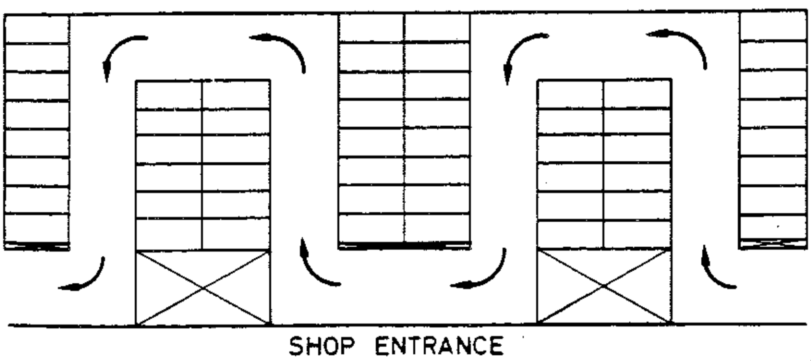

FIGURE 2 PARKING NETWORK 1

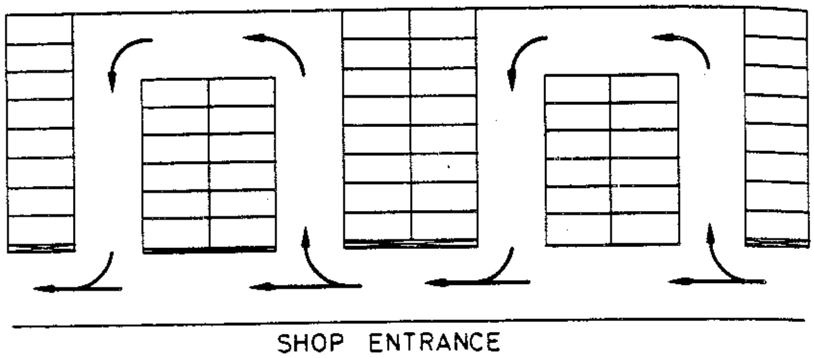

FIGURE 3 PARKING NETWORK 2

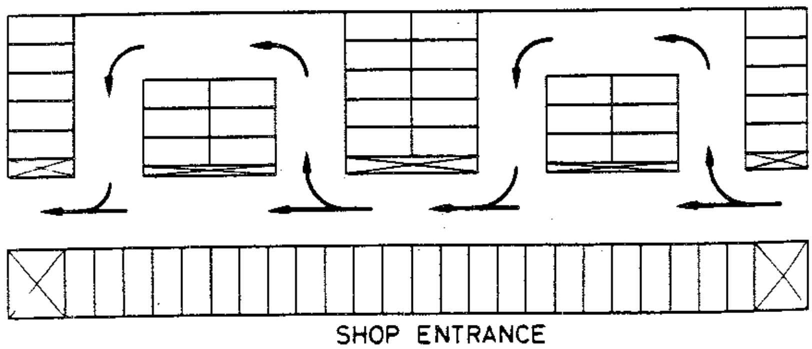

FIGURE 4 PARKING NETWORK 3

The traffic conditions simulated included four traffic flows (30, 60, 90 and 120 vph). These conditions ranged from under capacity, through the capacity situation to the over capacity situation. The parking and unparking times were taken from Hobbs' (1974) study and were 9 seconds for parking and 20 seconds for unparking. The average parking duration of 1 hour was typical of a small shopping centre. The mean traffic speed was 15 kph and the average gap between vehicles was 2 seconds.

The comparison of the performance of each of these systems will be based on the utilisation factor, the number of vehicles finding a parking place and the travel time through the system. The following sections will discuss each of these measures in turn.

The model runs used the maximum warm-up-period of 60,000 seconds and extracted ten samples each of 20,000 seconds duration. The space between samples was 1,000 seconds.

Utilisation of parking networks

Table 6 presents the results of the utilisation calculations. It can be seen that the utilisation factors increase with increasing traffic flow. The lowest utilisation is for 30 vph. This varies between 0.49 and 0.55. The highest utilisation is for 120 vph. This varies from 0.92 tp 0.95. The major increase in the utilisation is between the traffic flows 30 and 60 vph. The increase in utilisation evens out after 60 vph. The utilisations for network 3 tend to be a little lower than those for the other two networks. The difference is not significant, but its consistency across the traffic flows, indicates the possibility of a difference in the drivers ability to handle the three parking networks. This difference is likely to be due to:

* the possibility of driver not seeing a parking places

* the possibility of not seeing a vehicle in the system and making the incorrect decision as to which direction to take.

Proportion of parking vehicles

The proportion of parking vehicle for each network and traffic condition is presented in Table 7. It can be seen that the proportion of parking vehicles for the three networks decreases with increasing traffic flow. The traffic flow of networks allow all the drivers at a traffic flow of 30 vph to find a parking place. However only 50% of the drivers entering at a traffic flow of 120 vph are able to find a parking place. The lowest proportion of vehicles finding a parking place is for network 3. The main reasons for this were outlined above.

TABLE 6 PARKING NETWORK UTILISATIONS

TRAFFIC FLOW (vph)	30	60	90	120
Demand/supply ratio	0.54	1.07	1.61	2.14
Network 1	0.55 (0.03)	0.88 (0.05)	0.94 (0.04)	0.95 (0.04)
Network 2	0.51 (0.05) ns	0.88 (0.04) ns	0.94 (0.04) ns	0.96 (0.04) ns
Network 3	0.49 (0.05) ns	0.84 (0.04) ns	0.91 (0.04) ns	0.92 (0.03) ns

ns - no significant difference at 5% level between network 1 nad network compared with it.

TABLE 7 PROPORTION OF PARKING VEHICLES FOR NETWORKS

TRAFFIC FLOW (vph)	30	60	90	120
Network 1	1.00 (0.00)	0.88 (0.05)	0.64 (0.06)	0.50 (0.04)
Network 2	1.00 (0.00) ns	0.89 (0.05) ns	0.63 (0.05) ns	0.48 (0.03) ns
Network 3	1.00 (0.00) ns	0.83 (0.06) ns	0.59 (0.05) ns	0.47 (0.05) ns

ns - no significant difference at the 5% level between network 1 and network being considered.

Travel times of vehicles using network

The last measure of performance to be considered is the average travel time for the vehicles using the networks.

The first average travel time to be considered is that for all vehicles. Table 8 presents these travel times. It can be seen that the first network presents the slowest movement of vehicles. The travel times range from 42.65 to 47.87. This is to be expected since this network requires the vehicles to travel past every parking space. This trip with no interference from other vehicles takes the average vehicle 37.80 seconds. The second network has a lower average travel time than the first. The travel times ranging from 31.53 to 44.47 seconds. This network requires most vehicles to pass only half of the parking spaces. This requires only 27.36 seconds when there is no interference. However, as the traffic demand increases, above the parking spaces available, more and more vehicles will have to pass the entire set of parking places in their search and their exit from the facility. This will increase average travel times. The third network has the lowest average travel times. These range from 24.67 to 31.89 seconds. In this network the minimum travel time to the best parking place and then to the exit is only 21.09.travel time.

TABLE 8 AVERAGE TRAVEL TIMES FOR ALL VEHICLES USING NETWORKS (SECONDS)

TRAFFIC FLOW (vph)	30	60	90	120
Network 1	42.65 (2.61)	45.92 (2.39)	47.07 (2.51)	47.87 (1.45)
Network 2	31.53 (1.58) *	39.77 (2.09) *	42.60 (2.44) ns	44.47 (1.91) ns
Network 3	24.67 (3.17) *	26.20 (2.28) *	29.03 (2.34) *	31.89 (2.28) *

( ) Standard deviation of sample means
* - significant difference at 5% level between travel times on network 1 and the considered network

It is also of interest to look at the average delay to vehicles. This will be calculated by subtracting the travel time for a vehicle travelling at the average speed to drive to the best parking place and out of the system from the travel times extracted from the simulation runs. Table 9 presents the results. The delays for the flow of 30 vph vary from 4.85 for network 1, through 4.17 for network 2 to 3.58 for network 3. This trend is likely to result from the decreasing interaction between parking and unparking vehicles with through vehicles between networks 1 and 3. The flow of 60 vph shows a different trend. In this case, the delay for network 1 is 8.13, for network 2 it is 12.41 and for network 3 it is 5.84. The high average delay to vehicles in the second system indicates that the intersections of the links make a large contribution to the delay experienced by the vehicles. This general trend remains for the traffic flows of 90 and 120 vph.

TABLE 9 AVERAGE DELAY TO ALL VEHICLES USING NETWORKS (SECONDS)

TRAFFIC FLOW (vph)	30	60	90	120
Network 1	4.85	8.13	9.27	10.07
Network 2	4.17	12.41	15.24	17.11
Network 3	3.58	5.84	8.94	10.80

The final travel time that should be considered is the travel time to parked vehicles. Table 10 presents these results. As with the travel time for all vehicles the travel time for the first network is the largest and that for the third network is the smallest. Interestingly, the average travel times for the parked vehicles for networks 2 and 3 is similar to the average travel times for all vehicles. This is markedly different to the situation when all vehicles travel along the same route (network 1). It indicates that some of the vehicles that cannot find a parking place, in networks 2 and 3, travel through the entire network in search of a parking place. This is likely to be a much longer trip than that of the vehicle that parks and will increase the travel time for the vehicles who cannot find a parking place.

TABLE 10 TRAVEL TIME FOR PARKING VEHICLES USING NETWORKS (SECONDS)

TRAFFIC FLOW (vph)	30	60	90	120
Network 1	42.65 (2.61)	46.38 (2.39)	49.16 (2.51)	47.87 (1.45)
Network 2	31.53 (1.58) *	39.33 (2.09) *	42.33 (2.14) *	45.90 (1.92) ns
Network 3	24.71 (3.19) *	26.60 (1.77) *	28.45 (1.85) *	31.22 (1.75) *

( ) standard deviation of sample means

* - significant difference at 5% level between travel times on network 1 and that on considered network

Remarks

This section has discussed the application of the simulation to three small parking networks. It demonstrated that the philosophy of asking each driver to travel past every parking place is likely to result in a high utilisation of the parking spaces but maximum travel time through the system. The network that keeps parking away from the major circulation routes is likely to reduce the travel time and maintain a high utilisation. It is therefore to be preferred from the point of view of circulation. The network with parking on the major circulation routes and the minor routes is also likely to decrease travel times but the complexity of the decisions at each decision point in the system is likely to result in a decrease in utilisation.

CONCLUSIONS

This paper investigated the existing literature, described the development of a simulation model (PARKSIM/1) of vehicle movements in parking facilities, verified PARKSIM/1 by comparison with some numerical models and applied the model to a variety of parking problems.

The development, verification and application of the discrete event simulation model indicated that it is feasible to model the movements of vehicles in a parking facility. Two versions of the program were developed. The Kaypro II microcomputer version of the program was found to run very slowly and the networks that could be considered were very small. The version of the program compiled on the Hewlett Packard 1000 minicomputer was found to run at better than real time for many combinations of input parameters and enabled networks of a reasonable size to be studied.

The study presented in this report makes only one small step towards the development of a design tool for studying the efficiency of parking facilities. There are a number of further steps required before the model can reach its full potential. Some of the possible developments are: the incorporation of two way links into the model, the introduction of pedestrians and the incorporation of a computer graphics capability

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