AN INTRODUCTION OF A PARKING DESIGN AND SIMULATION MODEL

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abstract: This paper is to introduce the procedures involved in the development and validation of a parking design and simulation model, PARKSIM 2, which could be used to evaluate the design of a parking lot layout. The performance measurement on a design will provide quantitative information to parking lot designers enabling them to choose the best layout. PARKSIM 2 is a PC-based microscopic, discrete computer simulation model. It can duplicate the vehicle and pedestrian movements as well as the interactions between them in a parking lot. The measurement includes space utilisation, vehicle travel time and conflicts.

1. INTRODUCTION

Transport systems provide a variety of services allowing users to partake in desired activities. The provision of parking facilities is an integral part of the system and has an important role to play in providing the required services, and therefore enhancing the system. In providing an efficient parking service to satisfy the coherent demand, the design of parking lots and the management of the facilities should be taken into account.

1.1 Current Design Procedures

In current parking lot design process, standards are available to guide the designers on the correct size of parking lot components. Recommended practices for the design of parking lot components are plentiful. In Australia, the National Association of Australian State Authorities published the guide to Traffic Engineering Practice (NAASRA, 1982) to aid in the design of parking facilities. Other useful references include Brierley (1972), the Transportation and Traffic Engineering Handbook (ITE,1982) and Ogden and Bennett (1989). However, no reference is available on the investigation of the performance or the "level of service" of a parking lot. Research into the development of a design tool to estimate the overall performance of a particular parking layout is limited (Farrow, 1984). The difficulty in developing mathematical models for investigating parking lot performance has long existed.

Although the existing references and manuals provide useful information on parking surveys and design procedures for the individual components of a parking system, methods to gather these components into an overall systematic design are not well described. Moreover, no method is available on the evaluation of the performance of a parking lot. In particular, little effort has been directed at researching into the "level of service" on off-street parking facilities. The standard of parking lot designs varies with the experience of the designers or planning engineers. Therefore, considerations need to be given to the development of procedures to improve the design and management of parking facilities.

1.2 The Problems Associated with Current Design Methods

There are many references, and computer aided design and analysis packages available to assist engineers to evaluate their proposed designs (e.g. ARR123, SIDRA and INTANAL for the design of a signalised intersection, and Traffikplan for network assessment). Determining the best parking lot layout, however, has not been effectively addressed by the current design process (Young, 1986). From a user's point of view, it is useful to introduce the concept of "level of service" into the design considerations. The "level of service" of a parking station is a slippery notion. It is influenced by the delay experienced by the drivers, ease of movement into and out of the facility, ease of parking and unparking, pedestrian movements and the physical environment of the facility (e.g. lighting, drainage etc.). Apart from these requirements, there are still some other concerns needing to be considered in the design process towards the development of a good parking lot layout. In general, the design of a parking lot includes three important concerns:

- the definition of the static capacity,
- the circulation of vehicles searching for a space, parking in a space, looking for an acceptable gap to unpark, unparking and leaving the lot, and
- the level of conflicts between parking lot users.

The determination of the static capacity has been well researched (Young, 1988). The investigation of vehicle circulation and parking lot conflicts, however, has not been so well studied. Although parking system designers often consider the efficiency of a parking lot layout in terms of space-hours, they can rarely quantify the "level of service" offered by the lot due to the absence of physical and theoretical development in design process (Young and Yue, 1992).

There are several dimensions to be taken into account in measuring the "level of service" of a parking lot. One of them relates back to the static capacity. The probability of finding a parking space influences a parker's perception of the quality of the system. This may also affect the utilisation of the lot. Another dimension relates to the travel time within the lot. A lower travel time may indicate a better parking lot layout. The third dimension is vehicle to vehicle conflicts and vehicle to pedestrian conflicts in a parking lot. These have been left to the designer's judgment in parking lot design practice and no systematic evaluation method has been developed to solve the uncertainties.

1.3 The Use of Models in Parking Lot Design

Although the comparisons of the performance for different existing parking lots is always possible, using video recording techniques to collect and analyse parking related data are often time consuming and can only be used to investigate the existing parking lots. New or proposed designs cannot be investigated using this approach. Moreover, changes of an existing parking lot layout involve a considerable cost associated with remarking and reconstruction if it has been found inefficient. Therefore, it is necessary to consider a more efficient method to assist in the evaluation of parking lot layouts at design stage. One approach is to develop a simulation model which can be used to evaluate the performance for different parking lot layouts.

Using computer aided design methods and simulation models in solving transport and traffic engineering problems have considerable advantages. Simulation offers the means of quantifying measures of performance for complex situations where theoretical models are inconclusive. Simulation models can be used to estimate the likely effects for various changes that a traffic engineer or planner may have in mind only for one particular layout. They can also be used to gain increased understanding of traffic systems by experimenting with the models in ways that are not practical in reality (Allsop, 1985). Therefore, it is necessary to consider using computer technology to improve the traditional parking lot design and evaluation techniques. Based on the existing computer hardware and software, it is possible to incorporate parking lot design procedures into a computer simulation model, as models can carry out this task very rapidly in a convenient way at a lower cost. Consequently, it will make the design and layout selection process reach a higher standard. This will help traffic engineers and parking lot designers to judge if a design is good regarding the measurements of the "level of service" including parking lot utilisation, average travel time and the degree of conflicts.

2. THE DEVELOPMENT HISTORY OF PARKSIM 2

There are three stages in the development of the parking design and simulation model. It was first developed as PARKSIM based on a simple link simulation model (Young, 1986). Then the model was refined as PARKSIM1 to include a better search strategy and two way links. The current version called PARKSIM 2 includes a pedestrian movement model and a model to simulate the level of conflicts in a car park.

2.1 The Early Version of the Model - PARKSIM

The application of microsimulation to parking networks was first attempted by Bourton, Miller and Sutton (1971). They applied this approach to the modeling of vehicle movements in multistory car parks. The model generated vehicles entering a parking lot with information on time of arrival, passenger occupancy, parking duration, parking time and unparking time, etc. The output which could be obtained from the simulation model was the time vehicles took to find a vacant parking space, the distance driven in the car park and the time spent queuing in the car park. When the model was run and compared with the results reported by Ellson (1984), a good correspondence was found. However, the multistory car park design simulation model did not consider the existence of through vehicles in the unparking aisles. The simplifications of uniform speed for vehicle and pedestrian reduced the amount of information on the interactions of the system users. The application of the model was limited since the model did not consider vehicle searching for a parking space and assumed that drivers had perfect knowledge about the system.

To investigate the parking and unparking manoeuvres in multi-level parking structures, Ellson (1984), in an extension of a previous study (Ellson, 1969), used a discontinuous distribution model based on discrete time intervals of a half-second. The choice of parking spaces by drivers in the model was predetermined. This model could deal with some of the relationships between parking stall/aisle dimensions and layouts of car parks and the maximum flows, and it sought to provide a quantitative basis on which some of the traffic implications of various designs of car parks could be assessed. Although this model was useful in assessing the design of multi-level car parks, its assumption of a predetermined search process limited its application. No information on the level of service and conflicts was provided by this model.

Farrow (1984) developed a discrete event simulation model to study the operation of a simple parking lot consisting of a single row of parking spaces served by a one way circulation aisle with a one way entrance and exit. Individual vehicle movements were incorporated into the parking simulation model. This approach was shown to be a considerable development. The model basically contained the following three phases:

- an input phase which described a parking lot layout, specified the program control parameters, and generated the characteristics of a set of vehicles that were simulated.
- the simulation phase which consisted of a number of update procedures that simulated each vehicle movement through the parking lot.
- an output phase which summarised and analysed the various measures of the simple parking lot that included vehicle delay and the number of vehicles unable to park.

Although Farrow's (1984) simulation model combined parking lot design procedures with a simulation model, the information which could be provided by the model was limited. This model could only be used for a very small and simple parking lot layout (one way link with a single row maximum of 20 parking spaces). Furthermore, the model could not simulate traffic conflict situations. These restrictions limited the model's applications. Young (1988) extended the work of Bourton et al. (1971) and Farrow (1984) to incorporate the process of searching for a parking space, the variability in parking and unparking times, the interactions of through vehicles with parking and unparking vehicles, different vehicle speeds, car-following behaviour and gap acceptance into a computer aided design simulation package, called PARKSIM. It was validated on vehicle travel/search time, parking lot utilisation and the possibility of finding a parking space.

2.2 The Refined Version - PARKSIM1

Notwithstanding the fact that PARKSIM made a number of significant advances over the other simulation models, the limitations involved in the model development have restricted its application. Generally speaking, PARKSIM was deficient in its specification of the parking network and the parking space search process. It could only be used to simulate parking lots with one way links (aisles). Its performance was also affected by the parking space search process since it was based on a simple assumption which did not replicate to the actual parking behaviour. These limitations restricted its potential applications. It was, therefore, necessary to refine and upgrade the model before incorporating pedestrian movements and conflict measurements with it.

Searching for a parking space is a common activity in a car park. In general, the probability of finding a parking space influences a parker's perception to the quality of a parking lot.

Drivers will not visit land-uses such as supermarkets if they cannot find a parking space or cannot use other forms of transport. This factor also relates to the ability of drivers to locate their parking spaces within a parking lot. Moreover, different parking lot layouts may affect the travel/search time for a drivers looking for an appropriate parking space and the level of congestion of the car park.

To improve the level of service for a car park, the design of parking lots should be considered as the first step. Poor designs may result in increased searching/travel time, cause more interactions between users and reduce the efficiency of a lot. Sections in a parking lot that are not visible or are difficult to reach may be underutilised and this lot may never achieve its maximum capacity. Consequently, it is necessary to investigate the parkers' searching procedures and behaviour in a parking lot. The search behaviour is also important in the development of the parking lot simulation model.

Although the search process may vary among parkers, the general performance can still be investigated by field observations. Conventional wisdom may assume that a driver would choose the parking space closest to the final destination. To validate this, a study was undertaken by Young (1988) to investigate whether drivers choose the closest space. Figure 1 shows the survey results. The vertical and horizontal axes represent the frequencies and the vacant spaces close to the final destination in terms of distances respectively.

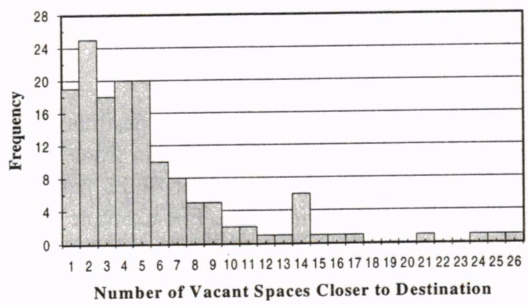

Figure 1 Distribution of Parking Space Choice (Young, 1988)

From the distribution, it can be seen that the parking spaces closer to the destination attract more drivers than those far from it. For instance, the first five closest vacant spaces have almost the same frequency of being chosen. This indicates the fact that parkers prefer to choose spaces close to their destination. The closeness to destinations is therefore used as a basis of ranking parking space priority.

Presenting searching behaviour in the form of a model needs setting up a series of specifications. To simulate the vehicle searching behaviour in a car park, there are two aspects which appear potentially important and therefore need to be taken into account in model development. One is the determination of the destination link. The destination link is the link containing the selected parking space. The other one is the way to replicate drivers' decision making process in selecting a space. To accomplish this process, a parking space rank/priority data base is employed in the model. The rank/priority data base is formed by calculating the distances from each parking space to the destination. In the model, each vehicle reaching an intersection (end of a link) is provided with a knowledge matrix. This matrix includes a perceived minimum travel time to each parking space seen at a decision point. The selection of the parking spaces is based on a list of spaces by decreasing space rank/priority.

There are two considerations involved in refining and improving PARKSIM. The first is the determination of final link (destination link). Based on the space priority order, vehicles look at each parking space in turn after reaching an intersection. If there are no parked vehicles on the line of sight of a searching vehicle to a space with higher priority, the vehicle will be given the opportunity to consider the minimum travel time and check the number of vehicles in front. It then chooses the link (destination link) with shorter travel time and lesser number of vehicles in front. This link choice algorithm may closely reflect the general vehicle searching behaviour.

The second consideration is the use of a parking space preference system. The preference system is used to overcome the limitations in PARKSIM. It is also particularly designed for modelling two way link parking lots. Based on the principle described in the link choice process, a vehicle determines the destination link containing the preferred space at an intersection point. At the same time, an indicator will be set up for the particular parking space. Once the indicator is on, this parking space represents the destination for the vehicle. The driver will move towards this space. However, if a better available space is to be passed, the new space will be chosen for parking and the parking space indicator which is set up previously will be withdrawn. Similarly, if a second vehicle passes the space chosen by a vehicle as the destination and the second vehicle finds it is appropriate, the second vehicle will park there and the first vehicle must find a new space. This process will continue through the program updating.

As the determination of the preferred space and the destination link is based on the considerations of travel time and the number of vehicles in front, the algorithm is generally able to avoid the possibility of that vehicles can never find a parking space. However, the above situation may exist in an extreme instance. For example, when many vehicles are looking for spaces to park while there are limited spaces available in the lot. This situation may only occur when the car park almost reaches its full capacity. Although the preference system still works in the circumstances, the first arrival would take the available space. In reality, it is particularly true that parkers always choose the spaces they can see. In determining the destination link and the space to park, the closeness of the surrounding vehicles are also taken into account in the process. When the car park moves towards its full capacity, it can often be seen that vehicles move around circulating the car park and the first arriver will take the available space.

The second refinement work carried out was to extend the model to simulate two way links as PARKSIM could only be used for one way link. Although there are many car parks using one way system, two way parking lots are even more common. Moreover, as a simulation model, its one way link capability limited the application. Therefore, another improvement in the refinement procedure is to extend PARKSIM's capability to simulate two way link parking lots.

This extension includes two steps. Firstly, the consideration of two way traffic condition in an aisle is incorporated into the network description. In the network input program, one section of road between two nodes is defined as two links when it is a two way road. The start of a link and the end of a link at intersections are specified through the network specification. The link description determines the link directions as well as turning movements. Secondly, the model assigns vehicles on each link according to their moving directions and the intersection algorithm considers vehicle turning movements. "U" turns are banned at any location in a parking lot. Vehicle changing link can only occur at intersections.

Two way link provides the flexibility for vehicles to choose an appropriate link which is closer to their desirable destination (parking space). Vehicles at junctions have more choices to enter or exit a certain link to reduce queuing delays and may reduce vehicle travel times. This procedure appears closer to the behaviour in a real parking lot.

After the improvement, the refined model, PARKSIM 1, was validated using the data from two car parks in Melbourne, Australia. The simulated results on parking space utilisation and vehicle travel time were compared with the data collected. It demonstrated a reasonable closeness with the real world situation.

2.3 The Current Version - PARKSIM2

Traditionally, the movements of vehicles in parking lots attract more attention due to the thought that parking lots are used to supply storage for vehicles. Most of the parking lot layouts are dominated by the needs for vehicles. Pedestrian movements are usually given in a lower priority or have been ignored in the parking lot design process.

Pedestrian movement does affect people's driving behaviour in a parking lot. For instance, parking or unparking vehicles have to negotiate with pedestrians who are close to their driving path for the right of way. From field observations, many conflicts can be seen between pedestrian and vehicle movements. Therefore, there is a need for a more coherent approach to study vehicle and pedestrian movements in the process of improving parking lot design. Although this can be done by field observations, the cost and time consuming would discourage the possibility. The other way to accomplish this objective is the use of a simulation model. As it has been testified by previous studies, a simulation model can be employed to replicate a dynamic system and to evaluate its performance. This was achieved by incorporating pedestrian movement into PARKSIM 2.

Another feature in PARKSIM 2 is that it can be used to evaluate interactions between parking lot users in terms of the degree of conflicts. The following modules of vehicle to vehicle and vehicle to pedestrian conflicts were incorporated into the simulation model:

- unparking vehicle with other vehicle conflicts;
- parking vehicle with other vehicle conflicts;
- rear end vehicle conflicts;
- junction vehicle conflicts;
- vehicle parking/unparking with one adjacent space occupied and vehicle parking/unparking with both adjacent spaces occupied;
- unparking vehicle with pedestrian conflicts;
- parking vehicle with pedestrian conflicts;
- on road vehicle with pedestrian conflicts; and

■ junction vehicle with pedestrian conflicts.

3. THE STRUCTURE OF THE MODEL

PARKSIM2 is a discrete event microsimulation model which replicates the movement of individual vehicles through a parking lot. As with most of the simulation models, PARKSIM2 consists of three parts: the input program, the simulation model and the model output. The structure of the model is presented in the following sections.

3.1 Model Input

The ability of computer graphics has provided the opportunity of on screen design. The on screen design system used in PARKSIM is menu driven and user friendly. It runs on an IBM microcomputer with enhanced graphics. The parking lot layout can be input using a graphical method or a previously created file. Figure 2 presents a typical parking lot layout design window. The graphical method requests the designer to move the cursor around the computer screen until it is at the correct point on the component being considered. The designer then records the point by pressing the appropriate keys shown on screen menu. It can be seen that the top left of the window indicates the cursor coordinate, the operation menu is displayed at right of the window and the centre part of the window provides the view of the parking lot.

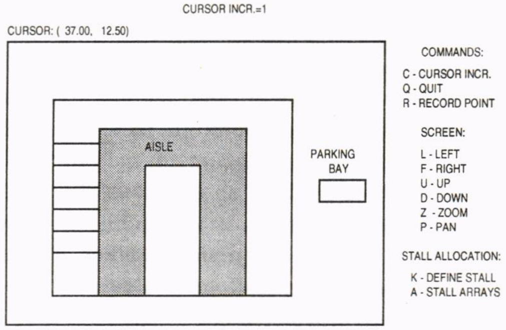

Figure 2 Graphical Input

After specifying the parking lot layout the designer is given the option of entering the network information: the boundary conditions, road network and parking stall locations. The traffic conditions which include hourly parking demand, origin-destination matrix and average parking duration are also required to input into the program. The designer can also revise/modify the inputs when it is necessary.

3.2 Simulation Model

The simulation model accepts information from the input program and provides information to the output program. It contains an event scheduler, an executive routine and a number of event routines. The general flow chart of the model is presented in Figure 3.

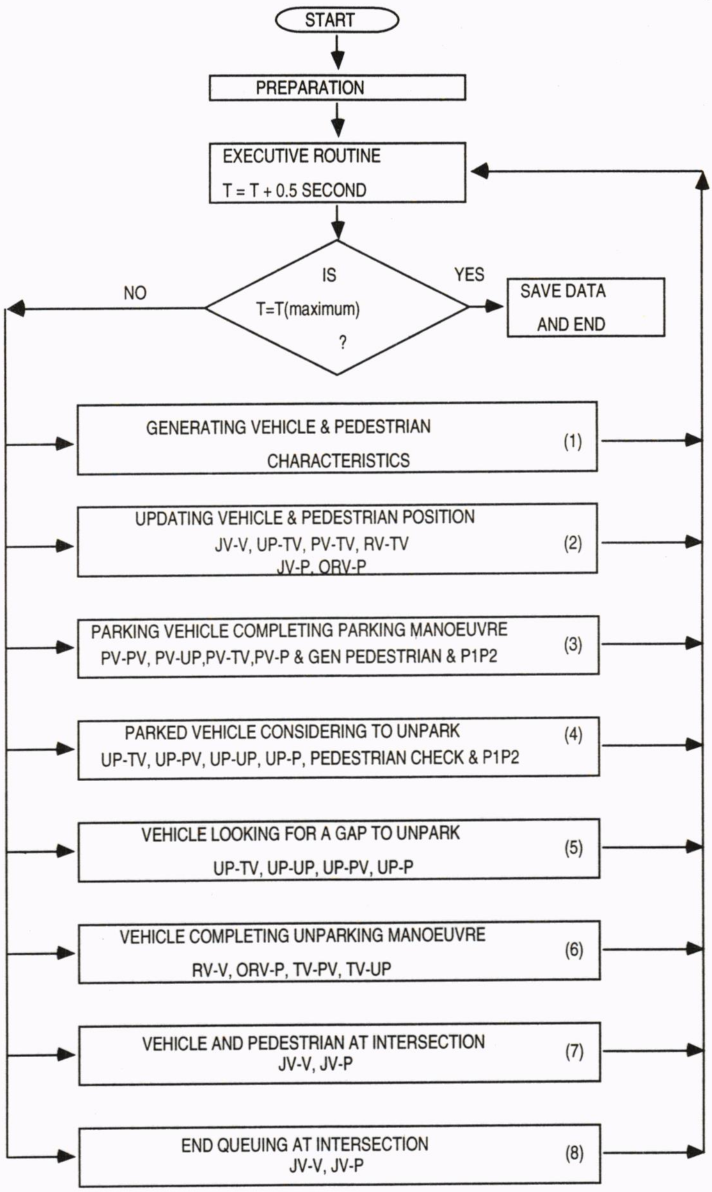

Figure 3 The General Flow Chart of PARKSIM 2

- ***Routine 1:*** Pedestrian characteristics will be generated.
- ***Routine 2:*** Program updates the positions of pedestrians. Conflicts such as "junction vehicle to vehicle (JV-V)", "unparking vehicle to through vehicle (UP-TV)", "parking vehicle with through vehicle (PV-TV)", "rear end vehicle to through vehicle (RV-TV)", "junction vehicle with pedestrian (JV-P)" and "on road vehicle with pedestrian (ORV-P)" will be recorded in this routine.
- ***Routine 3:*** The conflicts of "parking vehicle with parking vehicle (PV-PV)", "parking vehicle with unparking vehicle (PV-UP)", "parking vehicle with through vehicle (PV-TV)" and "parking vehicle with pedestrian (PV-P)" are considered.

Pedestrians will be generated after a vehicle completes its parking manoeuvre. The number of parking constraints (P1P2) is also recorded.

- ***Routine 4:*** "Unparking vehicle with through vehicle (UP-TV)", "unparking vehicle with parking vehicle (UP-PV)", "unparking vehicle with unparking vehicle (UP-UP)" and "unparking vehicle with pedestrian (UP-P)" conflicts are assessed in this routine. Unparking constraints (P1P2) are also recorded.
- ***Routine 5:*** "Unparking vehicle with through vehicle (UP-TV)", "unparking vehicle with uparking vehicle (UP-UP)", "unparking vehicle with parking vehicle (UP-PV)" and "unparking vehicle with pedestrian (UP-P)" conflicts are recorded in this routine.
- ***Routine 6:*** Routine 6 considers the conflict situations of "rear end vehicle to vehicle (RV)", "on road vehicle with pedestrian (ORV-P)", "through vehicle with parking vehicle (TV-PV)" and "through vehicle with unparking vehicle (TV-UP)".
- ***Routine 7:*** This routine looks at "junction vehicle with vehicle (JV-V)" and "junction vehicle with pedestrian (JV-P)" conflicts.
- ***Routine 8:*** "Junction vehicle with vehicle (JV-V)" and "junction vehicle with pedestrian (JV-P)" conflicts will be evaluated here when they are queuing at an intersection.

An important feature of PARKSIM 2 is that it is able to display vehicle and pedestrian movements and the interactions between them. This is facilitated by a colour graphic presentation as shown in Figure 4. The display allows individual vehicle and pedestrian movements in a parking lot to be monitored by the designer.

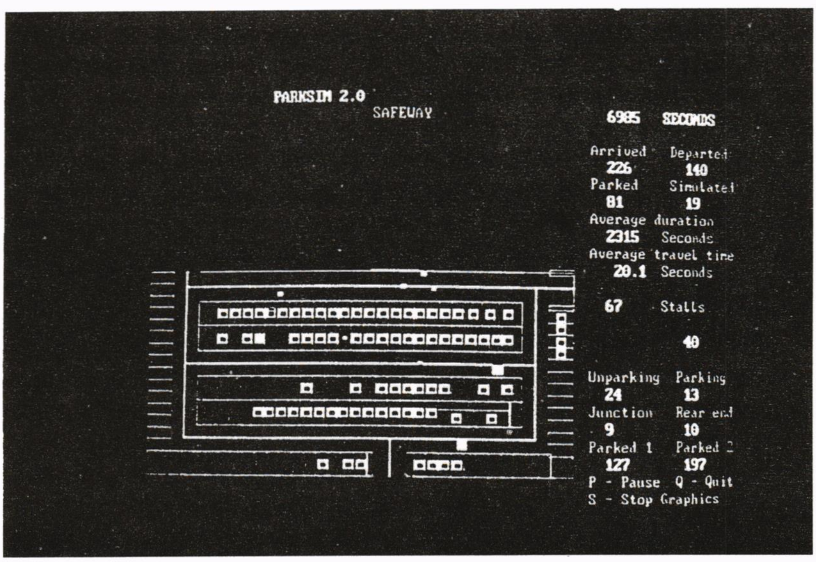

Figure 4 Dynamic Display of PARKSIM 2

The graphic output enables the system performance to be observed and provides the possibility in evaluating the parking lot performance before its construction. Problem areas in the lot can be detected more easily than by other methods. It is also useful in program verification and development stages.

3.3 Model Output

The output of PARKSIM uses files created in the input and simulation stages. The general level of service can be provided by this model. The performance measurements include the average travel time/search for vehicles which parked and exited the system, the proportion of vehicle which could not find a parking space in the lot and the utilisation of the parking spaces and the level of conflicts.

4. MODEL VALIDATION PROCEDURES

After developing a simulation model, it is necessary to test its reliability and suitability before its application. Validation is an important step in achieving this objective. It involves not only field data collection but the calibration of model parameters and comparisons of field data with model outputs.

Since simulation models are always based on certain assumptions and simplifications, it is unavoidable to contain some specification and measurement errors. Specification errors result from the assumptions made to specify a particular situation in a model. Measurement errors come along with the model outputs. For instance, a more complicated model would minimise its specification errors, while its measurement errors may be maximised. Therefore, simulation models should be calibrated and validated in terms of minimising both errors before their applications. To evaluate the feasibility and reliability of the parking simulation model, the traffic and conflict data collected from the field surveys were used. Several different procedures were adopted in the calibration process.

4.1 Sensitivity Test

Sensitivity is a measure on the performance of a model. An applicable model should be sensitive enough with any changes of its input data. To examine the model's sensitivity, PARKSIM 2 was applied to different parking lot layouts with a similar traffic flow condition and one particular layout with deferent traffic flow conditions. From the model outputs, vehicle travel time, the numbers of vehicle to vehicle and vehicle to pedestrian conflicts for different layouts were compared and the reasonableness of the results with common perceptions assessed.

For the purpose of examining the model's suitability with different parking lot designs, PARKSIM 2 was applied by a group of students. The first step in the study was to test the robustness of the model to inexperienced users and to investigate a variety of parking lot designs. Third and fourth year undergraduate students are relatively inexperienced in the design of parking systems even with available references; but they have clear views on what is a good and a bad design. The students were given a parking lot 40 metres by 100 metres and asked to design a parking layout that catered for a total of 800 vehicles in one day. The shop entrance was placed along the long axis and opposite the adjacent road (on the top edge). Approximately 100 students took part in the assignment.

All students experienced some difficulties in learning to use the model. This is common with all software. However, the students became reasonably proficient after using the model for a few days. Communications between students reduced the learning curve for some students. This was particularly true for those who started the assignment later.

Even though the parking lot was relatively small, the students still managed to develop over 80 different layouts. The performance of these layouts are shown in Table 1. The layouts had between 6 to 17 intersections; 11 to 36 links, and 120 to 152 parking spaces. The number of entrances/exits varied from one to three. The traffic flow into the lot was set at 800 vehicles per day. However, because PARKSIM 2 is a simulation model, stochastic variations between 720 to 880 vehicles per day were achieved. Based on these layouts, the model was employed to investigate the performances of the designs. A range of outputs for different conflicts are presented in Table 9-1. It can be seen that there was considerable variations on the performance of the lots. The vehicle travel times varied between 20.1 to 136.8 seconds. Pedestrian walk times varied between 30.1 to 41.0 seconds. These travel times are relatively small but still enable a rough comparison to be made between lots.

Table 1 Range of Performance of Student Parking Lot Designs

Contents	Lower value	Upper value
Parking lot layouts		
Junctions in lot	6	17
Links in lot	11	36
Stalls in lot	120	152
Number of entrances	1	3
Number of exits	1	3
Traffic flow	720 vph	880 vph
Performance		
Vehicle travel time	20.1 seconds	136.8 seconds
Pedestrian travel time	30.1 seconds	41.0 seconds
Probability of finding a space	100 percent	100 percent
Maximum accumulation	106 vehicles	122 vehicles
Occupancy	55 percent	76 percent
V-V Conflicts:		
Junction conflicts	17	61
Rear end conflicts	23	74
Unparking conflicts	70	385
Parking conflicts	21	96
Parking (unparking) with adjacent space full	348	515
Parking (Unparking) with both adjacent spaces full	788	1231

The probability of finding a space was 100 percent in all networks since the number of spaces in most of the lots designed exceeded the maximum accumulation of 122 full spaces. The occupancy varied between 55 and 76 per cent since it was related to the total number of parking spaces provided in each design. The vehicle to vehicle conflicts in the different designs varied from 17 to 61 intersection conflicts, 23 to 74 rear end conflicts, 70 to 385 unparking conflicts and 21 to 96 parking conflicts. For the situations where vehicles were parking (unparking) with constraints, they varied from 348 to 515 with one adjacent space full, and between 788 to 1231 with the spaces on both sides occupied. As students are not very experienced in the design of a parking system, many of the designs were relatively imaginative. However, there were still a number of designs that provided reasonably good performance. To conduct a more detailed evaluation of the sensitivity of the model with different parking lot layouts, three designs from the student exercise were chosen to investigate the measurements of conflicts.

These layouts are presented in Figures 5 (L1, L2 and L3 refer to layout 1, layout 2 and layout 3). It can be seen that all three layouts have two entrances/exits. The number of junctions varies from 6 to 10. Links in the designs are between 12 to 24. The parking spaces vary from 140 to 152.

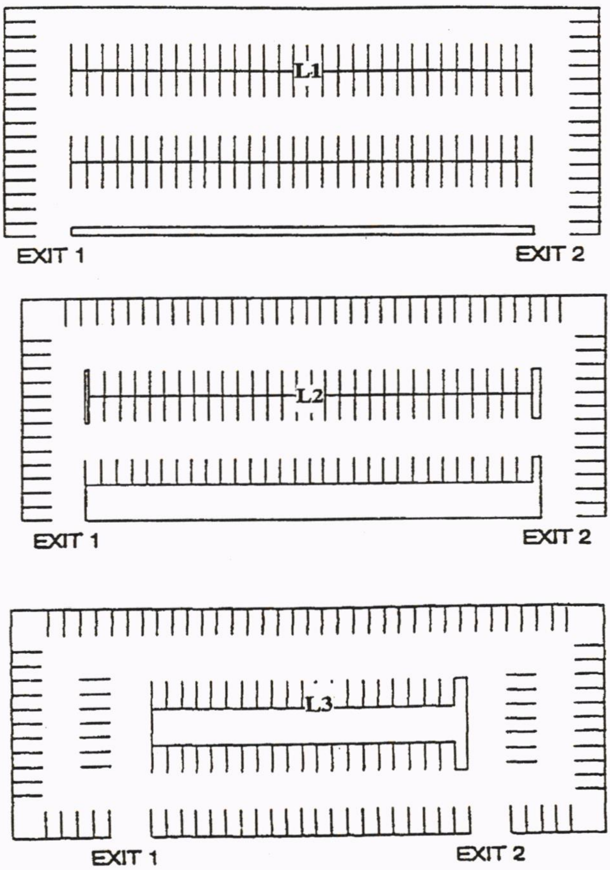

Figure 5 Parking Lot Layouts

These three parking lot layouts will be discussed in more detail than those provided by the students. The model was run 12 times for layouts 1 and 3 except for a few unsuccessful runs, and 17 times for layout 2. The input traffic volume was 800 vehicles daily. Because the random nature of the simulation model, the traffic volumes varied from 752 to 877 daily. Problems found were corrected during the testing.

The model was run in a mixed order throughout the testing processes. After applying the model to three different layouts, a set of data can be compared. With the simulated measurements, the different performance of these layouts with respect to vehicle to vehicle conflict, vehicle to pedestrian conflict, constraint in parking and unparking can be evaluated and is shown in Figure 6.

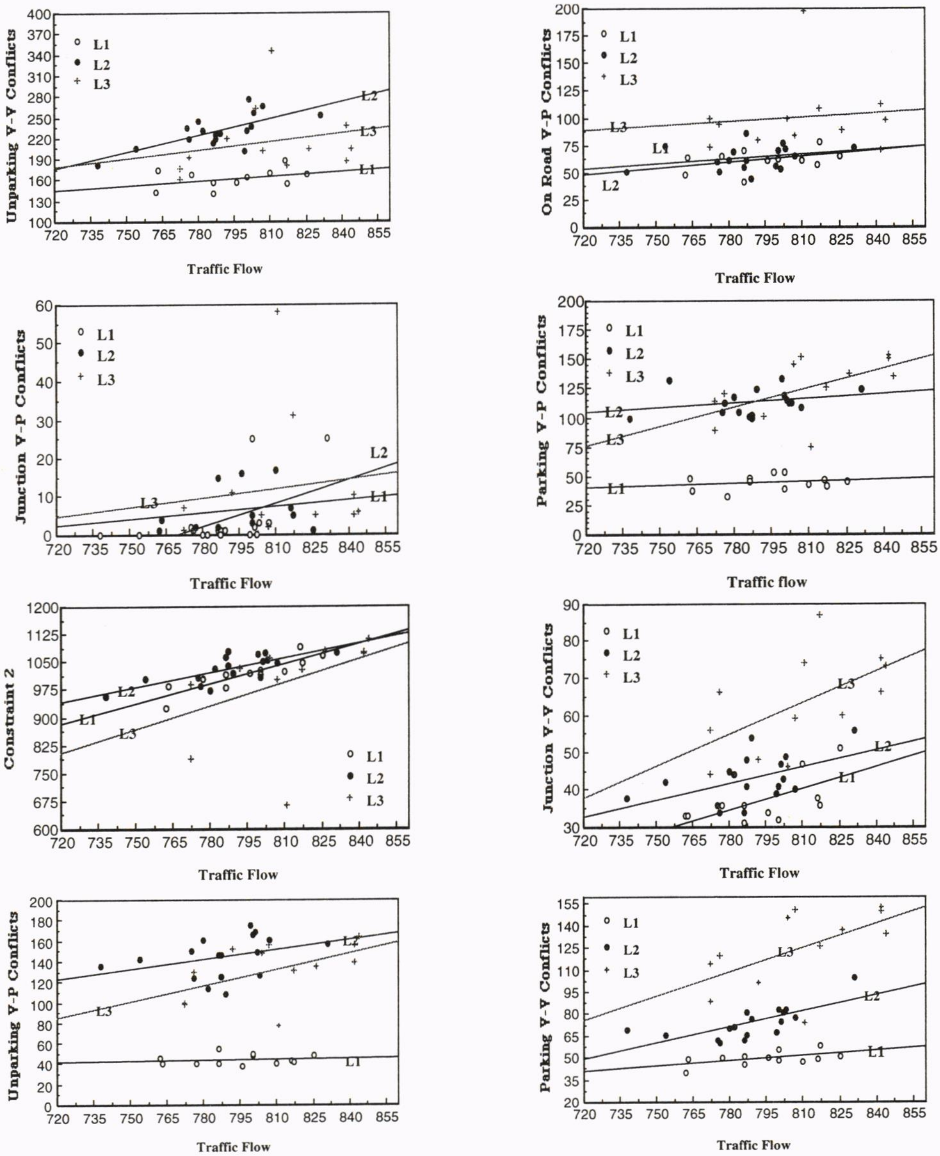

Figure 6 Performance Measurement

As the sensitivity test carried out at this stage was to assess the sensitivity of the simulation model for different input conditions, no rigorous statistical analysis was conducted in the process. The individual points in Figure 6 represent the number of daily conflicts measured against the particular traffic flow levels. The lines in the figures are linear regression curve fits. Although the coefficients of correlations for these lines were low (between 0.2 to 0.7) based on the limited runs, it could be improved through increasing the number of runs. Even though, a clear trend is still able to be distinguished from the figures.

In overall terms, layout one appears to provide the lowest levels of vehicle to vehicle and vehicle to pedestrian conflicts. Layouts two and three provide marginal different information on their performance associated with different measures.

In comparison with our common perception with the three different layouts presented, it is no doubt that PARKSIM 2 was able to cope with different designs. Although the variations with the model outputs are relatively high, it still provides a positive indication that the model could distinguish the differences in layouts and simulate a set of reasonable performance data.

Based on the above analysis, it can be seen that PARKSIM 2 enables the different parking lot layouts to be simulated and it is sensitive to different layouts. Through the comparison of the three layouts, the model demonstrated its capability in evaluating the performance of various parking layouts. It provides consistent outputs which are reasonable when compared with anticipated performance.

In testing the sensitivity of PARKSIM 2 further, the use of different parking demands with a same layout was adopted. To accomplish the sensitivity test for different traffic flows, the model was applied to a layout shown in Figure 7. The car parking provides parking service for a Safeway in Melbourne, Australia. This is the parking lot used to collect traffic and conflict data for the purpose of model validation. It consists of 149 parking spaces, three entrances/exits and one shop entrance.

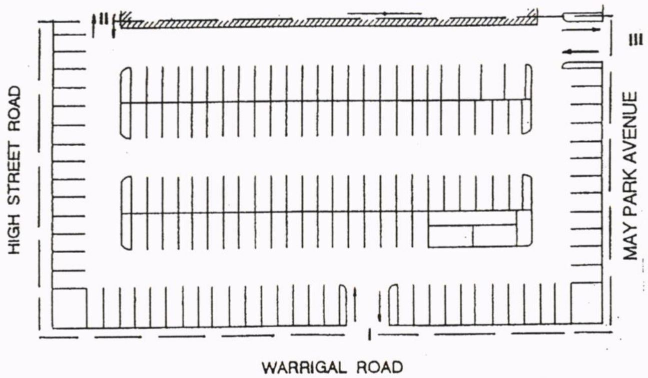

Figure 7 The Parking Lot In Melbourne, Australia

PARKSIM 2 was applied to the parking lot for parking demand ranging from 100 to 1500 vehicles per day. The distribution of hourly traffic flow and the origin destination matrix associated with the different ranges of traffic flows were calculated according to the proportions of the actual traffic data. Based on the real parking lot layout, the collected average parking duration, the calculated distribution of hourly traffic flow and origin destination matrix, the traffic flows of 100, 500, 1200 and 1500 vehicles per day were used as input variables in the testing process. After running the model for a number of times, a set of model outputs associated with different traffic flow conditions were obtained. The range of model outputs is presented in Table 3.

Table 3 Range of Output Summary

Contents	Parking demand (vehicles per day)			
Parking demand	100	500	1200	1500
Vehicle to Vehicle Conflict				
Junction conflicts	0-3	6-22	89-185	186-215
Rear end conflicts	0-5	12-20	63-118	88-125
Unparking conflicts	0-7	53-90	300-360	600
Parking conflicts	0	18-37	79-157	212-260
Parking (Unparking) with adjacent space full	60-90	325-360	610-680	695-715
Parking (Unparking) with both adjacent spaces full	20-40	450-550	1210-1420	1890-1990
Vehicle to Pedestrian Conflict				
Junction conflicts	0	0	24-63	78-102
On road conflicts	0	25-40	130-280	380-425
Unparking conflicts	0-4	22-31	90-135	150-175
Parking conflicts	0-3	18-27	76-103	111-135

From Table 3 it can be seen that the changes of parking demand clearly affect the performance of a parking lot in terms of level of conflicts considerably. The above results are expected from our daily experience about the operation of a car park - when parking demand increasing, the conflict frequency increases. The relationships are monotonically increasing when parking demand increases since more vehicles and pedestrians will cause more conflicts. The outputs from PARKSIM 2 are consistent with the general understanding of the operation of a parking lot. The simulation results vary with the changes of the input traffic flow. Therefore, it is believed that the model has the ability to produce results consistent with general expectation.

Based on the above sensitivity test, it can be seen that the model itself is stable. It satisfies the requirement that small changes to the input data will lead to small changes in the output. The model appears to produce the likely response to the particular traffic circumstances.

4.2 Model Validation

After the sensitivity test, PARKSIM 2 was validated. Model validation is an important stage, yet a difficult task to be achieved in the process of a simulation model development. It requires the application of the model to a real situation and comparisons of the model's outputs with real data (Yue and Young, 1992).

As mentioned in the model sensitivity test, PARKSIM 2 is sensitive to changes in the parking lot layout or traffic flow conditions. Parameters such as traffic flow levels, average parking duration and the origin destination flows will definitely affect the model's performance. Since field data collection is time consuming, the model validation in this study did not attempt to use a different car park. PARKSIM 2 was applied to the same car park as used for the model calibration (Friday Data, 1/11/91. Although the use of the same car park with different traffic conditions may be a less rigorous validation test, it would still demonstrate the transferability at certain level (Yue and Young, 1993). Therefore, this application can be considered as an independent model validation process.

To test whether or not the simulation model was reliable enough to predict a real world conflict situation, PARKSIM 2 was validated with the Saturday traffic conditions (2/11/91). The parking system is the Safeway Supermarket as described and shown in Figure 7.

The input variables into the model are the origin destination matrix, traffic flow variations on hourly basis and the average parking duration collected on the Saturday (Yue and Young, 1994). In the investigation of the efficiency of the model, a confidence interval test was employed in evaluating the performance of the model. The model outputs were based on the traffic flow conditions, the origin destination matrix and the average parking duration for Saturday (2/11/91). The parking lot data used to compare with the model results were collected on the Saturday. To generate a sample, the model was run thirteen times. This sample was used to evaluate whether or not the model performed well. The confidence interval test is presented in Figure 8 in which "+" means upper and lower limits and "▲" means field data points..

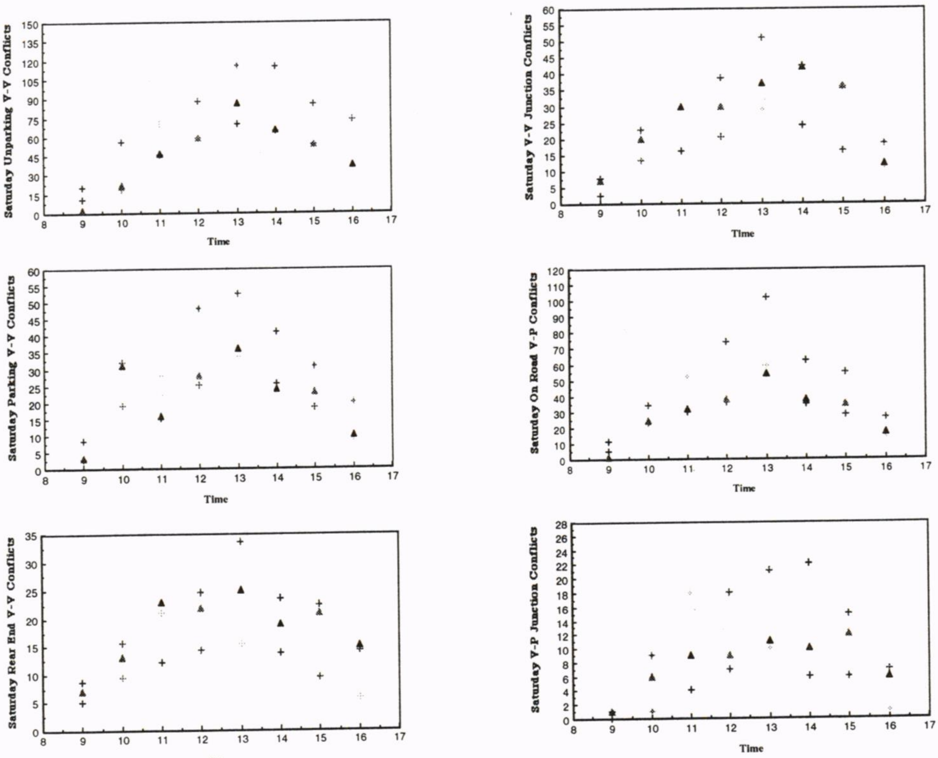

Figure 8 Confidence Interval Test

Through the confidence interval test, PARKSIM 2 has demonstrated the potential ability to predict the interactions between system users in a parking lot in terms of conflicts. The 99 percent confidence interval test has demonstrated that most of the real conflict data points are within the confidence intervals. This indicates that PARKSIM 2 has the potential to be a predictable tool in investigating the performance of a parking system.

5. CONCLUSION

Through all these test and validation procedures, the model demonstrated the capability to predict the performance of a parking system in terms of conflict levels reasonably well. In light of the above, the following conclusions are reached:

PARKSIM 2 was sensitive with parking lot layout changes. The model outputs were consistent with the general perceptions of the layouts. It appeared to provide the likely response with the different layouts.

PARKSIM 2 was sensitive with changes in parking demands. It provided a monotonic increase when parking demand increases. This reflected the fact that the simulated results were consistent with the general understanding of the operation of a parking system.

The conflict assessment criteria and the minimum thresholds used in the field surveys were employed to form the specification parameters in PARKSIM 2.0. The model calibration procedures were systematically consistent with the field data collection approach.

The calibration procedures were efficient. This was proved by the comparison of hourly conflict data. To evaluate the effectiveness of the model parameter optimisation, a confidence interval test demonstrated PARKSIM 2 enabled the calibrated condition to be replicated.

To ensure the reliability and predictability of PARKSIM 2.0, the model was applied to investigate the conflict situation for a real parking lot. The Saturday (2/11/91) traffic data (the traffic flow, origin destination matrix and the average parking duration) from a Melbourne parking lot was used as the model's inputs. The model outputs show that PARKSIM 2 is able to be considered as a tool to investigate the conflicts for a parking lot. This conclusion was examined by comparing the hourly model results and real data as well as the confidence interval test.

Due to the limitation of time and resources, the model hasn't reached its desirable level yet. It is expected that the delay experienced by drivers in a car park could be included in the model in the future development.

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