Simulation in Selecting the Best Parking Lot Layout

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Abstract: Simulation techniques provide a unique way in solving and analysing problems with random properties. With the well developed technology in computer hardware and software, computer based simulation models have been widely used in engineering decision making processes. In the last few decades, due to the nature of traffic and transport related problems, there have been many opportunities for transport professionals to employ simulation method in finding solutions for complicated transport problems. The rapid improvement in computer applications and associated graphic functions enable the design of road components to be conducted on computers and models can be developed to simulate the likely performance. Using computer aided design method and simulation models in decision making process produce considerable efficiencies. Simulation offers the means of quantifying measures of performance for complex situations where theoretical models are inconclusive and estimating the changes that a traffic engineer or planner may have in mind only for a particular system. They can also be used to gain increased understanding of traffic systems by experimenting with models in ways that are not practical in reality. This paper aims at presenting the concept, the structure and the application of a parking design and simulation model to evaluate the various layouts of a parking lot. The simulation model is PC-based with discrete update process and has a graphic dynamic display for pedestrian and vehicle movements. The measurements with different layouts will provide an indication on the possible performance. This will help traffic engineers and parking lot designers to judge if a design is good regarding the measurements of "level of service" including parking lot utilisation, average travel time and degree of conflicts.

1. INTRODUCTION

With the continuing progress of human civilisation, the travel of people and the distribution of goods have put more and more responsibilities onto transport professionals. More than ever before, the requirement for a good transport system has become a demanding issue. Among these issues, road safety, road traffic generated air pollution and urban traffic congestion problems are causing more and more concerns over governments and community bodies. Efforts are therefore required to study the phenomena and develop countermeasures to minimise the problems.

In general, road traffic system comprises three elements, the road network, the user and the vehicle. Two of these, the user and the vehicle, are variables beyond traffic engineers' control although they still provide significant input into vehicle design and user education processes. Traffic engineers' tasks are mainly concentrated on the design of the road network, the management and the control of the road traffic system. Although the advanced traffic control facilities and the well established management procedures can improve the traffic conditions, the design of the road components has still been the first step in the development of an efficient road transport infrastructure. Parking facility is an integral part of a road traffic system and it plays an important role in implementing the function of the system. Due to the low speed driving environment and low fatal accident rate within car parks, the performance evaluation in the design of a car park has been left out in the process. No appropriate method and tools to assess a particular design have been developed. Therefore, it is necessary to conduct studies and to develop an engineering tool in selecting the best parking lot layout.

2. PROBLEMS WITH CAR PARK DESIGN

In the current parking lot design process, standards are available to guide the designers on the correct size of parking components. Recommended practices for the design of parking lot components are plentiful. Although existing references and design manuals provide useful information on parking surveys and design procedures for the individual components of a parking system, procedures for gathering these components into an overall system design are not so clearly described (Young, 1988). Moreover, no reference is available on the evaluation of the performance or "level of service" of a parking lot. In particular, traffic conflicts/potential accidents faced by drivers and pedestrians in parking facilities have been left to the users. Existing numerical models can only analyse simple performance and cannot investigate the interactions of a complex parking facility. Research into the development of a design tool to estimate the overall performance of a particular parking layout is limited (Farrow, 1984). The standard of parking lot design therefore varies with the experience of designers. Specifically, little effort has been directed at researching into the "level of service" of an off-street parking facility. Therefore, consideration needs to be given to the development of procedures to improve the design of parking facilities.

3. THE NEED FOR A MODEL

Using computer aided design methods and simulation models in transport and traffic engineering produce considerable efficiencies (Young, Taylor and Gipps, 1989). 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 of various changes that an engineer may have in mind only for a particular system. 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). In evaluating the "level of service" of a parking lot, there are several dimensions to be taken into account. One of them relates to the static capacity which is largely decided by the space available. 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 considers the travel time within the lot. A lower travel time may indicate a better parking lot layout. The last dimension is to measure the level of conflicts within a car park. As all the dimensions consider the random movement of vehicles and pedestrians, traditional methods are difficult to be applied in evaluating the performance of a car park. In quantifying the "level of service" for these dimensions, a computer simulation model, PARKSIM2 has been developed (Young and Yue, 1992). This model is able to be applied to investigate the travel time, parking lot utilisation and the level of conflicts for a particular layout in terms of a good or poorly designed car park.

4. THE MODEL - PARKSIM2

PARKSIM2 is a PC based program and is a discrete event micro-simulation model – it simulates each vehicle and pedestrian in the considered parking lot. As time is a common factor for the movement of vehicles and pedestrians, time update procedure is adopted in the control program – executive routine. Since there are many movements, activities and interactions in car parks, half a second is used as the update time interval – the positions of vehicles and pedestrians, and their activities will be updated every 0.5 second. The simulation model replicates the movement of individual vehicles and pedestrians through a parking lot. As with most simulation models, PARKSIM2 consists of three parts: the input program, the simulation model and the presentation of the output. The structure of the simulation model is presented in the following paragraphs.

4.1 Model Input

The well developed computer graphic capacity has provided the opportunity of on screen design. The on screen design system used in PARKSIM2 is menu driven and user friendly. The parking lot layout can be input using a graphical method or a previously created file. Figure 1 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.

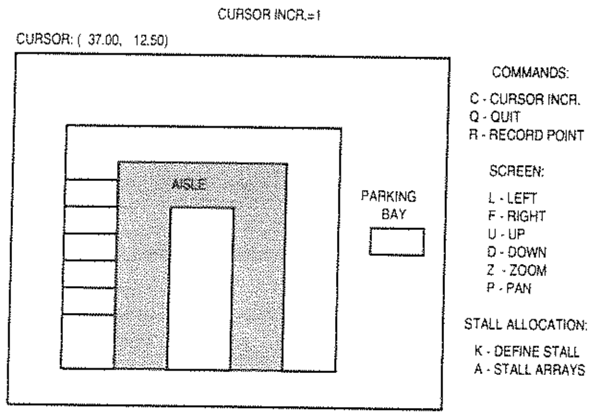

Figure 1 Graphical Input in PARKSIM2

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

4.2 Simulation Model Structure

The simulation model first accepts the information from the input program to display the parking lot layout and to initiate the basic traffic data. It then starts from time zero with an increment of 0.5 second and ends with a designated time. The simulation model contains an event schedular, an executive routine which controls the state of the program and a number of event routines which conduct designated tasks – for example, parking, unparking and waiting for unparking. The program flow chart of the model is presented in Figure 2.

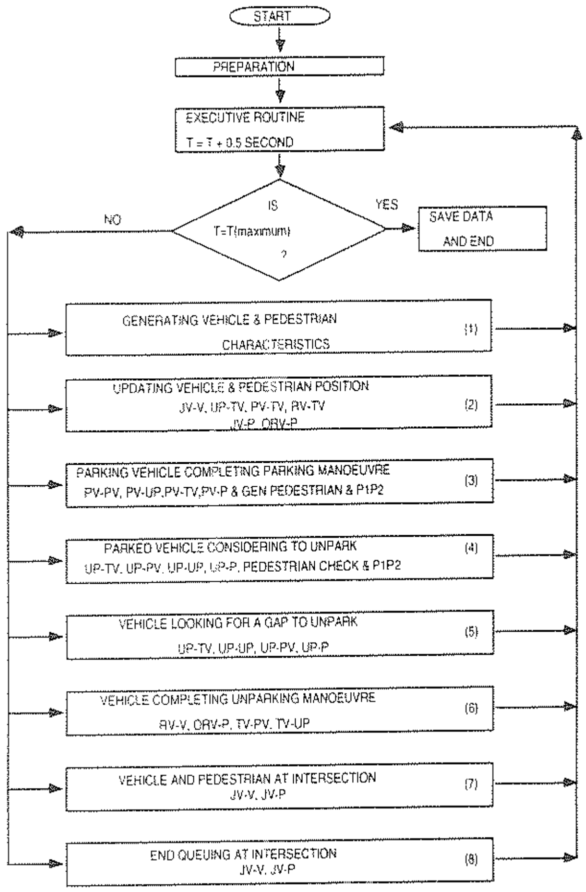

Figure 2 Simulation Flow Chart

The simulation program follows an event schedule according to the activities in a car park. The schedule organises a series of subroutines in a systematic order. The executive routine manages the actions of event routines which carry out the simulation and provide the dynamic updates. The simulation model starts by reading information from the input and initialises the variables required by the program. After completing the initial step, the executive routine calls for the first set of arrival vehicles to be generated. The coming vehicles are then ordered on a basis of first come first service and the executive routine calls the next action to be carried according to the particular situation. The model provides a dynamic graphic display which allows the vehicle movements to be presented to the designer.

There are eight event routines under the control of the executive routine. Each of them plays a unique role in the simulation process to duplicate a real situation. Based on the time update process, the executive routine calls one of the event routines considering the state/position of a vehicle or pedestrian. It checks every vehicle and pedestrian through the system according to a vehicle/pedestrian status indicator. For instance, the intersection routine (7) will be called if a vehicle or pedestrian is at the end of a link. The executive routine also checks to see if a new vehicle needs to be generated based on the parking demand information.

4.2.1 Simulation of travel time

Travel time is an important indication of the efficiency of the design for a car park. It also reflects the delay experience within a car park due to search activities and interactions with vehicles or pedestrians. The model considers each vehicle as a time accumulator through a car park. Time update procedures add additional travel time to vehicles for each interval through the system. Routines (2), (6) (7) and (8) carry out this process as presented in Figure 2.

4.2.2 Simulation of space utilisation

Parking space utilisation provides information for parking managers and designers to identify the problem areas within a car park. The method used for simulating space utilisation is parking space based. Each parking space is assigned a unique space identification. Time is directly accumulated to the space when a car parked.

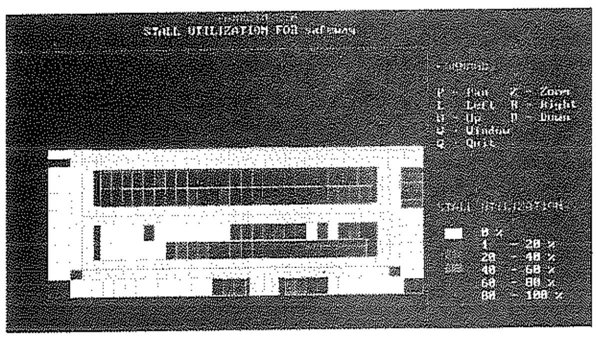

Figure 3 Parking Space Utilisation

Figure 3 demonstrates an example of parking space utilisation of the model. The shop entrance is on the top of the car park and one of the three entrances to the car park is at the bottom. Different colours are used to present the level of utilisation. Routines (3) and (6) contribute to this task.

4.2.3 Simulation of conflicts

In general perception, traffic accidents are often on highways and parking lots are a safe place due to the driving environment. According to a study conducted by Yue and Young (1992), however, more than 14 percent of all road accidents occurred in car parks during the years from 1981, 1986 to 1989 in the Australian Capital Territory (ACT). Therefore safety in parking lots should be treated as other highway locations. Accidents are only an overt measure of the hazards associated with a particular transport system.

These hazards include inconveniences, constraints and conflicts. Parking lots are a dynamic driving environment with many possible conflicts. The number of conflicts has a large influence on the efficiency of a parking system and its safety. Astute design may enable the number of these conflicts to be reduced. This could improve the "level of service" provided by a parking system and in turn may reduce the number of accidents in parking lots There are four vehicle to vehicle conflicts, two vehicle parking constraints and four vehicle to pedestrian conflicts being considered in the simulation model. These conflicts and constraints are simulated in routines (2), (3), (4), (5), (6), (7) and (8).

To simulate each type of conflict, a number of modules were developed to accomplish the purpose. The following flow chart presents the module used for simulating unparking vehicle conflict.

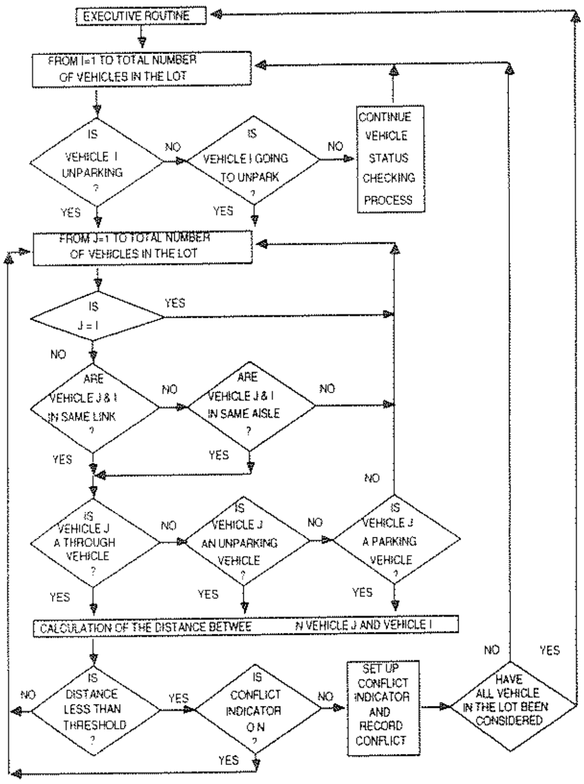

Figure 4 Flow Chart of Vehicle Unparking Conflict

The module for unparking vehicle conflict simulates a situation in which an unparking vehicle has to stop or slow down when another moving vehicle (a through vehicle, an unparking vehicle or a parking vehicle) is too close to it. For a situation in which approaching vehicles have to stop to let the unparking vehicle complete its unparking manoeuvre is also considered as a conflict. As illustrated in Figure 4, the module considers each vehicle position and movement status in the car park. The module checks each vehicle in the system and considers only the moving vehicles in the same link (i.e. through, parking and unparking). If a situation meets the criteria for an unparking conflict, the module will set up an indicator avoiding a same conflict being counted a few times and the location of the conflict will be recorded. The record of the unparking conflicts is parking space based. It will help to identify the problem areas.

4.2.4 Model output

The output of PARKSIM2 uses files created in the input and simulation stages. The general level of service can be presented through a number of parking space based maps. The graphic presentation enables the system performance to be observed directly and provides the possibility of assessing the parking lot performance before its construction. Problem areas in the lot can be detected more easily than by the other methods. The following paragraphs demonstrate a few examples of the model outputs.

Unparking Vehicle Conflicts: Interactions between unparking vehicles and other vehicles and pedestrians can be simulated by PARKSIM2.

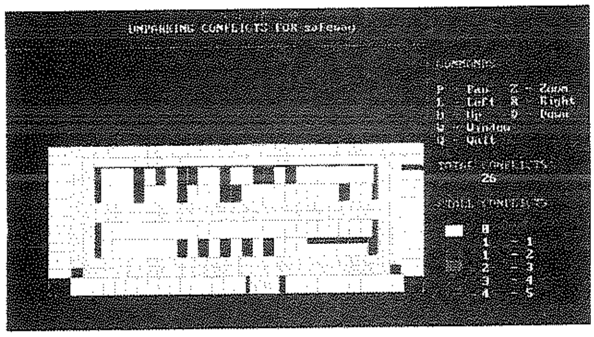

Figure 5 Unparking Vehicle Conflicts

From Figure 5, it can be seen that the level of unparking conflicts can be assessed. As the shop entrance is on the top edge and one of the three entrances/exits is at the bottom, there are more active vehicle movements. Consequently, more conflicts are recorded around these locations.

Intersection Vehicle Conflicts: As intersection is one of the major sources of delay and conflict, locating these spots becomes particularly important. In Figure 6, it can be seen that intersections near the entrances/exits generates more conflicts than other places as there are more vehicles coming in and going out.

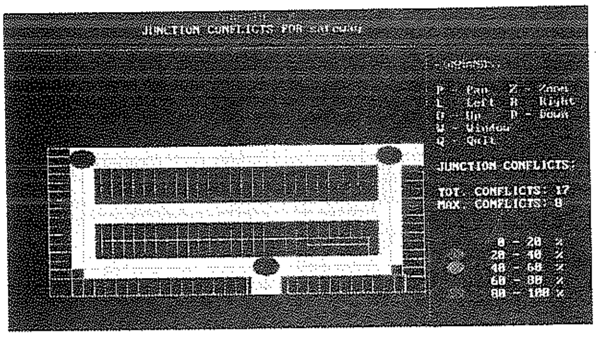

Figure 6 Intersection Vehicle Conflicts

Pedestrian with Unparking Vehicle Conflicts: Compared with vehicle manoeuvres in a car park, pedestrians play a more flexible role as they are not restricted by most of the traffic regulations in the circumstances. A simplified pedestrian movement module was developed to assist in the simulation of pedestrian caused unparking vehicle conflicts. Figure 7 shows the distributions of pedestrian with unparking vehicle conflicts.

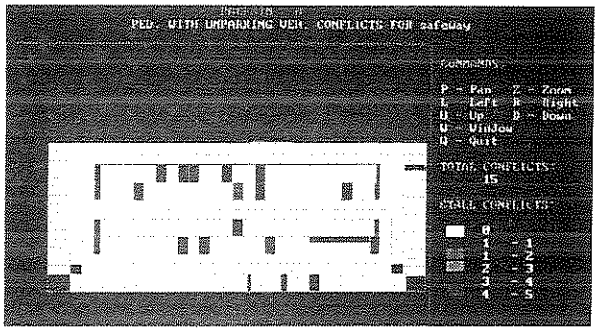

Figure 7 Pedestrian - Unparking Vehicle Conflict

Pedestrian Intersection Conflicts: As a common experience, vehicles have to give way to pedestrians in a car park. Whenever a vehicle has to stop or slow down at an intersection due to the appearance of a pedestrian, the simulation model considers it as a conflict. This conflict indication could provide useful information in the selection of the best parking lot layout in terms of pedestrian safety.

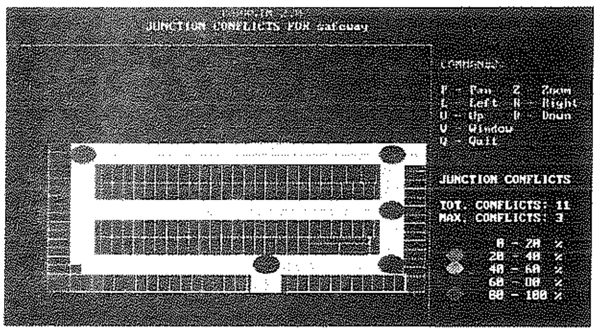

Figure 8 Pedestrian Intersection Conflict

5. VALIDATION OF PARKSIM2

With regard to the performance of a parking system, there are many factors affecting its efficiency (i.e. layout, traffic flow, number of spaces, O-D distribution, parking duration, speed, travel time etc.). Among these factors, the layout of a car park and the level of traffic flow are considered to be potentially sensitive since they may play a major role in contributing to the level of interactions. Therefore different parking lot designs and traffic flow levels were used in the model sensitivity test before model validation was conducted.

To test the sensitivity of PARKSIM2, several procedures were applied. These procedures were used to ensure that the model could provide reasonable information on the performance of different parking lot layouts or a parking lot with different traffic flow conditions.

Firstly, the model was tested by applying the model to three different parking lot layouts with similar traffic flows for a same running period. This process is able to verify the capability of the model for simulating variety of parking lot designs and to evaluate the performance of the model when layout has been changed. From the comparison made, the model's outputs are consistent with general perceptions of the performance of the layouts. It appears to provide likely outputs with different layouts.

Secondly, the sensitivity of the simulation model associated with different parking demands (traffic flows) is evaluated. Based on a same parking lot layout, a range of traffic flows was used to examine the model's performance. The model provides a monotonical increase in all measures when parking demand increases. This reflects that the simulated results are consistent with the general understanding of the operation of a parking lot.

The validation of the model took place at two stages. The first stage validation was facilitated by collecting data on travel/search times and utilisations from a parking lot for two different layouts. The model was calibrated on one layout and applied to the second one. The parking system used in the validation is the Mountain Gate Shopping Centre, Melbourne (Young, 1988). The validation of the model provided a positive indication that the model could replicate real world situations. The second stage validation was concentrated on the measurement of the level of conflicts. Conflict data were collected from a car park at the corner of High Street Road and Warrigal Road in Melbourne (Yue and Young, 1994). Conflict data were collected on a Friday and a Saturday for a same car park. The data from the Friday was used to calibrate the simulation model and the model output was employed to compare with the Saturday data.

In quantifying the closeness of the model with real situation, a 99 percent of confidence interval test was employed. Hourly based data were tested and a reasonable result was achieved (Yue and Young, 1994). As one example, unparking vehicle conflicts on the Friday is illustrated here. Figure 9 shows the comparison result for unparking vehicle with vehicle conflicts on the Friday. In Figure 9, "+" represents the upper and lower limits and "•" represents the real data points.

The upper and lower limits were calculated using the model outputs at 99 percent confidence level. It can be seen that the observed data lie in or are close to the lower limit. Although one of the observed data fails to be positioned in the intervals (at 4 pm), the general shape of the distribution of the simulated and real data are consistent.

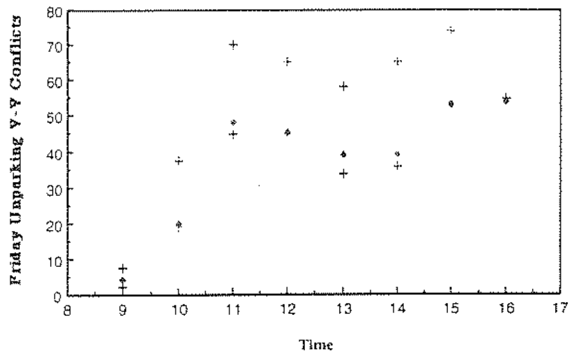

Figure 9 Unparking Vehicle with Vehicle Conflict

6. CONCLUSION

The objective of the paper is to present the development of a parking design and simulation model. Since the traditional design and assessment techniques could not deal with the evaluation of the level of service for parking lots, new approaches to assist engineers and planners in parking lot designs and decision making need to be developed. With the development of computer technology, computer aided design and simulation techniques have demonstrated the potential to represent a dynamic system. Considering its advantages, computer simulation method was chosen to develop the model. It considers the parking space search process and the interactions between vehicles. Vehicle travel time, space utilisation and traffic conflicts are able to be measured by the simulation model. The model is able to replicate vehicle and pedestrian movements as well as the interactions between them through a parking facility. Through the sensitivity test and model validation, the model has demonstrated a strong capability with different parking lot layouts and traffic flow levels. This model has a potential application in engineering decision making process.

7. FUTURE DEVELOPMENT

As no model can precisely simulate a real world situation and provide completely information on the topic which is focusing on, PARKSIM2 is still on the way of further development. Although the model demonstrated its suitability and predicability for different parking lot layouts and traffic flow levels, there are still some limitations with regard to its capability. Therefore, further improvement and model extension is necessary. Considering the further development, there are two aspects to be concentrated on. One is the improvement on the performance of the current model. The second step is the extension of its capability to simulate parking lots with more complicated designs. Along with the development, further validation is also required.

Regarding the consideration of the model extension, some new features should be taken into account in the future. At this stage, the model is reliable for simulating independent parking lots. However, in the real world, some of the large parking lots comprise a few small parking lots. It is possible that some vehicles will cross one small parking lot to park in another small parking lot. Consequently, the through vehicles between parking lots will affect the vehicle search pattern, travel time, space utilisation and conflict situations. It is therefore necessary to consider the relationship between the O-D matrix and the impacts of through vehicles. It is possible that a large parking lot could be divided into a few independent small parking lots, and that the factors of through vehicle movements may be incorporated into the current model. This could be achieved by modifying the input part of the current model. Thus, PARKSIM2 itself can become a key sub-model under a control program. It is believed that after these improvement and extension, PARKSIM2 would become a more useful and practical tool in the design and decision making process.

8. REFERENCES

Allsop, R.E., Modelling local area traffic management - some principles and practicalities. *Australia Road Research 15(1)*, 3-6., 1985.

Farrow, D., A simulation model of a simple parking system. Master of Engineering Science, Department of Civil Engineering, Monash University, Melbourne, 1984.

Young, W., A review of parking lot design models. *Transport Reviews 8(2)*, 161-181, 1988.

Young, W., M.A.P. Taylor, and P.G. Gipps, Microcomputers in Traffic Engineering. (Research Publishing Press: Taunton, England), 1989.

Young, W and W.L. Yue, A study of the performance of two parking lot layouts. *Traffic Engineering and Control (33)*, 434-439, 1992.

Yue, W.L. and W. Young, The evaluation of the parking design model: PARKSIM2. Proc. 4th Australian Parking Convention, Hobart, 1994.

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