**TOPIC 15**
TRAVEL CHOICE AND
DEMAND MODELLING

# A PARKING CHOICE MODEL

RUSSELL THOMPSON
Department of Civil and Environmental Engineering
The University of Melbourne
Parkville VIC 3052, AUSTRALIA

ANTHONY RICHARDSON
Transport Research Centre
RMIT University
PO Box 598, Market Street
Melbourne VIC 8007, AUSTRALIA

## Abstract

Parking plays an important role in urban transport systems. A large number of vehicles travelling into central city areas must search for a car park. However, there is currently a lack of understanding of how motorists choose car parks. This paper presents a model that represents the parking search behaviour of motorists. A search process was defined within a behavioural modelling framework and subsequently represented using analytical procedures. Applications of the model showed that long term experience, does not necessarily lead to better choices. The effects of contemporary parking policies were also investigated.

## INTRODUCTION

Parking systems play an important role in many urban city centres since all vehicle trips when terminated require a parking location. A high proportion of vehicles parking within central city areas must search for a car park, due to the inherent uncertainty associated with many of the attributes of public car parks, including availability and location (Salomon 1986; Polak and Axhausen 1990). Drivers have been observed spending a significant percentage of their total trip time searching for a car park (Huber 1962; Axhausen and Polak 1991). Motorists searching for a car park can significantly effect the level of traffic congestion and environmental quality within an urban centre (Parker 1973; Gillen 1977; Miller and Everett 1982; Feeney 1989).

The need to develop a parking search model stems largely from the lack of understanding of how drivers actually choose parking spaces within central city areas. Existing parking choice models have little behavioural basis (Salomon 1986; Young et al 1991; Axhausen and Polak 1990). There is therefore a need to understand the complex decision making process underlying parking choice behaviour. The development of a behavioural model of parking search is considered essential to understanding and explaining the choices being observed in central city areas. There is currently only a partial understanding of the parking search process. Although some broad strategies have been identified (Layzell 1985; Polak and Axhausen 1989), they do not explicitly represent the complicated decision making processes underlying these overt patterns. A sound understanding of parking choice behaviour is also required to predict the impacts of Parking Guidance and Information (PGI) system technology and to provide a basis of comparison with current choice behaviour. This paper describes the development of a model of parking search behaviour. An outline of the procedures used to represent the decisions and processes of drivers when searching for a car park is presented. A summary of the verification and application of a computer based simulation model is also given.

## THE PARKING SEARCH PROCESS

A conceptual representation of the parking search process was developed after detailed analysis of survey data from the Wollongong and The University of Melbourne parking surveys (Thompson 1993a and Thompson 1993b). This subsequently orientated much of the model's development. The parking search process consists of various stages or phases, each with their own specific characteristics (Figure 1). It comprises a series of decisions, linked in a temporal fashion. It is a dynamic process, where car parks are examined in sequence before a selection is made. Drivers are assumed to examine individual car parks sequentially as they move within an urban centre. As each alternative is inspected, drivers have the option of selecting it or continuing the search by travelling to another car park. The process is initiated when searching begins. Once searching has begun, the process of inspecting and evaluating car parks commences. The decision of whether or not to accept the current car park determines if the process is terminated or continues. This assumes that motorists are committed to a car trip and to parking within the central city area. After parking, the process continues when the next search is undertaken.

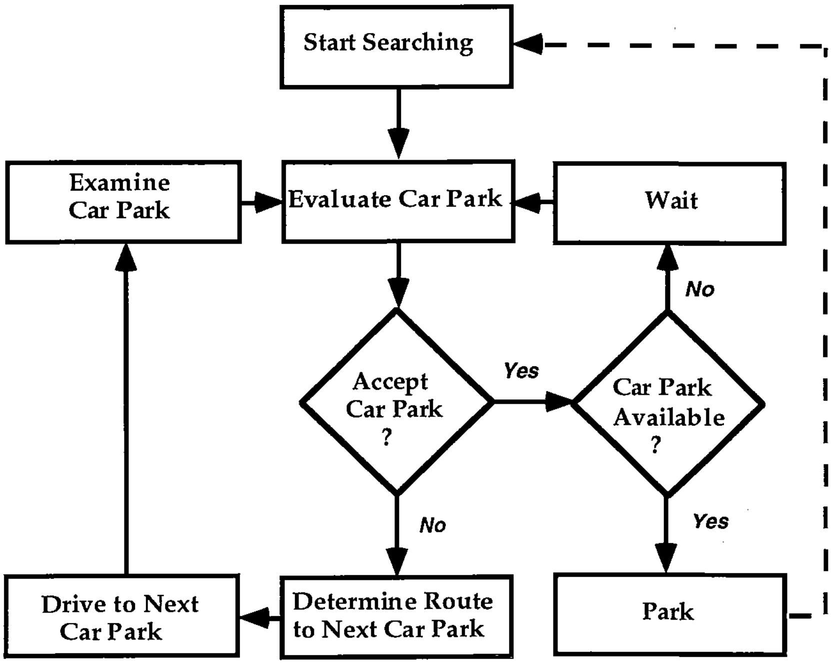


**Figure 1 The parking search process**

The process assumes that searching commences at the same time as the vehicle trip. That is, all parking alternatives that are encountered during the journey are assumed to be evaluated. However, in practice many of these are rejected subconsciously or with little consideration. It is argued that this still constitutes searching. Information on all parking alternatives encountered while travelling is incorporated within the search process. This definition of search alleviates the need to define an arbitrary point upon which searching is said to commence. The physical inspection or examination of car parks is necessary to identify their attributes and to determine the availability of spaces. After performing this task, an accurate assessment of a car park's utility can be made.

Evaluation involves comparing the level of satisfaction of the current car park with the expectations associated with other car parks. The decision of whether or not to accept the present car park determines the length of the search. If the car park is accepted and a space is available, the current search is terminated. This is usually well before all the feasible alternatives have been inspected. If the present alternative is rejected, searching continues. This generally involves moving to a new traffic link by selecting a turning movement. The selected turning movement effectively determines the next parking alternative physically encountered by the driver. Drivers are assumed to proceed on their selected route until the next car park is encountered. It is possible that a car park will be selected that currently has no unused capacity. In this case, the motorist must wait for a space to become available before parking. This usually involves queuing at a car park entrance for a period of time.

During this waiting period the current car park is assumed to be regularly re-evaluated in light of the knowledge gained from directly observing the departure rate of vehicles.

## ANALYTICAL REPRESENTATION

### Car park disutility

The various costs associated with selecting a car park are combined to determine a generalised cost or disutility. This provides a numerical measure of a car park's attractiveness which can be compared with other car parks in evaluating parking alternatives. Past studies of parking choice have identified numerous factors that influence parking choice (Van der Goot 1982; Hunt 1988; Axhausen and Polak 1991; Bradley and Layzell 1986). The total disutility of a car park used in this model consists of four major components, each relating to the costs associated with selecting it. It incorporates costs relating to its access, usage, waiting time and egress (Figure 2). Each of these are represented in terms of their cost attributes and are combined with their relative importance weightings to form an overall measure of disutility. Access costs are those costs incurred while gaining access to a car park. They include the in-vehicle travel time to the car park as well as the time spent searching within the car park for a space. Native costs associated with a car park include the monetary cost of the direct fee and expected fine as well as the egress time (ie walking travel time from the car park to the final destination). These are the inherent costs of a car park which are incurred when it is selected. Drivers can also incur waiting time costs before entering a car park which occurs when motorists have to queue at a car park before being able to enter and park.

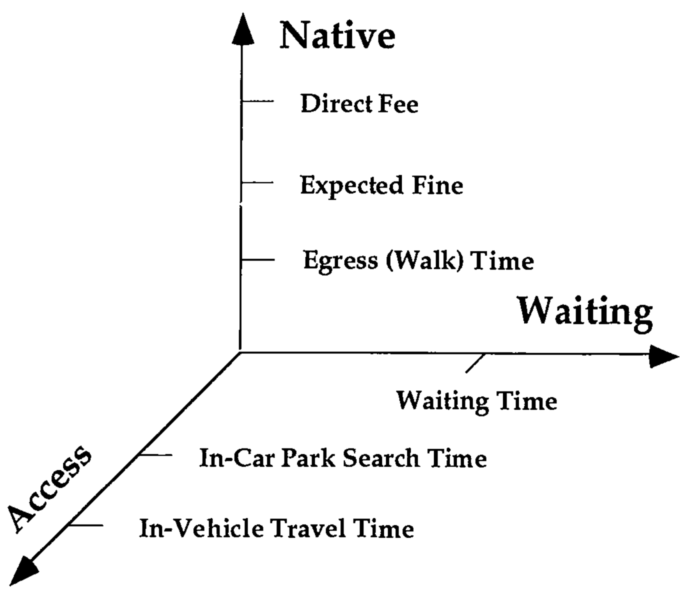


**Figure 2** **Car park cost attributes and dimensions**

### Utility estimation

The following sections describe the procedures developed for estimating the various cost components of utility expression.

*In-vehicle travel time*

The in-vehicle travel time is the time taken between the vehicle's current location and the car park. It is estimated by computing the minimum travel time path between the vehicle's current link and the link adjacent to the car park. Travel times on traffic links are estimated using standard traffic modelling techniques. Intersection delays are estimated on the basis of turning movement type, control type and specified traffic volume levels.

*Egress time*

The egress or walking time is the time cost incurred whilst travelling from a car park to the final destination. It is assumed that the minimum travel time path from the car park to the final destination is taken. Car parks, as well as the final destination are assumed to be located adjacent to the middle of their respective traffic links. It is also assumed that two way pedestrian pathways are present on the left side of all traffic links. The minimum travel time paths for pedestrians are determined by considering all possible routes from the car park to the final destination. Average times for walking along pathways, walking across traffic links and waiting to cross traffic links have been estimated. Travel times for pedestrians to traverse pathways adjacent to (ie left of) traffic links are calculated by dividing their distance by an average walking speed.

Estimates of the delays encountered while crossing traffic links at un-signalised intersections are based on average waiting times using gap acceptance methods (Sheffi 1985). Average waiting times for pedestrians crossing links at signalised intersections are estimated using relationships based on the assumption of random (or uniform) arrivals (Thompson 1994b). The average waiting (or delay) time incurred while crossing traffic links are combined with pathway and link crossing travel times to form estimates of the total time taken to walk between links.

*In car park search time*

Relationships were developed for estimating the travel or search times within car parks. Basic probability analysis was used to estimate average travel times of vehicles within car parks (Thompson 1994b). The analysis related the within-car-park search time to its occupancy, as well as some of its other basic geometric characteristics.

The procedure initially involves estimating the expected number of spaces that will need to be inspected until an available one is encountered. It then calculates the mean travel time within the car park required to inspect this number of spaces. This assumes that searching within the car park will terminate upon reaching the first available space. This is valid for the situations where there is at least one un-occupied space within the car park. When the car park is fully occupied, the expected waiting time is estimated by calculating the time it would take to inspect all spaces within the car park.

*Direct fee*

If payment is required (ie not optional) for access to or egress from a car park, the fee paid is estimated by multiplying the fee rate by the intended parking duration (Thompson 1994b). However, if a fee is legally payable for using a car park, but it is not mandatory, the decision of whether or not to pay the fee involves consideration of the expected fine, which is discussed in the following section.

*Expected fine*

The fine component of a car park's disutility is assumed to be a function of the type of infringement as well as the level of enforcement. The level of enforcement is quantified by estimating the probability of an offence being detected by an enforcement officer. This is assumed to be a function of the probability that a car park's regulations are being actively enforced and the probability of an offence being detected, given that the car park's regulations are being enforced. Assuming both these events are independent, the probability of being fined is calculated as the product of the probability that the car park is being policed and the probability that an offence will be detected, given that it is being enforced. Relationships for determining the probability of an infringement being detected have been derived for two types of offences; where motorists park for a longer period than the prescribed maximum duration and where motorists park at a metered car park without paying. If a car park is free, the risk of being fined is generally related to the parking duration exceeding the regulated limit. In this situation it is assumed that two sightings of a vehicle are necessary to detect an offence and the intended parking duration is greater than the parking duration limit (eg signs). These relationships are based on uniform (random) arrivals of enforcement patrols.

When payment for using a car park is not mandatory, but is required to legally use it, drivers can choose whether or not to pay the specified fee. This situation typically occurs with on-street parking meters and ticket vending machines at parking lots. The expected costs associated with parking at a facility with a non-mandatory fee paying system depends on whether or not a parker decides to pay the fee or not. It is assumed that drivers will decide to pay the direct fee for using a car park only if the fee is less than the expected fine component of the native disutility. The expected native disutility of a car park when there is a choice of whether or not to pay the fee, depends on the searcher's parking duration. When the parking duration is less than the duration limit, the fee is assumed to be paid if the native disutility by paying the fee is less than the native disutility without paying the fee, but including the expected fine. In this case only one sighting of a vehicle is necessary to detect an illegal parking offence.

It is only necessary to consider the cases where fees are paid for the entire parking duration or not at all, since the minimum expected cost occurs at either of these two situations. When the parking duration is greater than the duration limit, the fee is assumed to be paid if the native disutility by paying the fee is less than the native disutility without paying the fee. Where car parks have parking prohibitions for certain periods of the day, the car parks duration limit is assumed to equal zero and the expected fine estimated using only the amount of the fine and the level of enforcement. Examples of this case are no standing zones and clearways. The above analysis assumes that drivers do not split their parking duration by moving the vehicle or feeding parking meters. It also assumes that parkers are rational and will behave dishonestly if the effect on the utility of a car park, by doing so, is positive. This implies a rational choice maker, which may not represent the actual choice behaviour of some parkers.

*Expected waiting time*

Waiting time may be incurred before entering a car park. This is estimated by calculating the expected waiting time which depends upon the vehicle's current location with respect to the car park being considered. If the car park cannot be observed from the current position, the expected waiting time is calculated by considering the perceived probability of a car park having at least one space available when it is inspected as well as the mean waiting time. Details of the procedures used for estimating these perceptions are given in the next section. The mean waiting time for vehicles at car parks that have no spaces available is estimated by considering the number of cars already queued at the car park and the departure rate from the car park (Thompson 1994b).

## Parameter estimation procedures

Individual searchers have perceptions of the attributes and parameters associated with the utilities of car parks. These are considered to be based on either their actual (objective) or subjective values. It is impossible for drivers to have perfect knowledge of many of the attributes of a car park, since they are stochastic (or uncertain) in nature (Polak and Axhausen 1990; Salomon 1986). This relates to the availability of parking spaces, but also extends to other attributes (eg waiting times). If a perfect level of knowledge could be assumed, the actual or objective values of these parameters could be used. Instead however, searchers must base their choice on imperfect information, relying on their mental images of these values developed through their perceptual and cognitive processes. This results in drivers having at any point in time a mental image of a car park's attributes, developed by transforming the initial perception with the new information gained from the previous as well as the current searching experiences.

Each of these sources combine to influence the instantaneous mental image of a car park's attributes. Searchers were frequently found to update their information on the levels of car park attributes by direct observation (Thompson 1993b). Gathering visual information requires attention or perceptual focusing on objects in the physical environment. The routes taken while searching and walking largely determine the car parks which can be observed. Searchers are assumed to have perceptions based on the actual (objective) values of a number of car park attributes and related parameters, including its capacity, fee rate and duration limit. Searchers are also assumed to have a mental image of several of the disutility parameters and attributes of a car park, which may be quite different than their actual value. A number of general subjective parameters within the model are specified as exogenous variables which are the same for all searchers and are assumed to remain constant throughout the simulation. These include the probability of car parks' regulations being enforced and walking speed (Thompson 1994b).

*Stochastic subjective parameters*

There are a number of car park characteristics and disutility parameters that are inherently stochastic in nature and are assumed to be variable for drivers depending on their current and previous searching experiences. These include the probability of a car park being available and the number of vehicle queued upon inspection. The values of these parameters are therefore, uncertain unless the car park can be directly observed. Perceptions of these attributes are assumed to be formed from previous and current search experiences by combining perception and cognition. Various states were defined to represent the levels associated with the stochastic subjective parameters when they were observed (Thompson 1994b). Procedures were developed for estimating the subjective parameters of a car park's utility which were uncertain in nature, by focusing on the perceptions that individual searchers have and how these are formed.

A general procedure was developed, incorporating three separate input sources, initial perceptions, observations made on previous trips and observations made during the current trip. The initial perceptions of the stochastic subjective attributes and parameters for on-street car parks, including the utilisation were defined (Thompson 1994b). A major influence in determining the mental image (or perception) of the variable characteristics of car parks is from information gained from direct observations made during previous searching experiences. Secondary information sources such as the observed attributes of other car parks while searching may influence this perception, but have not been incorporated within the model. A trip is considered to be a journey from an origin to a destination (within the CBD) with a regular frequency.

Observations of car parks from each trip are considered to be independent random variables. The perceptions of the attributes of a car park are considered to be a function of the observations gained from previous searches. The values of the current perceptions of the car park attributes and parameters represented are based on the weighted averages of observations made during previous searches. These weights represent the relative influences of recent and past observations of attribute levels have had on current perceptions. This was performed using a weighted mean, which could be adjusted by a coefficient to reflect the relative weighting given to previous observations.

The process whereby previous observations of car park attributes are combined to form perceptions have been represented using a function that has been used in modelling temporal relationships in route choice (Horowitz 1984). This relationship allows the weights to increase or decrease exponentially from the past into the present are specified by a parameter.

*Observations from the current trip*

There still exists considerable uncertainty relating to many of the characteristics of car parks even when they have been already observed during the current search. The modelling of the perceptions of the attributes of these car parks was therefore undertaken. The perceptions of the stochastic subjective attributes of a car park (when it has already been observed on this trip but can no longer be sighted from the current location) involves many factors. It is assumed to be a function of the status of the attribute of the car park at its last sighting (on this trip), the perceptions based on the previous trip sightings (including this trip's latest observation) as well as the elapsed time from when the car park was last sighted (incorporating the time it would take to return to it). A linear functional form was used to represent this relationship.

## Stopping rule formulation

The parking search process (Figure 1) assumes that drivers decide whether or not to stop searching after evaluating the current parking alternative. This involves comparing the utility of the present car park with the utilities of other car parks in the choice set. A number of modelling approaches were considered for their suitability to represent the searching behaviour of parkers. There are many behavioural weaknesses with discrete choice models or search theory. After a detailed examination of numerous choice modelling approaches it was considered that economic search principle based on expected gain in utility could be adapted to represent many of the behavioural characteristics of the parking search process (Thompson 1994b). However, the conventional economic search modelling approach based on the expected gain in utility (Richardson 1982) could not be directly transferred to represent the parking search process since a large number of its general assumptions were violated (Axhausen and Polak 1990). This approach assumes that decision makers are risk neutral, have an unlimited time budget, face constant search costs, have full recall and possess a perfect knowledge of the utility distribution.

Since car parks may be only temporarily available, the rejection of a car park upon inspection at a point in time means that it may not be available if the driver decides to return to it at a later stage in the search. This general 'lack of recall' relating to the availability of previously inspected car parks results in the current alternative being the most appropriate basis of comparison in the calculation of the expected gain in utility when deciding whether or not to continue the search. This is in contrast to basic economic search modelling where the maximum of all the previous alternatives inspected so far is usually used as the basis for comparisons. It is difficult to make general assumptions relating to the type of distribution of utilities or its parameters in parking search. Perceptions of the utilities of car parks are largely based on previous experience and network knowledge (those in the choice set) and hence do not generally conform to common statistical distributions.

The costs of continuing searching have been internalised by including the travel time to a car park within the utility of each car park. This component is represented by the minimum in-vehicle travel time to reach the car park being considered from the vehicles current location. The expected values of the stochastic cost components were used to represent individuals' perceptions. The disutility was converted into a utility using an additive inverse transformation combined with a scaling parameter. The net change in utility made by selecting another car park from the current one was estimated by comparing the utilities of the respective car parks (Equation 1). That is,

$$DU = U_k - U_{current} \qquad \text{for } k \in T \qquad (1)$$

Where

DU net change in utility by selecting car park k instead of the current car park

$U_k$ utility of car park k

$U_{current}$ utility of the current car park

T set of car parks in an individual's choice set, excluding the current park

Searching is assumed to continue if the expected gain in utility, by continuing the search, is positive. That is, searching continues if

$g' > 0$

Where $g'$ expected gain in utility

A number of formulations for representing the expected gain in utility were evaluated (Thompson 1994b). The Expected Selected Utility (ESU) was considered the most suitable for representing the expected gain in utility of car parks for searchers since it incorporates random choice and allowed a direct comparison with the current alternative to be easily performed.

The expected gain in utility from continuing to search from the current alternative is estimated by multiplying the change in utility associated with selecting alternative car parks, by the probability that they will be selected, assuming searching continues (Equations 2, 3 and 4). That is,

$$g' = \sum_{k \varepsilon T} (U_k - U_{current}) * p_k \tag{2}$$

$$= \sum_{k \varepsilon T} (U_k * p_k) - U_{current} \tag{3}$$

$$= ESU - U_{current} \tag{4}$$

Where,

$p_k$ probability of selecting car park k, k e T

ESU Expected Selected Utility from continuing to search

The probability of a car park being selected is estimated by using a logit type model which relates the probability of selection directly to its utility. To distinguish between types of car parks (ie on-street, garages and lots) separate (nested logit) models for each type are estimated (Hunt 1988).

## Direction of search

Drivers must select a route (ie a series of turning movements) when searching for a car park which effectively determines the range of parking alternatives encountered. Drivers searching within an urban centre are not offered car parks in a random fashion since parking alternatives are usually ordered in their quality due to the spatial nature of the parking system arising from local parking policies. The direction of search is important in parking choice since the access costs of a car park are included in the expected utility and numerous attributes of car parks are assumed to be updated upon direct observation. A relationship between the likelihood of searchers selecting a particular turning movement and the quality of car parks the movement leads to, was developed (Thompson 1994b). The expected maximum utility of the set of car parks on links directly accessible from each movement were used to estimate this probability. Movements leading directly to significantly better car parks, therefore have more chance of selection.

## System representation

A range of physical and operational characteristics of the traffic and parking system were defined to represent the search environment (Thompson and Collins 1992; Thompson 1995). Traffic volumes on the links and turning movements were assumed to be constant for the entire period being modelled. Travel times within car parks were used to schedule vehicles by estimating when they would reach the decision point to evaluate on-street car parks. It was assumed that drivers evaluate on-street car parks upon reaching the first unoccupied space. If there were no available spaces, this decision point was presumed to be after reaching the last space in the car park. For off-street car parks (ie garages and lots) it was assumed that drivers evaluate at their entrances, before inspection, implying that motorists only enter off-street car parks with the intention that they will park there if a space is available. This appears consistent with observed parking behaviour. Drivers are also assumed to possess a set of characteristics that influence their search for a car park. The attributes of individuals affecting parking choice generally relate to the utility of car parks and the level of knowledge of the characteristics of the system. Individuals are assumed to possess a set of attitudes relating to the importance of the various attributes of car parks. These are used to compare car parks when searching. Models of parking choice have grouped individuals into trip purposes (Van der Goot 1982) and duration ranges (Axhausen and Polak 1991). These segments have been used to estimate the importance weightings of the car park disutility components as well as the value of time.

An individual's level of knowledge relating to car parks also influences their search behaviour. This knowledge is assumed to be imperfect and related to their past and present searching experiences. It directly influences the perception of the existence of car parks and their attributes (eg availability and departure rates). This personal knowledge or perception is considered important when comparing the current parking alternative with other alternatives, since this comparison assists in deciding whether to continue to search or not. In addition to system and decision maker characteristics described above, there are a number of factors relating to the trip that also need to be specified in the model. Important attributes relating to the trip that influence parking choice include; the parking duration, the origin and the final destination as well as the arrival time (Bates and Bradley 1986). The parking duration is assumed to be fixed, ie it is not affected by the search or parking conditions. The final destination is the location where the vehicle's occupants will be engaging in their desired activity. The trip origin is the location where the vehicle began the journey, and the arrival time is the time that searching begins.

## VERIFICATION AND VALIDATION

The model was verified using a hypothetical CBD and parameter values adapted from previous studies (Thompson 1994b). It generally performed as expected and produced results consistent with the behavioural concepts outlined above. The choice set of drivers increased as off-street car parks were encountered while searching or observed when walking to the final destination after a car park had been chosen. A substantial amount of sub-optimal choices were simulated which is consistent with observed behaviour (Thompson 1993b).

Perceptions of the stochastic attributes of car parks were also observed to change depending on conditions simulated drivers encountered. Numerous parameters of the model were varied in order to test the sensitivity of the outputs and to check their relevance for inclusion in the model. Responses to changes in these parameters appeared to be reasonable and consistent with prior expectations. The model was also able to replicate various observed parking choice strategies reported by Polak and Axhausen (1990). The effect of experience gained by searchers over a number of successive runs representing independent daily trips was investigated.

**Table 1 Model results from reducing on-street parking duration limits**

| Averages (for 5th run) | Before | After |
|---|---|---|
| In-Vehicle Travel Time (min.) | 3.76 | 1.35 |
| Excess In-Vehicle Travel Time (min.) | 1.98 | -0.65 |
| Walking Travel Time (min.) | 2.61 | 4.34 |
| Selected Native DisUtility (NDU) | 9.07 | 10.39 |
| Selected DisUtility (DU) | 12.83 | 11.74 |

On average, the experience or increase in the number of runs did not significantly influence the quality of the car parks selected—represented by the native disutilities of the selected car parks. This appears to be largely due to the uncertainty associated with the availability of car parks. However, the overall utilities of the selected car parks (which includes waiting time) did improve dramatically after the first run, due to the increased knowledge of the availability and departure rates at car parks. Drivers commonly waited to enter car parks on the first run, but this was not so prevalent in subsequent runs. The variation in the average selected disutility seemed to stabilise as the number of runs increased.

# APPLICATION

## Introduction

The model was applied to predict changes in choice behaviour when on-street car park duration limits and enforcement practices were modified. A more comprehensive account of these and other more comprehensive applications of the model are presented by Thompson (1994b). A small hypothetical CBD network was used to investigate the effects of parking policies using the model.

The on-street parking network used in this investigation was partitioned into 3 zones, based on duration limits. An inner zone (adjacent to the central traffic links) was designated as short term (up to 2 hours), while long term parking (up to 12 hours) was permitted along side the outer (fringe) links. Medium term parking (up to 4 hours) was permitted at on-street parking adjacent to the other traffic links. Vehicle trips used to assess the impacts of these parking policies were assigned parking durations between two and three hours with destinations on links in the inner part of the network.

## Duration limit reductions

The effect on searching patterns by changing the duration limits of car parks within the CBD network was investigated using the model. There exists a trend in many cities to reduce the on-street duration limits to encourage short and medium term parkers to shop and conduct business there. Short term on-street parking was reduced to 1 hour in the inner area, while fringe parking was restricted to 4 hours. On-street parking duration limits adjacent to other links was limited to 2 hours.

The effects of changing the duration limits were estimated by running the model for both on-street parking networks. The results produced by the model show a significant change in parking search patterns. These have been summarised by considering the searching characteristics of all trips for the fifth run (Table 1). The results show a substantial reduction in searching time as well as a significant increase in walking times due to the policy change.

The trend after the duration limit changes was for vehicles to generally park on the outer (fringe) areas. The effect on the quality of alternatives selected was not significant as motorists seemed to trade off increased walking time for a reduction in searching time. Experience appeared to play a more positive role in the selection of car parks after the change to the duration limits was introduced. This was attributable to drivers learning more about the location and details of off-street car parks after the initial search. Off street facilities became quite attractive once they became known, particularly after the duration changes were made. This was confirmed by comparing the means of the disutilities from the first and fifth runs for before and after the introduction of the changes to the duration limits. These were statistically different at the 2.5% level.

## Elimination of enforcement practices

The effect of not enforcing the time limit restrictions and fee payments for using on-street car parks was also investigated. The network used for this exerçise was based on the three zones of duration limits with moderate utilisation levels. Eliminating the enforcement of the regulations associated with on-street car parks was undertaken by assigning the probability of the car parks being enforced to zero. This parameter represents the perceived enforcement level by all searchers. In contrast, the initial situation where enforcement was assumed to be present was represented by assigning the probability of car parks being enforced to unity. Numerous effects due to the elimination of enforcement practices were predicted by the model (Table 2).

The amount of illegal parking time increased from nothing to the situation where all vehicles parked illegally. The quality of the car parks selected increased considerably also. Since motorists destinations were in the inner core zone, in-vehicle travel times increased. Walking distances, fees paid and waiting time all decreased.

**Table 2 Model results for enforcement changes**

| Averages (for 5th run) | With Enforcement | Without Enforcement |
|---|---|---|
| In-Vehicle Travel Time (min.) | 1.30 | 2.23 |
| Waiting Time (min.) | 0.40 | 0.00 |
| Fees Paid | 0.61 | 0.00 |
| Expected Fines | 0.00 | 0.00 |
| Walking Travel Time (min.) | 3.90 | 1.71 |
| Excess In-Vehicle Travel Time (min.) | -0.68 | 0.74 |
| Selected NDU | 10.70 | 3.03 |
| Selected DU | 12.00 | 5.26 |
| Illegally Parked Time (min.) | 0.00 | 176.00 |
| Trip Parked Illegally (%) | 0.00 | 100.00 |

### Limitations of the applications

The above applications of the model are limited and the results require careful interpretation. Due to the small number of vehicles and range of trip attributes represented in the above applications, the results cannot be generalised. However, to increase the reliability of the results would involve the systematic variation of trip parameters to represent a range of trip patterns into a central city area. A trip makers origin and destination links, as well as their parking durations have a large influence on their parking choice. Unfortunately due to the models complexity, large scale variation of these trip parameters reflecting the full range of trips into a central city area would consume a substantial amount of computer resources. A limitation in the application of the model can be illustrated by examining the enforcement reduction application. In this case the overall effect of eliminating the enforcement of parking duration regulations was that motorists were generally much better off, indicated by significantly lower selected disutilities (Table 1). One implication that might be drawn from this conclusion is that this policy may be worth implementing on the basis that there were no negative effects associated with it. However, only medium term duration trips were represented in this application. If these trips were combined with a group of short term parkers the result may be more neutral with the effect on short term parkers perhaps, negative. Thus a comprehensive analysis of this type of policy would need to include consideration of the impacts to all types of trip makers.

## CONCLUSIONS

In conclusion, this paper has shown that parking choice behaviour in competitive situations can be described by a search process. This dynamic and sequential decision making process incorporates the selection of information channels, inspection and evaluation of alternatives. The economic search principle of expected gain in utility was adapted to represent the searching patterns of parkers in congested city centres.

Numerous characteristics of the parking search process were incorporated within this structure. Statistical expectation methods were developed to estimate the expected utility of a car park. Relationships incorporating the expected waiting time and expected fines were defined to allow for the stochastic nature of several important attributes of car parks. The application of the simulation model illustrated that experience in parking search does not necessarily lead to better car parks being selected. This is due to the inherently uncertain nature of the car parking system.

## REFERENCES

Axhausen, K. and Polak, J. (1990) An exploration of parking search strategies, Transport Studies Unit, *Report TSU Ref. 510*, Oxford University.

Axhausen, K.W. and Polak, J. (1991) Choice of parking: stated preference approach, *Transportation* 18, 59-81.

Bates, J. and Bradley, M. (1986) The CLAMP parking and policy analysis model, *Traffic Engineering and Control* 27 (7), 410-1.

Bradley, M. and Layzell, A. (1986) Parking behaviour in a suburban town centre, *Transport Study Unit Working Paper 354*, Oxford University.

Feeney, B.P. (1989) A review of the impact of parking policy measures on travel demand, *Transportation Planning and Technology* 13, 229-44.

Gillen, D.W. (1977) Estimation and specification of the effects of parking costs on urban transport mode choice, *Journal of Urban Economics* 4, 186-99.

Gur, Y.J. and Beimborn, E.A. (1984) Analysis of parking in urban centres: Equilibrium assignment approach, *Transportation Research Record* 957, 55-62.

Horowitz, J.L. (1984) The stability of stochastic equilibrium in a two-link transportation network, *Transportation Research* 18B (1), 13-28.

Huber, M.J. (1962) Street travel as related to local parking, *Proceedings 41st Annual Meeting, Highway Research Board*, Washington DC.

Hunt, J.D. (1988) Parking location choice: insights and representations based on observed behaviour and hierarchical logit modelling formulation, Institute of Transportation Engineers, *58th Annual Meeting, Compendium of Technical Papers*, Vancouver, Canada, 439-46.

Layzell, A.D. (1985) Behavioural aspects of parking: report on the exploratory interviews, *Technical Note*, Transport Studies Unit, Oxford University.

Miller, G.L. and Everett, C.T. (1982) Raising commuter parking prices: An empirical study, *Transportation* 11, 105-29.

Nour Eldin, M.S., El-Reedy, T.Y. and Ismail, H.K. (1981) A combined parking and traffic assignment model, *Traffic Engineering and Control* 22 (10), 524-30.

Parker, G.B. (1973) A method of assessment of the effects of parking policy on movement, *Traffic Engineering and Control* 15, 28-33.

Polak, J. and Axhausen, K. (1990) *Parking Search Behaviour: A Review of Current Research and Future Prospects*, Transport Studies Unit, TSU Ref. 540, Oxford University.

Polak, J. and Axhausen, K.W. (1989) CLAMP: A macroscopic simulation model for parking policy analysis, *68th Annual Meeting, Transportation Research Board*, Washington DC.

Richardson, A.J. (1982) Search models and choice set generation, *Transportation Research* 16A (5), 403-19.

Salomon, I. (1986) Towards and behavioural approach to city centre parking, *Cities*, August, 200-8.

Thompson, R.G. and Collins, E.C. (1992) Information systems for traffic planning, *Australian Planner* 30 (2), 98-102.

Thompson, R.G. (1993a) A Survey of Motorists Parking in the Wollongong Central Business District (CBD), *Transport Systems Working Paper TSWP 93/P045*, Department of Civil and Environmental Engineering, The University of Melbourne.

Thompson, R.G. (1993b) The University of Melbourne Parking Survey, Transport Systems Working Paper TSWP 93/P046, Department of Civil and Environmental Engineering, The University of Melbourne.

Thompson, R.G. (1994a) Concepts of Parking Search Behaviour, *Transport Systems Working Paper TSWP 94/P06*, Department of Civil and Environmental Engineering, The University of Melbourne.

Thompson, R.G. (1994b) A Parking Search Model, *Transport Systems Working Paper TSWP 94/P07*, Department of Civil and Environmental Engineering, The University of Melbourne.

Thompson, R.G. (1995) *PARKSEARCH Documentation, Transport Systems Working Paper TSWP 95/P08*, Dept of Civil and Environmental Engineering, The University of Melbourne.

Van der Goot, (1982) A model to describe the choice of parking places, *Transportation Research* 16A (2), 109-55.

Young, W. and Thompson, R.G. (1990) Parking duration surveys: a comparative study, *Australian Road Research Board, AIR179*, Vermont South.

Young, W., Thompson, R.G. and Taylor, M.A.P. (1991) A review of urban car parking models, *Transportation Reviews* 11 (1), 63-84.