ALLOCATION OF PARKING DEMAND IN A CBD

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This paper describes a behavioral model for estimating the use of parking spaces in a CBD. The model examines drivers' ultimate destinations in the CBD and uses relations between walking time and parking costs to simulate their choices of parking facilities. The model recognizes that people differ as to how they equate walking time to parking cost and that drivers destined for a particular block in the CBD do not necessarily all use the same parking facility. The model provides for the different choices by distributing persons in each block among different parking facilities on the basis of time and cost. By allocating parking demand on the basis of driver behavior, the model provides a valuable tool for studying the location of new parking facilities. Its application is particularly relevant to the siting of peripheral parking facilities served by people-mover systems.

•A PROBLEM faced by many cities is where to provide adequate parking facilities for automobiles whose drivers are going to the CBD. The larger the CBD is, the more complex the problem is because the number of possible solutions is greater. The cost of providing parking in any particular locality must be balanced against the estimated use and revenue, which in turn will depend on the convenience of the location. The provision of low-cost peripheral parking areas, for example, may be of little value if drivers do not patronize them because of preferable (from the driver's point of view) alternatives. To fully evaluate such proposals, a method is needed that can estimate where drivers will park in relation to their actual destinations.

Described here is a behavioral model for choice of parking facility. The behavioral nature of the model is emphasized because some approaches to parking models tend to be more oriented to allocating parkers to facilities on the basis of overall optimizing criteria than of actual driver behavior. It would seem unrealistic to assume that drivers act in a way that will optimize overall benefits rather than their own.

In many behavioral models involving personal choice, the basic variable governing the behavioral process is disutility. In the case of parking, disutility is made up of many factors, the most important of which are probably time, cost, inconvenience, and various intangibles related to inconvenience. All those different factors require a single unit of measurement, and cost is generally used. However, the contribution from each of the various components should be recognized, and, if necessary, the sensitivity to different values should be tested. In this parking model, disutility is taken to be the cost of parking plus a cost for the time spent walking from the parking facility to the actual destination. The model assumes that, in choosing among parking facilities, drivers trade off those 2 variables. A high-cost parking area close by may be as desirable as a lower cost facility some distance away. However, the trade-off will be different for every driver, and the model recognizes that by the use of frequency distributions that represent the range of values drivers place on their time.

METHODOLOGY

The basic methodology of the model is best described by referring to a simplified parking-choice situation such as that shown in Figure 1. Zone D is a typical block in

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the CBD, and persons destined to zone D have a choice of parking facilities A, B, or C. Each facility has a different walking time and parking cost associated with it. The question is, What proportion of drivers destined for Zone D will use each of the 3 facilities?

The disutility of each facility as a function of the value of time is shown in Figure 2. Those relations have some interesting implications. For example, persons with a value of time below 6 cents/min will favor facility A, those with a value of time between 6 and 13 cents/min will favor facility B, and those with a value of time higher than 13 cents/min will favor facility C.

It is reasonable to assume that drivers destined to a typical downtown destination zone will all have different values for their walking time. The value of walking time depends first on the trip purpose and parking duration, but even drivers with the same purpose and duration will have different values of walking time.

Less obvious but also important is the fact that each person's perceived walking time to a given facility tends to differ from the actual walking time, and thus based on perception the cost will be correspondingly different. Both factors—the variation in the value of walking time and the variation in perception of that walking time—are taken into account in the model.

Different values for walking time are incorporated into the model by a distribution of the type shown in Figure 3. Such a curve represents the distribution of walking time to a given destination zone for drivers with the same purpose and parking duration. A family of curves would represent all zones, purposes, and durations. The shape of the distribution and the exact value of parameters, such as the mean and standard deviation, depend on the type and diversity of land use activities in the zone. High-density office development generally exhibits characteristics different from those of low-density industrial development.

The disutility values shown in Figure 2 as functions of the value of travel time indicate that facility A, B, or C will be chosen depending on whether the value of time is 0 to 6 cents, 6 to 13 cents, or more than 13 cents. For such a case, the area under the time cost curve in Figure 3 gives the proportion of persons in each of those ranges. If everyone takes the facility offering the lowest disutility, those proportions will represent the allocation to the corresponding facilities.

Although the allocation given by the appropriate areas under the curve is theoretically valid in a strict minimum disutility choice sense, in actuality it is unlikely that everyone with a value of time of 12.9 cents will use facility B and those with a value of 13.1 cents will all use facility C. A more gradual diversion will obviously take place. Some persons with a value of 12.9 cents will choose C instead of B, and some with a value of 13.1 cents will choose B instead of C.

Much of this diversion effect can be attributed to the individual differences in perceived versus actual walking times. Differences in perceived time (and, hence, perceived disutility) are a characteristic incorporated into many behavioral models. One example is the case of highway route selection where it is recognized that not everyone will necessarily select the quickest route. A certain proportion will take a slower route, particularly if the difference in time is small. This characteristic results in the well-known diversion-curve method of distributing trips between alternative routes.

The same procedure can be applied to the parking facility situation. If C_{ij} = disutility of using parking facility j for persons in destination zone i, then, for a given time value v, $C_{ij} = vt_{ij} + k_j$, where t_{ij} = time to walk (or ride local transit) between i and j and k_j = cost of parking at j. A typical diversion relation is, then,

$$P_{ijv} = \frac{\frac{1}{C_{ij}^n}}{\sum_{j=1}^{n} \frac{1}{C_{ij}^n}}$$

where P_{ijv} is the proportion of drivers who are destined to zone i, have value of time v, and use facility j.

Figure 1. Simplified parking-choice situation.

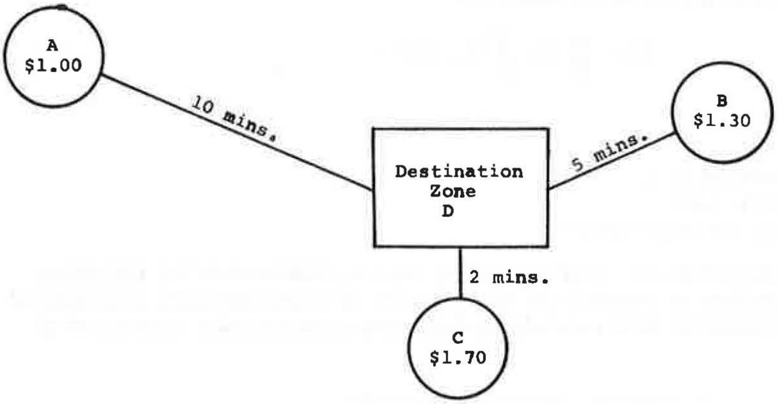


Figure 2. Disutility versus time cost.

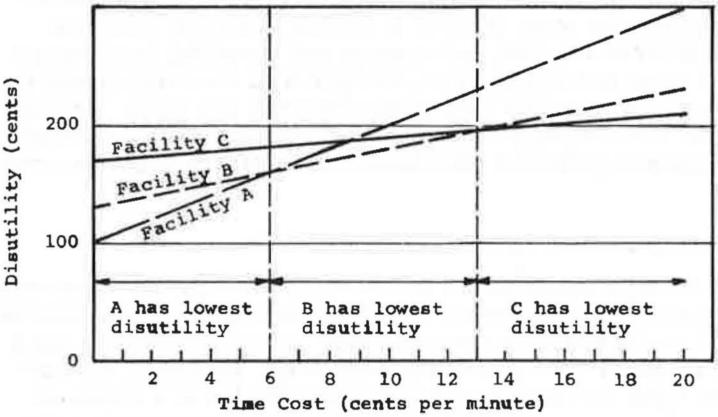
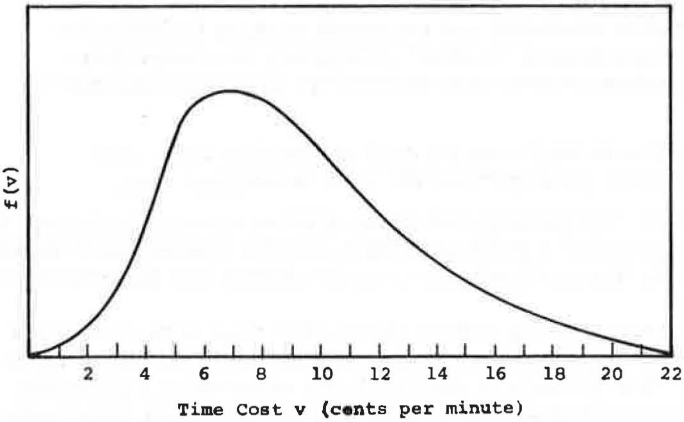


Figure 3. Typical distribution for cost of walking time.



The parking allocation model uses that relation together with the previously described time-cost distribution to determine the actual choices of parking facilities. The parking distribution is thus determined from

$$T_j = \sum_i D_i \int_V P_{ijv} f(v)$$

where

T_j = total trips allocated to j,
D_i = total demand at i, and
f(v) = density function for time value v.

Because of the summation in the denominator of the expression for the diversion relation P_{ijv}, the integration is carried out numerically by using discrete intervals of v. Computatively, the integral thus essentially becomes a summation over a set of time-value intervals.

PARKING SPACE CAPACITY

Although the model is basically a demand model, it has the capability of carrying out successive iterations so that the demand in each zone does not exceed the supply. That is achieved by successively raising the parking cost in zones where demand exceeds supply and iterating in much the same manner as highway capacity restraint procedures. The difference between the final cost figures and the initial input values in those zones where demand exceeded supply can be thought of as the extra disutility experienced in delays or general aggravation when those facilities are used. Perhaps more important, the final cost indicates what the actual free-market cost of parking at that facility should be (i.e., assuming that the only factors in determining parking cost are supply and demand).

CALIBRATION OF THE MODEL

The 2 relations that must be determined before the model is used are the time-value distribution and the diversion function. The value of walking time cannot be measured directly from observations of parking behavior or even from driver interviews, and a special analysis is required to derive the distribution indirectly. However, the calibration can be carried out by using the data that are usually collected in a downtown parking survey. Generally such surveys provide information on where drivers park and the locations of their ultimate destinations. Parking costs are also obtained.

The calibration requires that a walking-time network of the downtown area first be developed in much the same way as a normal link-node highway network. Blocks or portions of blocks are designated by centroids and represent parking facilities (or groups of parking facilities) and destination "zones." Combining the centroid-to-centroid travel times with the parking survey data enables the following relations to be formed:

1. Frequency distributions of walking times for each destination zone, and
2. Walking times versus average parking costs for each destination zone.

In a behavioral modeling sense, the parking cost-time relation represents the set of choices confronting drivers destined for a particular block and the walking-time distribution represents the result of the interaction between those choices and the behavioral characteristics of the drivers.

Calibration of the model is carried out by making successive runs of the model for different values of the exponent in the diversion relation and successively adjusting an initial time-value distribution. The process is similar to the successive adjustment procedure used to derive the empirical distribution functions in the gravity distribution model.

USE OF THE MODEL

The model described here has been used in Los Angeles to examine the feasibility of providing peripheral parking facilities around the CBD. A feature of the study was the proposal to connect the peripheral parking facilities to the CBD by a people-mover system.

The first stage of the analysis was to estimate the number of vehicle trips destined for each CBD block. That estimate was made by using a regression type of trip-generation process. The estimate was for all-day parkers only, because they were the drivers considered most likely to be attracted to peripheral parking sites, and did not include those who were provided free parking spaces. The parking model allocates only those drivers who have to locate and pay for their own parking. The provision of free (or partly subsidized) parking for employees creates essentially a captive rather than free-market situation and as such is independent of the allocation process required for examining alternative parking policies.

A base-year walking network was then developed as described above, and the model was calibrated. In this case, the necessary data were obtained from employee interviews in 7 large office buildings in the CBD. The required walking-time and parking cost data were thus available only from those 7 locations, but the sample was adequate for carrying out the required calibration. The walking-time distribution and parking cost relation for all 7 buildings combined are shown in Figures 4 and 5.

In this study, a gamma function was found to give a reasonably good approximation to the shape of the time-value distribution (a form that closely approximates income distributions). It was found that, in terms of sensitivity, large changes in the exponent of the diversion function were needed to affect the distribution appreciably compared to changes in the parameters of the time-value distribution. A value of 10, corresponding to that commonly used in highway diversion curves, was finally used. The parameters of the income distribution for each of the 7 buildings were determined by successive trials until the walking-time distribution could be matched as closely as possible. The ratio between the mean and the standard deviation was considered consistent for all cases (in common with this characteristic of income distributions).

Derivation of the income distribution for those surveyed in each building showed differences in mean values of time for each. Although partly attributable to variations of a sampling nature, such variation could more reasonably be expected to be an indication of actual differences. It was not possible with the data available to relate those differences with differences among the buildings, but it is reasonable to expect that the variation could be related to the average income levels of employees in each building. In cities where that characteristic varies considerably throughout the CBD, adding this variable to the model (rather than assuming that all zones are the same) would enable a more accurate allocation process to be carried out.

Comparisons between observed and modeled trip-length frequency distributions are shown in Figure 6 for the 4 buildings that provided the largest samples. Mean values of time varied between 18 and 25 cents/min.

A base-year run was made to test the validity of the model in simulating parking to peripheral sites. Only 1 peripheral facility actually existed in the base year; the connection was by surface bus. None of the employees interviewed in any of the office buildings used the peripheral site, and hence no data on its use had been collected. However, a distribution of parking for the whole CBD using the allocation model did result in some parkers being allocated to the peripheral site—about 80 in all—which agreed closely with actual usage.

The projection-year network contained various peripheral parking proposals and a people-mover system as shown in Figure 7. The people-mover system connecting the parking facilities with the CBD was added to the walking network to form a composite walking-riding network. Travel time from each parking facility (both peripheral and within the CBD) was computed by using the minimum time path. Although it is the intention of this paper to illustrate the methodology and not to discuss the study itself, it is interesting to note that, with a 15-mph people-mover system (average speed), the

Figure 4. Walking-time distribution.

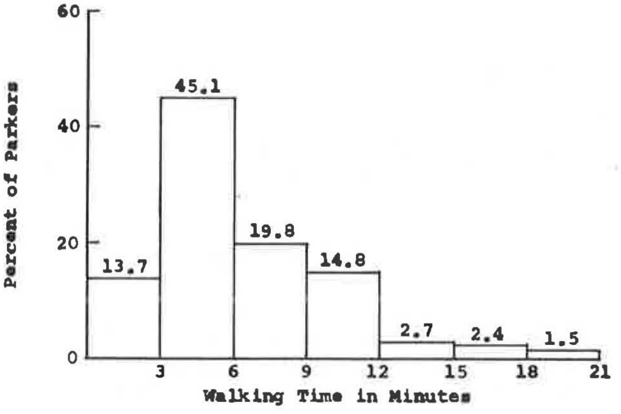


Figure 5. Relation between parking cost and walking time.

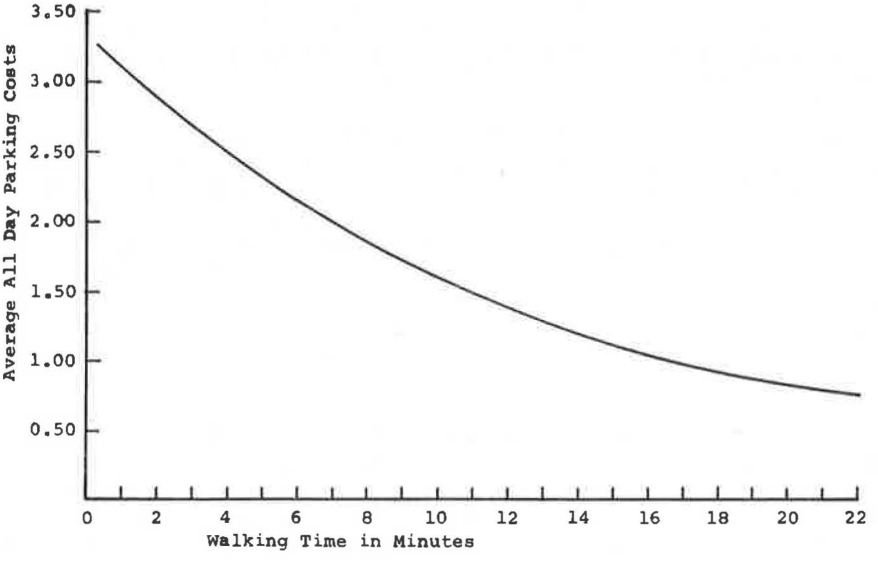


Figure 6. Observed versus modeled walking-time frequency distribution.

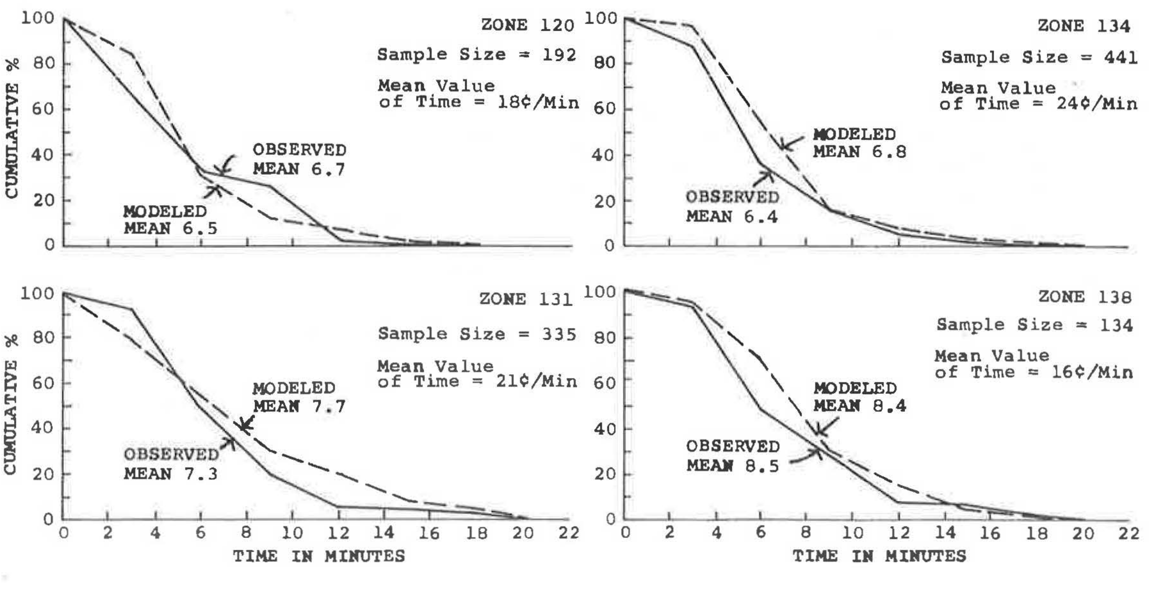
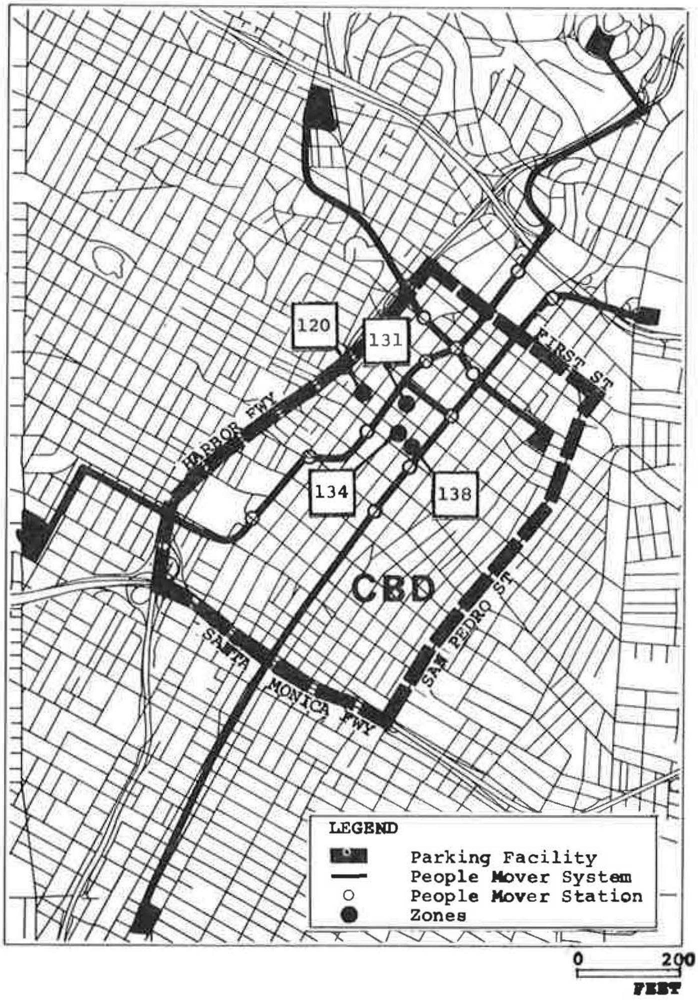


Figure 7. Proposed parking facilities and people-mover system.



results indicated that as many as 15 percent of all-day parkers could be expected to park outside the CBD if costs of parking in the downtown area were increased and a convenient people-mover system (i.e., high frequency) could be provided to serve the peripheral sites.

CONCLUSION

The purpose of this paper has been to describe the theoretical basis for a parking allocation model. Of prime concern is the fact that the method simulates driver behavior in relation to the available choices. In this way, it differs from entropy and linear programming models that use some form of collective rather than individual optimization function in the allocation process.

The underlying philosophy of the model is similar to other behavioral models of the disutility type, particularly those used in modal choice. Fundamental statistical methods are used to generate different driver characteristics, and those characteristics interact with the available choices in the physical system to produce a resulting behavior pattern. It is hoped that further use of the model will lead to a greater understanding of some of the components of individual disutility and the type of statistical distributions that they form.

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