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CONTENTS

FOREWORD

The 3 reports in the RECORD show the continuing interest in predicting the parking demands of automobile users as a tool in the decision-making process for parking facility location. A behavioral model is described that estimates CBD parking and accounts for parking preferences of people headed for a single destination. Siting of parking facilities that have maximum utility at minimum cost for institutions, such as colleges and hospitals, that have several generators is discussed in terms of a case study at Carnegie-Mellon University. Demand forecasts are described for peripheral parking proposals in Los Angeles, and estimates are given of the effects on CBD parking demand. A discussion of the second paper is also included.

The methods of forecasting demand and the forecasts themselves will be useful to traffic engineers, transit and parking authorities and administrators, and all who must help decide on optimum locations for facilities for the temporary storage of commuter vehicles.

ALLOCATION OF PARKING DEMAND IN A CBD

Terence W. Austin*, JHK and Associates

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

*Mr. Austin was with Wilbur Smith and Associates when this research was done.

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.

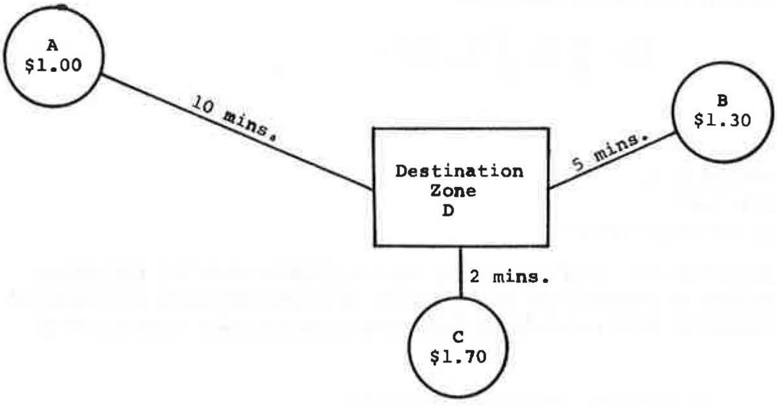


Figure 2. Disutility versus time cost.

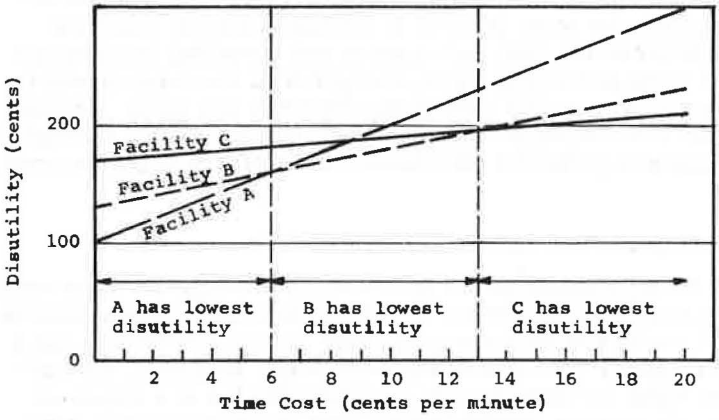
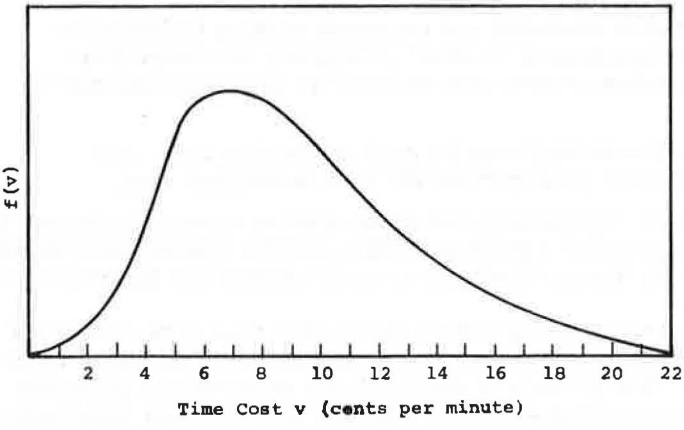


Figure 3. Typical distribution for cost of walking time.



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.

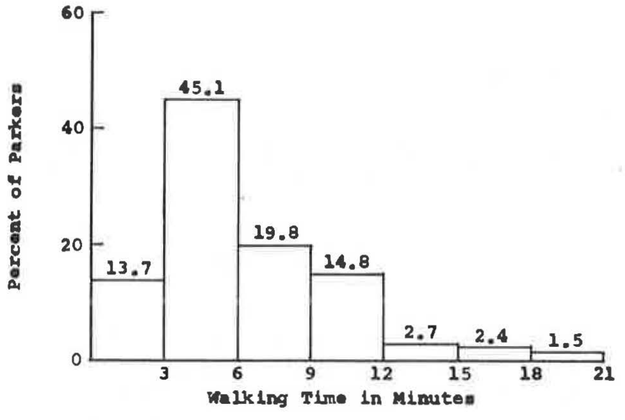


Figure 5. Relation between parking cost and walking time.

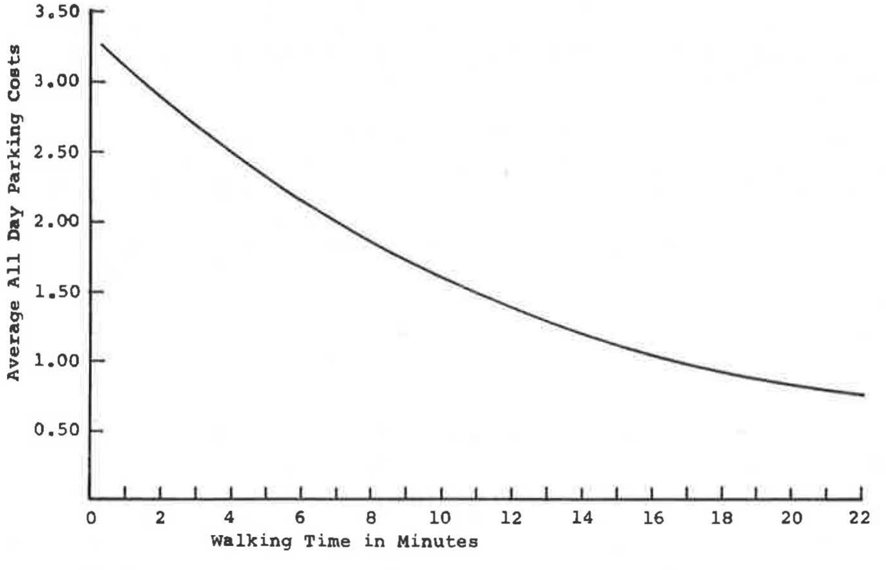


Figure 6. Observed versus modeled walking-time frequency distribution.

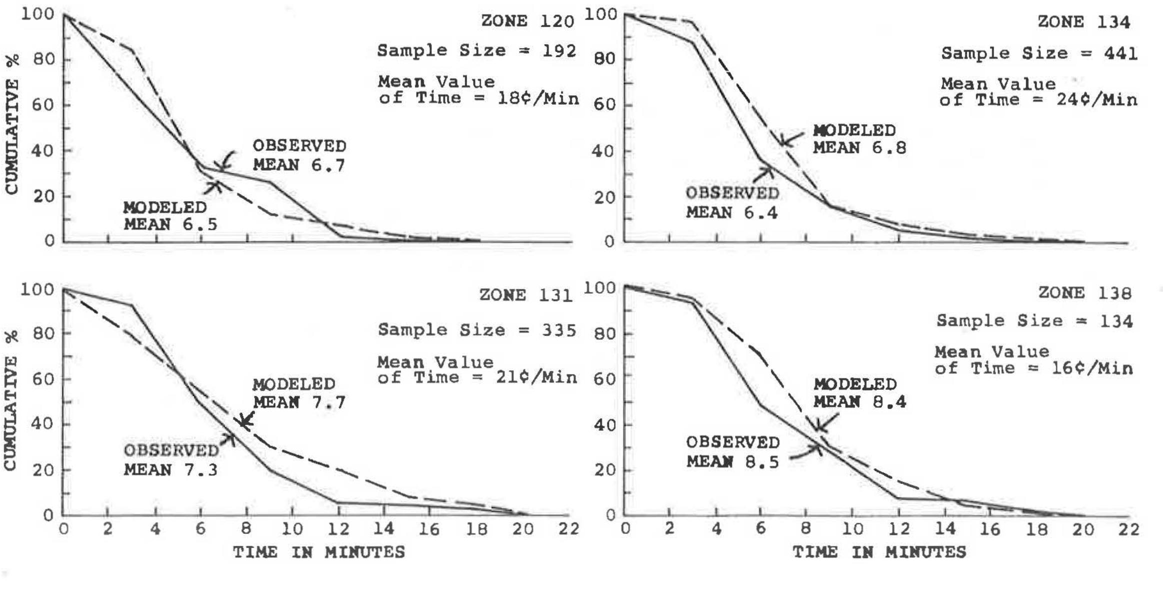
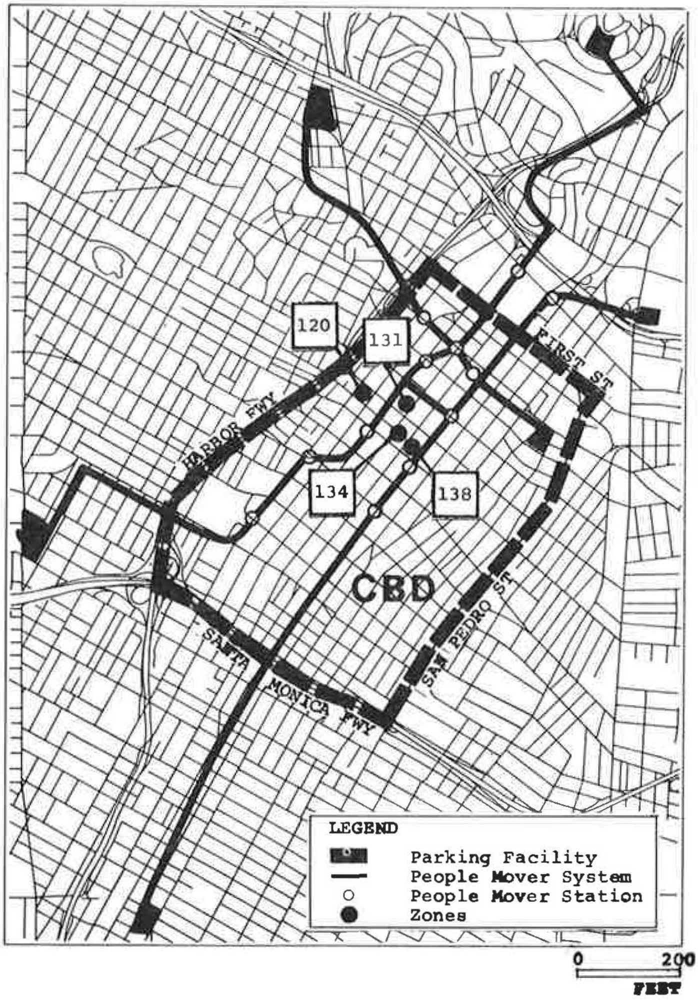


Figure 7. Proposed parking facilities and people-mover system.



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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USE OF LINEAR PROGRAMMING TO EVALUATE ALTERNATIVE PARKING SITES

E. M. Whitlock, Wilbur Smith and Associates

The author has related a detailed study of the development of a parking plan at Carnegie-Mellon University. Because it was possible to establish competitive plans and values between development and operating costs and user costs, a simplex network obtained from linear programming was used to determine that combination of facilities to serve 1980 parking needs with maximum utility and minimum cost. Application of the program assisted in determining the relative importance of each site with regard to its proximity to the many campus generators of parking demands. The time-distance relations of sites and parkers were measured on the assumption that each competitive site was developed with a given number of spaces in terms of cost of trip.

•THE SUCCESS of off-street parking facilities depends largely on their location relative to generators of parking demand. Other factors, such as charges, ease of access-egress, and functional design, also affect usage. When special-purpose parking facilities are planned, additional values can be given to the types of users who are expected to patronize the system. Those facilities would normally serve large office buildings, hospitals, institutions, universities, and other land uses having a number of different categories of users.

A CASE STUDY

In 1968-1969, Carnegie-Mellon University started a planning program to expand its off-street parking. There were 1,625 curb and off-street spaces at various locations on and adjacent to the campus, and those spaces served daily terminal needs of more than 5,000 staff, faculty, students, and visitors. By 1980, based on normal growth, the daily campus population is estimated to be 7,500. Estimates of parking demand are 3,400 spaces, based on study of travel, parking, and socioeconomic facts.

Final planning resulted in a study of selected alternative sites (Fig. 1) varying in size from about 2,000 spaces at sites A (Panther Hollow) and C (Skibo Hall) to 100 spaces in a surface lot near site F (near WQED radio station). Physical characteristics, given in Table 1, included integrated air-rights development, conventional free-standing parking structures, a subterranean garage, and 3 surface lots. Because land was not a cost factor, development costs versus utility of the sites to serve various categories of parkers were final determinants in the evaluation.

THE LINEAR PROGRAM

Primary reasons for selecting linear programming as the analysis tool were relative ease of adoption (off the shelf), economy of computer runs, and direct applicability to measure relative scale of capital, operating, maintenance, and user costs competitively. The objectives of using the linear program were

1. To distribute a maximum number of parkers from each building of campus activity to each potential parking location with minimum cost,
2. To test alternate combinations of off-street parking facilities, and
3. To identify parking facilities with the least cost to all parkers.

The inputs of the program included

1. A network description of campus buildings, facilities, and generators of activity and parking demand;
2. The number of potential parkers in each building in the categories of faculty, staff, and student;
3. Estimates of absolute costs of development, operation, maintenance, and parker assignment; and
4. Capacity of each parking facility.

The outputs of the program included

1. An input network description to authenticate possible errors,
2. An output network description to identify the flow and cost over each link and parker accumulation at each facility, and
3. A tabulation of the total cost for each facility and the daily estimate of cost per parker.

The network logic is shown in Figures 2 and 3; account is taken of parking supply-demand relations and the relative cost values of the transportation network connecting origins and destinations of parkers. The testing phase is shown in Figure 3 where different values of time and parking cost can be applied.

Mathematically, the equations describing the program are directed to seek a set of values that, moving from origin to destination, are equal to or greater than zero. With this case, the sum of the costs of traversing the network by the parkers will be minimized, subject to certain cost constraints imposed at each end of the parker's trip. The essential equations to be solved are as follows:

$$\sum_j f(i, j) = a(i)$$

where $a(i) > 0$ and $i = 1, \ldots, m$.

$$\sum_i f(i, j) = b(j)$$

where $b(j) > 0$ and $j = 1, \ldots, n$. A set of $f(i, j) \geq 0$ must be found such that $z = \sum_i \sum_j c(i, j) f(i, j)$ is minimized.

$$\sum_i a(i) = \sum_j b(j)$$

By definition,

$f(i, j)$ = quantity of parkers destined from place of parking to generator;
$c(i, j)$ = value of person's time consumed in traveling to parking facility (by vehicle) and from parking space to destination (on foot), plus parking cost;
$a(i)$ = supply and cost of parking spaces at origin i;
$b(j)$ = demand for spaces at destination j; and
z = total trip and parking cost.

PLANNING VALUES

Parking demands were determined by relating existing densities of people in the various classroom, administration, and activity buildings for each hour in the normal school day. In the calculations, assumptions were also made with regard to locations of new buildings anticipated (with their estimated parking demands).

Figure 4 shows the location of major parking generators, and Table 2 gives the parking spaces required for the generators excluding dormitories. The data given in Table 2 are based on distribution of computed parking demands by duration of time per building. The main academic thrust is in the enclosed loop comprising Doherty, Hamerschlag, Scaife, and Baker Halls; the Graduate School of Industrial Administration; and the College of Fine Arts. Student activities are generally centered in Skibo Hall near the track oval, and the university's business offices are in Warner Hall. Walking distances among those buildings are not excessive (Fig. 5) and range from about 150 ft in the loop to more than 1,000 ft to the fraternity-dormitory area across Forbes Avenue.

Figure 1. Possible off-street parking facilities.

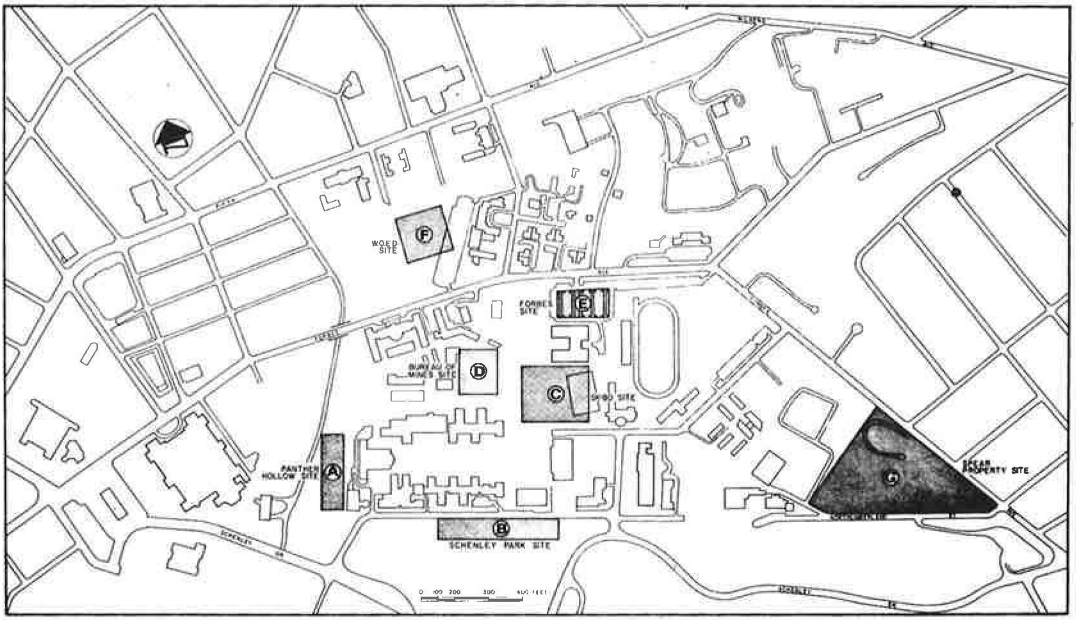


Table 1. Characteristics of possible parking facilities.

Site	Location[a]	Type	Maximum Capacity (spaces)
A	Panther Hollow	Air-rights structure	2,000
B	Schenley Park	Above-grade structure	1,800
C	Skibo Hall	Below-grade structure	2,000
D	Bureau of Mines	Above-grade structure	1,500
E	Forbes Avenue	Surface lot	300
		Above-grade structure	1,200
F	WQED	Surface lot	100
		Above-grade structure	1,000
		Below-grade structure	1,000
G	Spear property	Surface lot	960

[a]Figure 1 shows site location.

Figure 2. Network logic.

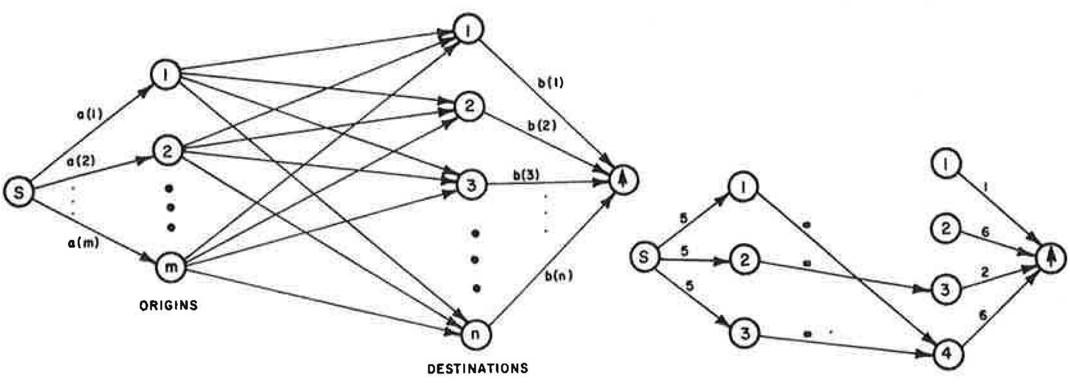
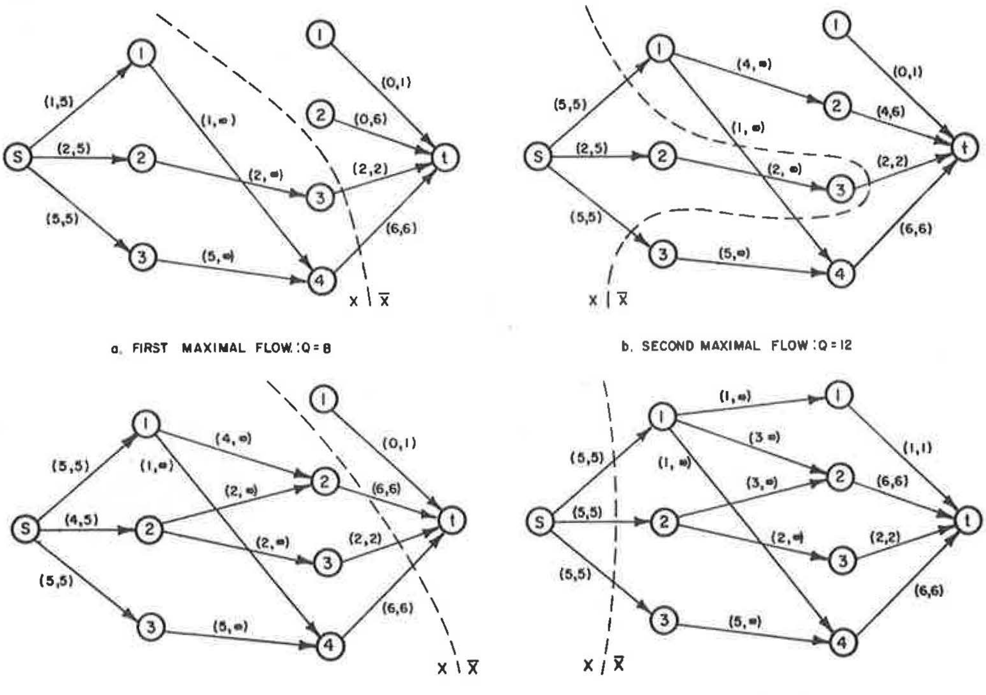


Figure 3. Maximum flow assumptions.



a. FIRST MAXIMAL FLOW: Q = 8

b. SECOND MAXIMAL FLOW: Q = 12

c. THIRD MAXIMAL FLOW: Q = 14

d. FINAL MAXIMAL FLOW: Q = 15

Table 2. Parking spaces required for major generators.

		Parking Spaces Required					
		For Faculty		For Staff		For Students	
Generator	Location	1975	1980	1975	1980	1975	1980
81	Baker-Porter Hall	100	105	182	195	764	803
82	Scaife Engineering	25	26	48	52	190	200
83	Hamerschlag Hall	16	18	43	45	154	161
84	Doherty Hall	44	47	71	76	410	430
85	College of Fine Arts	42	46	13	14	181	190
86	Margaret Morrison Carnegie College	22	23	38	40	119	126
87	Graduate School of Industrial Administration	14	15	23	25	96	102
88	Warner Hall	6	7	165	176	—	—
89	WQED, Dramatic Arts	30	32	77	83	70	74
90	Computer Science Building	37	39	84	90	149	157
Total		336	358	744[a]	796[b]	2,133	2,243

[a]Includes 131 visitors. [b]Includes 138 visitors.

Figure 4. Major parking generators.

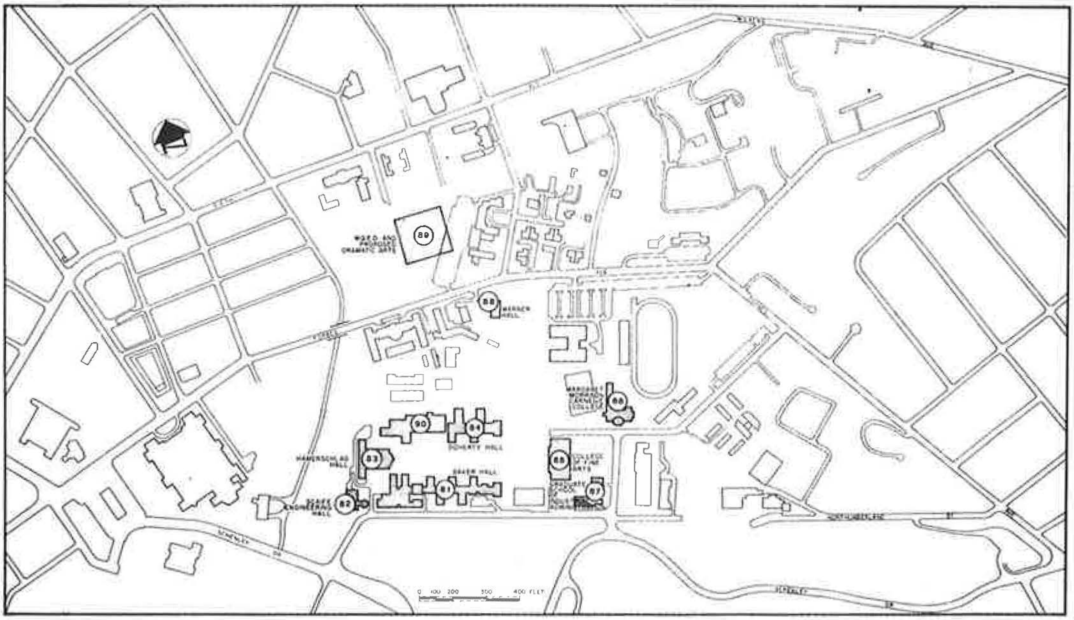
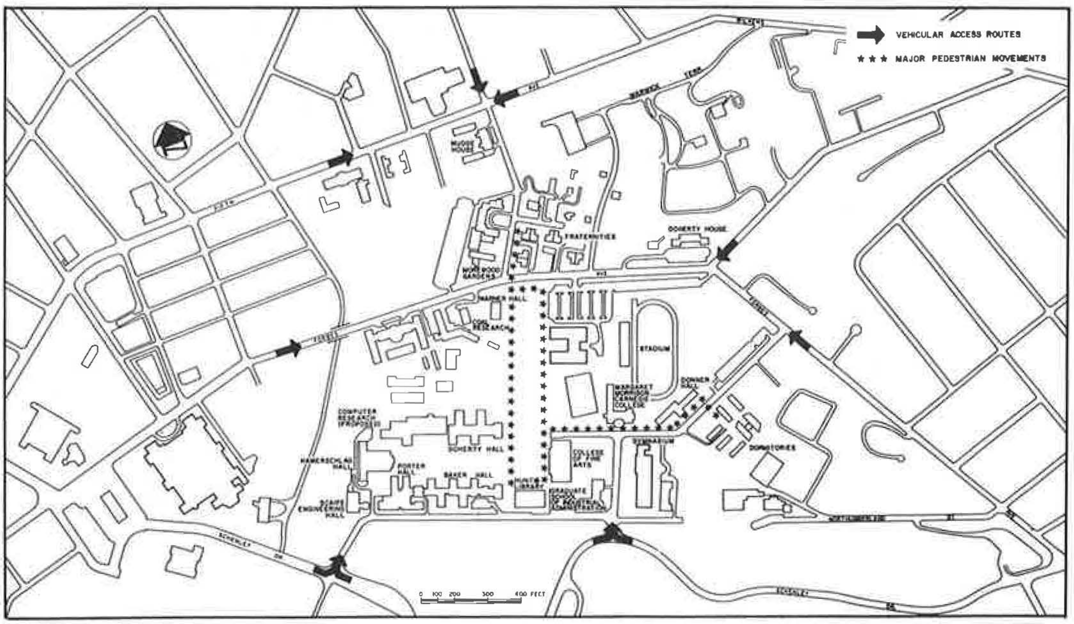


Figure 5. Vehicular access and major pedestrian movements.



Total parking demand by 1980 for all users of the 10 selected generators is expected to be about 3,400 spaces. The demand is 3,200 spaces in 1975 and 2,550 spaces in 1967.

Because the analyses for relative importance of parking sites were sensitive to cost variables of user's time, 1980 parking spaces were divided according to the estimated number in each user category as follows:

Category	Number	Parking Spaces
Faculty	575	358
Staff	1,150	796
Students	5,750	2,250
Visitors	–	130
Total	7,375	3,534

For assumed development costs, the program was used because of its capability to account for total trip costs of all parkers. Development costs of estimated new parking facilities then became key to the total economic implication of building a new facility; the assumption was that user income would self-liquidate the investment. Those values were established by taking into account design, construction, financing, operating, and maintenance costs at the parking end of the trip. Each cost factor, however, was determined separately (Table 3). Development costs exclude land acquisition.

The program measured relative attraction of sites based on travel and parking costs and on the value of time for various categories of users. Therefore, the daily annual implication of amortizing development costs from user revenues was further stated in a breakdown of annual per-space development costs on the basis of a 20-year amortization period. Based on self-liquidation from user charges, the higher the annual cost was, the greater the penalty applied to the user's trip. The annual per-space development costs were further extended for faculty, staff, and students based on the following frequencies of use:

Category	Parking Days	Percent of Parkers
Faculty	230	32
Staff	310	43
Student	180	25

A similar set of unit values was developed for operating and maintenance costs for the various users of the university's parking program. Those values are also given in Table 3.

Whereas the absolute values can be expected to vary depending on circumstance in other applications of the program, the important issue here is the ability to place different relative values on the cost of providing parking.

At the destination (generator) end of the parking trip, a measure of relative user importance was used to ascertain "place utility" of the alternative parking facilities. If the facility were convenient to the generators, a lesser penalty was applied to the trip because the pedestrian trip would be shortened. The indexes of user walking time are as follows:

Category	Estimated Avg. Weekly Income ($)	Walking Time Cost ($/min)
Faculty	230	0.110
Staff	145	0.070
Student	40	0.017

Only in special circumstances, such as a university, hospital, or other "place generators," can those varying time values be logically applied. The time values were determined from average weekly income levels of the faculty, staff, and student parkers. Visitors were not considered in this phase of the study because they constitute a relatively insignificant portion of the annual total of parkers at the university. It was also difficult to arrive at an appropriate income range for the visitor parkers.

Manual adjustments for service levels of street accessibility were made after the linear programming model was applied. They took into account minimum travel paths based on existing capacity and observed congestion measured by actual vehicular travel times.

DEVELOPMENT OF ALTERNATIVE PARKING PLANS

A number of alternate parking plans were hypothesized in the analyses. Six of them had location and capacity variables that supplied the optimum number of spaces for each user type and generator. Optimum-flow and least-cost comparisons were derived by relating parking sites, size, user type, all travel and parking costs, and destinations. Figure 6 shows a conceptual network diagram indicating the myriad of relations that could be tested by altering the previously mentioned assumptions.

RESULTS OF MODEL APPLICATION

A summary of the 6 plans tested is given in Table 4. The plans were modified according to the number of parking spaces expected to be provided at the 7 proposed sites. According to relative demands, proximity of new facility, and cost indexes (facility and user), each received assignments of vehicular flow likely to be related to the parking sites.

The parking concepts tested had the following space capacities based on realistic functional plans previously prepared:

Site	Spaces
A	1,000
B	900
C	1,200
D	960
E	300
F	100
G	960

The main variables evaluated in the testing procedure involved whether the parking facility was a surface lot or a structure. In plan 1, for instance, there were parking garages at sites A, B, C, and D and surface lots at sites E, F, and G. With these, appropriate unit costs were used to achieve a relative measure of utility. Table 5 gives the assigned "utility" of the first alternate plan tested and supports the expected favorable acceptance of the implied cheaper, more convenient parking plan. It also supports, by favoring sites A, B, D, E, and F, the relative attraction of strategic locations for the new parking facilities. Table 5 also gives the assigned utility of the other plans that were tested.

The plan finally recommended is that parking concept expected to achieve maximum flow and least cost to the university (Fig. 7 and Table 5). Though extensive and perhaps energetic from a monetary standpoint, it will best serve 1980 terminal needs of the campus. Expected needs are about 1,200 spaces in Panther Hollow, 1,800 spaces in Schenley Park, and 350 spaces in the surface lot along Forbes Avenue.

As expected in an analysis of this type, the facilities that are costly to develop and those sites that are more distant from generators of campus activity did not prove to be the best choices.

CONCLUSIONS

On occasions when time-cost values can be placed on development costs and categories of users, a relative measure of the optimum utility of a given parking site can be

Table 3. Estimated parking facility development and operating costs.

Parking Facility	Development Costs (dollars)					Operating Costs (dollars)			
	Per Space	Per Space per Year[a]	Per Day per Capita			Per Space per Year	Per Day per Capita		
			Faculty	Staff	Student		Faculty	Staff	Student
Surface lot	800	64	0.030	0.040	0.020	15	0.007	0.009	0.005
Above-grade structure	3,000	240	0.110	0.140	0.080	55	0.024	0.032	0.015
Below-grade structure	5,000	400	0.180	0.240	0.140	90	0.039	0.053	0.031
Surface lot plus shuttle	900[b]	70[b]	0.032[c]	0.043[c]	0.022[c]	—	0.015[d]	0.020[d]	0.012[d]

[a]Based on 5 percent interest rate for 20 years.
[b]Based on 20-year period and capital investment of approximately $100,000 for 4 buses, 2 for each 10-year operating period.
[c]Based on addition of bus operation.
[d]Includes salaries and maintenance for bus operation.

Figure 6. Simplex network.

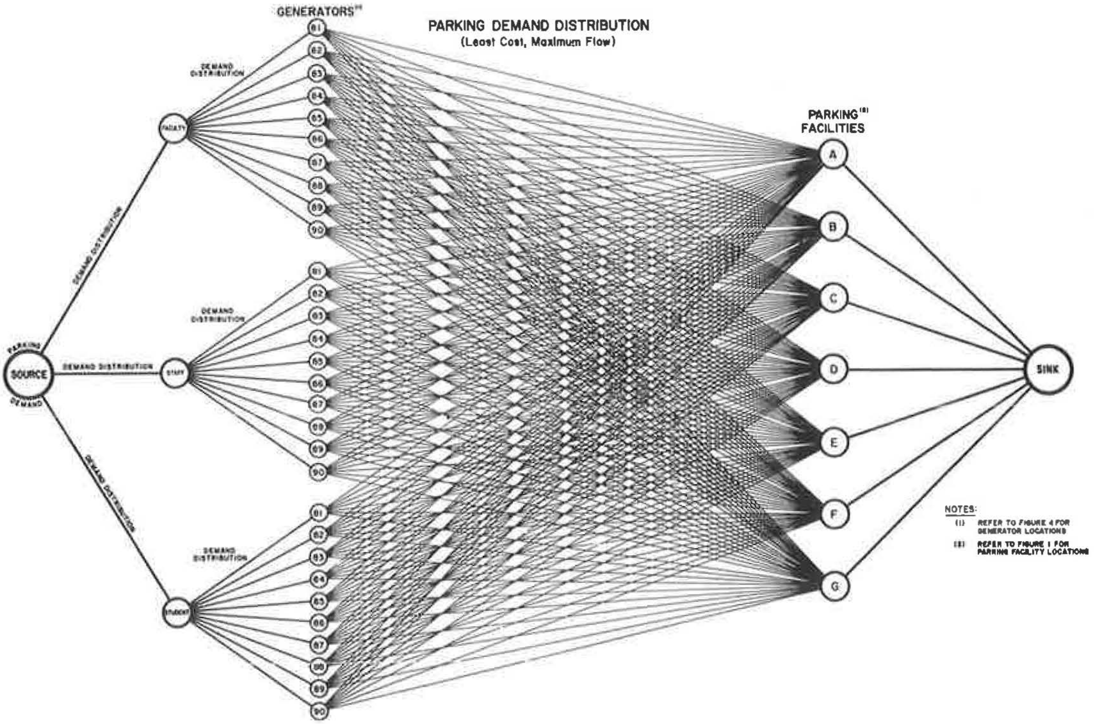


Table 4. Summary of parking plans.

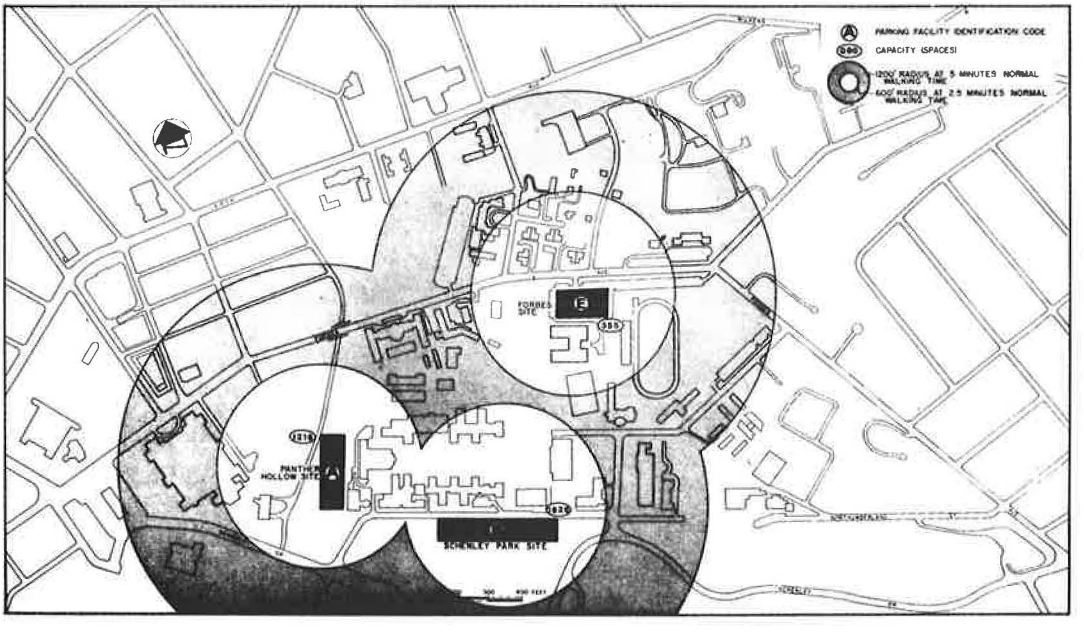
Site	Plan 1	Plan 2	Plan 3	Plan 4	Plan 5	Plan 6
A	Structure	Structure	Structure	Structure	Structure	Structure
B	Structure	Structure	Structure	Structure	Structure	Structure
C	Subsurface	Subsurface	Subsurface	Subsurface	Subsurface	Subsurface
D	Structure	Structure	Structure	Structure	Structure	Structure
E	Surface	Surface	Surface	Structure	Structure	Structure
F	Surface	Structure	Subsurface	Surface	Structure	Subsurface
G	Surface	Surface	Surface	Surface	Surface	Surface

Table 5. Optimum-flow and least-cost comparisons for parking facility alternatives.

		Flow of Vehicles[a]													
	Practical Capacity	Plan 1		Plan 2		Plan 3		Plan 4		Plan 5		Plan 6		Recommended Plan	
Site	(spaces)	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980
A	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,133	1,216
B	900	900	900	900	900	900	900	900	900	900	900	900	900	1,740	1,826
C	1,200	103	137	125	161	171	177	51	62	—	—	—	—	—	—
D	960	710	960	810	960	846	960	890	960	855	960	855	960	—	—
E	300	300	300	300	300	300	300	272	375	384	451	485	537	340	355
F	100	100	100	74	76	54	60	100	100	74	86	—	—	—	—
G	960	—	—	—	—	—	—	—	—	—	—	—	—	—	—

[a]For plans 1 through 6, flow of vehicles indicates relative acceptance of parking facility given in Table 4. Maximum acceptance is achieved when the number of vehicles equals the practical capacity. For the recommended plan, the flow of vehicles accounts for the number of spaces required for each forecast year if the recommended facilities are constructed.

Figure 7. Recommended off-street parking facilities and associated areas of influence.



determined. If given the variables of cost at the origin and destination ends of the trip (parking cost versus value of user's time), the linear program can quite readily and inexpensively correlate the pertinent factors to ascertain the optimum plan for off-street parking. The circumstances where model application is most effectively achieved are where categories of users can be quantified by type and time value. The program will aid site planners to develop a parking plan that is most cost-effective.

DISCUSSION

Edgar Elias Osuna, Instituto de Urbanismo, Universidad Central de Caracas

The subject of the paper appears to be quite interesting in the sense of applying some linear programming techniques, basically of the Hitchcock-Koopmans type, in a field where until now most of the trials of this kind have been unsuccessful.

In effect, for many years these techniques have been used, not quite successfully, in the treatment of problems related to urban flows, urban activity locations, and the like. The reasons for failure may be attributed to the fact that in most cases the optimization of the studied systems has been based on the assumption of an optimum collective behavior. However, what really occurs is an aggregate of individual decisions that are basically independent of each other and that pursue individual benefit or optimality. Obviously this result is not always the optimum for the entire system. The case presented here might not be an exception for this failure unless some provisions are made.

In effect, the formulation of the problem here states that at the optimal solution the expected parking demand from each building should be allocated to a specified set of parking facilities in such a way that total trip and parking supply cost is at a minimum. Once this solution has been found, the cost of parking supply is fixed (defined by the resulting facilities plan), while trip costs of parkers is a variable function of the allocation pattern resulting from parkers' decisions. If the solution is kept optimal, this pattern should be its resulting set of f(i, j), which would be the same set as the one obtained with a Hitchcock-Koopmans problem where the a(i) and b(j) were the supply and demand sources as given by the facilities development plan and the university buildings and the c(i, j) were as defined in the previous equations of the paper, except that parking supply cost would not be included this time.

As stated at the beginning of this discussion, however, every parker will try to maximize his own benefit, and the resulting allocation pattern will not be the required optimum unless some special control policies are used. A very important feature of the paper is that this can certainly be done in this case. In effect, here we can state "parking policies" that will require or encourage parkers to behave so that the desired optimum for the system is achieved. We can, for example, assign restrictive parking permits in the following way.

Let D_i^k be the parking demand of K-category (faculty, staff, or student) generated by building i and $f^k(i, j)$ be the number that should be allocated to facility j for the optimality condition. In a first approximation, we should assign to the D_i^k parkers only $f^k(i, j)$ permits that allow them to park on facility j only.

Obviously this control policy would be highly inconvenient. In the first place, D_i^k is only a fraction of the total population of potential parkers in K-category from building i. It probably represents their expected number at the moment of maximum accumulation.

This implies that the number of parking permits for facility j given to those in K-category from building i should be a number larger than $f^k(i, j)$, and probably proportional to it. Second, under any circumstance, the number of parkers of any type, from any building, at any facility, and during any time of day is a random variable, and the system will surely be designed in such a way that there will be a non-zero probability that a potential parker could find no space to park at his pre-assigned facility, or at any other one, at the time of requiring it.

This points out that permits should not be absolutely restrictive in the sense that they should allow for parking in some other facility (or facilities) in case the assigned one is full. To discourage any particular parker, however, to go for personal reasons to some of those other facilities instead of his assigned one even if that one is not full, a penalty, or differential fare, could be established. An appropiate penalty or differential fare could be determined, for example, on the basis of the expected increase in cost to the system caused by the misallocation of the parker or on the basis of his personal value system or on the basis of both.

In summary, the point I have tried to make in these comments is that the solution (recomended plan) is optimal only as long as parkers behave in a prescribed way, which is not necessarily the best way for them as individuals. The characteristics of the system studied in the example, however, do allow for simple control policies that could guarantee a behavioral pattern expectedly close to optimal.

The author must be congratulated for such an interesting paper, and I hope these comments will contribute at least a small portion to its better understanding and application.

ESTIMATION OF POTENTIAL USE OF PERIPHERAL PARKING FOR LOS ANGELES CBD

Terence W. Austin*, JHK and Associates; and
Michael J. Lee, David Bradwell and Associates

Peripheral parking is one of the proposals currently being examined in Los Angeles in an effort to cater to the growth in automobile traffic destined for the CBD. Major emphasis has been on investigating whether peripheral parking can help to reduce the concentration of automobiles in the CBD and the amount of area devoted to parking. A feature of the proposals is the inclusion of a people-mover system to link peripheral parking facilities with the CBD. This paper describes the major findings of the demand forecasting work carried out for the peripheral parking proposals. It was found that, with suitable headway times on the people-mover system, 10 to 15 percent of all-day parkers could be expected to use peripheral sites.

•THE CENTRAL CITY of Los Angeles is the major activity center of a region that has more than 10 million inhabitants. In addition to providing a diversity of commercial activities, it is the principal location of government, financial, and cultural services. It lies at the center of an extensive regional freeway system and is encircled by a freeway loop that provides 360-deg access to the core area.

Recent economic growth in the central city, fostered by the elimination of the 13-story, 150-ft height restriction on buildings in 1958 and promoted by private enterprise and city government, has resulted in a dynamic and rapidly expanding urban core. The city is beginning a major development program designed to direct the new economic growth into an organized pattern that will provide an attractive environment for residents and workers.

Although plans are now being considered for the possibility of constructing a regional rapid transit system sometime in the future, the private automobile can be expected to remain the principal mode of travel for urban area workers until well into the next decade. A major parking program will thus be required to provide the additional facilities necessary to accommodate the increased parking demands resulting from new CBD development.

If an urban environment is provided that is attractive to workers, residents, and visitors, then the practical limit to which the central city can be structured to accommodate this increased demand for automobiles is being reached. Studies are, therefore, being made of possible ways to reduce the number of vehicles entering the central city and, at the same time, to increase the capacity of the city to accommodate higher volumes of workers, shoppers, and residents. One such proposal, which recognizes the inherent importance of the automobile to Los Angeles residents and yet meets the desired objective of reducing the increasing number of vehicles entering the central city, is to create peripheral parking facilities. An integral part of the proposal is a people-mover system that would be within the CBD and would extend to the peripheral parking areas. The people-mover system would also function to provide intra-CBD mobility and link major transit lines to the CBD. It would operate on its own right-of-way and would be free of conflicts with other traffic. Coordinated with transit in this way, peripheral parking could strengthen the overall transportation system and consolidate the core area of the city.

*Mr. Austin was with Wilbur Smith and Associates when this research was done.

A study of the feasibility of peripheral parking in the Los Angeles CBD was undertaken to answer the following questions:

1. What factors are involved?
2. How many people would use peripheral parking facilities?
3. What level of revenue could be expected?

A particular characteristic of the Los Angeles CBD is that employees account for more then half of the automobile parking demand in downtown. If a significant number of persons who drive their cars to work could be attracted to peripheral parking, peak-hour traffic in the downtown area could be reduced and more efficient use of the downtown area could be realized. The study was thus aimed at estimating the potential diversion of all-day parkers into peripheral parking facilities.

At the same time, it was recognized that parking lots in downtown would continue to serve a large number of parkers, not only those who would park on a short-term basis but also downtown employees who would choose to pay higher prices to park closer to their destinations rather than park in peripheral areas. Hence, it was necessary to determine the conditions under which a sufficient number of CBD employees would be attracted to the peripheral parking system for it to be feasible and achieve the objectives of the overall transportation plan.

THE STUDY AREA

The study area includes the major areas of parking activity in the central city. It is approximately 1.9 miles long by nearly 1.2 miles wide and contains 63 million ft^2 of development. Serving approximately 183,000 employees, the 84,000 parking spaces are used by more than 120,000 parkers a day; the maximum accumulation of parkers reaches almost 64,000. Seven percent of the parking spaces are on-street, and the remainder are in privately owned or operated off-street lots. Figure 1 shows the downtown area and cost contours for all-day parking costs.

The peripheral parking sites evaluated for downtown Los Angeles are shown in Figure 2. Each site is intended to intercept a portion of the traffic destined for downtown. To a person driving on the Hollywood Freeway, for instance, and destined to the downtown area, the Hollywood peripheral facility represents another parking opportunity relative to all others in the downtown area.

Figure 3 shows the basic route alignment of the proposed people-mover system connecting the peripheral sites to the CBD. The alignment and the location of stations were planned to serve the destinations of the greatest number of potential users of the system. It was assumed that the people-mover system would operate at an overall speed of 15 mph.

PARKING ALLOCATION PROCEDURE

Basic to the parking allocation process was the assumption that the peripheral parking opportunities would compete with the other parking opportunities within the CBD. Drivers would be able to choose which facility they used on the basis of walking (or transit riding) time from their ultimate destination and the cost of using the facility. The actual choice of parking facility by the CBD employee involves a trade-off between the parking cost and the time spent between the parking facility and the destination. Some parkers prefer to pay a high parking cost and park very close to their destinations, but others are content to walk or ride some distance in order to pay a low parking cost. Those differences in parking behavior are explained by different values of time.

The parking allocation forecasts in Los Angeles required that the actual characteristics of downtown parkers be identified. That was achieved by conducting surveys at several office buildings and obtaining information that would help to identify parking behavior under different conditions of parking supply and cost. The surveys revealed the parking choices of the employees from each location. Associated parking costs were used to develop the actual trade-offs of parking cost and walking time to the parking facilities. Figure 4 shows the type of frequency distributions developed for parkers destined to 2 of the points surveyed. Those distributions indicate the effect

Figure 1. Parking cost contours in the Los Angeles CBD.

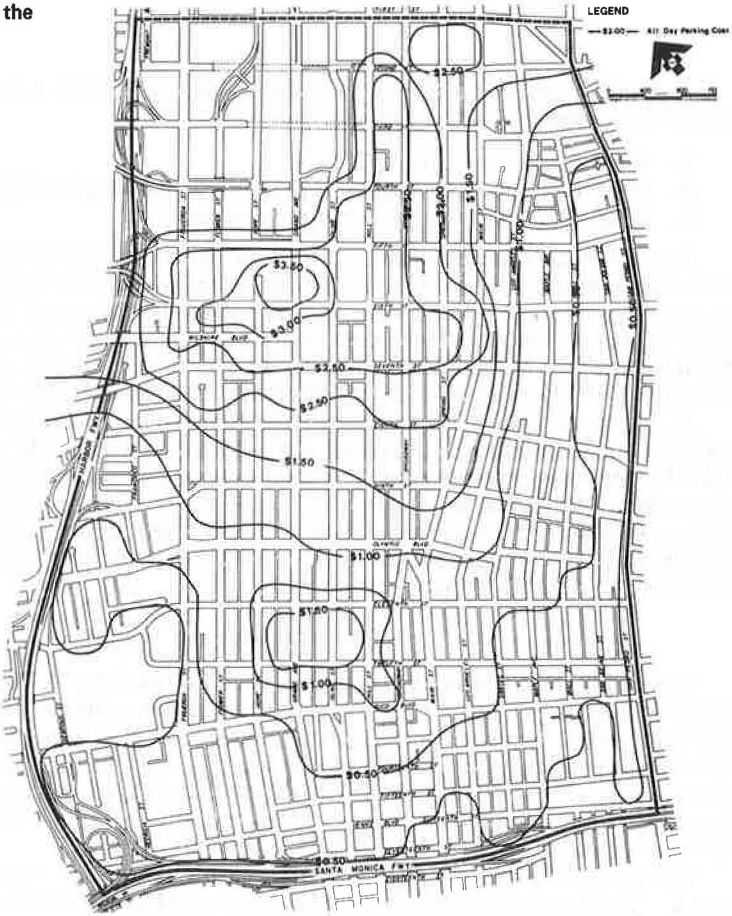


Figure 2. Freeway accessibility and potential peripheral parking locations.

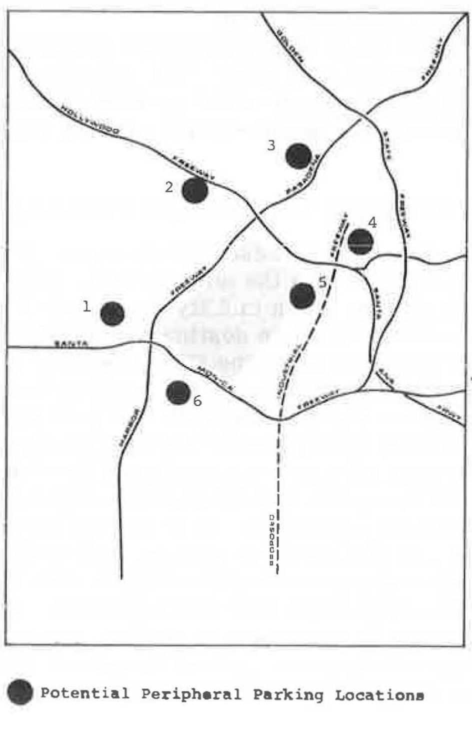


Figure 3. Alignment of proposed people-mover system.

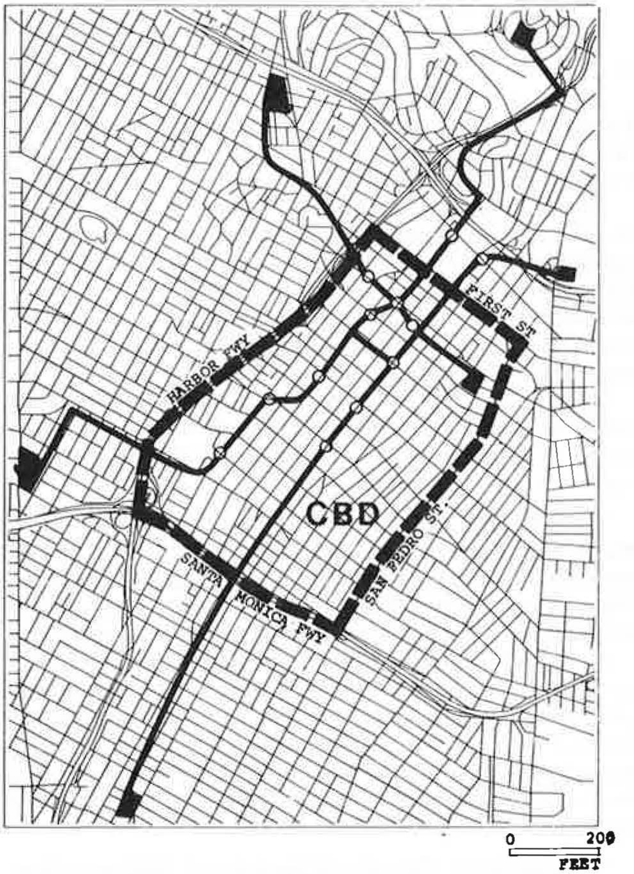
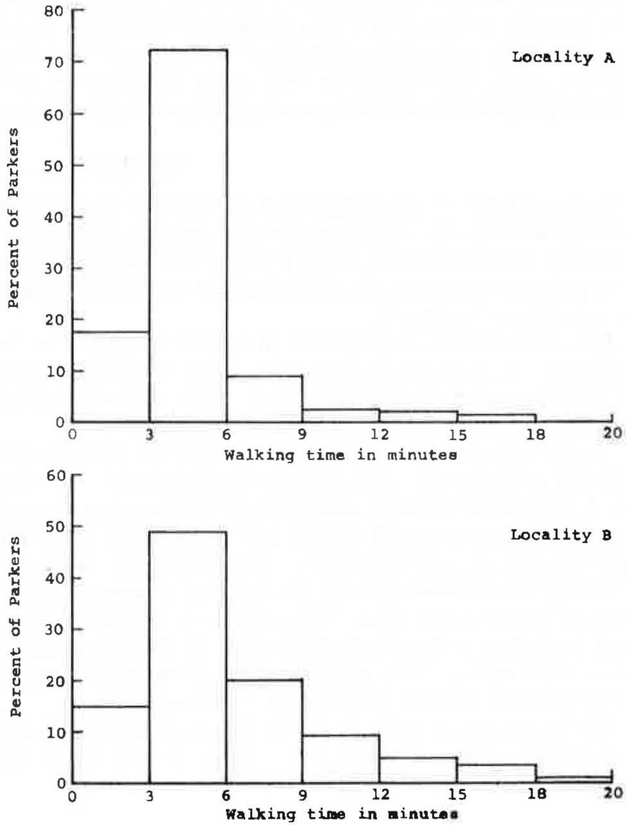


Figure 4. Typical walking-time frequency distribution.



of parking supply and cost conditions on parking behavior. CBD employees destined to locality A tended to park closer to work than employees destined to locality B because of lower parking costs in that area.

Demand estimates for the projection year of 1980 were developed for each block in the CBD. The necessary information was made available through an inventory of development plans and estimates of future employment in each block. Those data constituted the fixed factors in the analysis and were assembled along with the proposed peripheral parking sites, people-mover system, and pedestrian network into a composite picture of the Los Angeles CBD. Total 1980 daily parking demand for CBD employees was estimated to be 90,000.

Downtown parking costs and the service level of the peripheral parking and people-mover system were the variables in the analysis that needed to be tested for their effect on the feasibility of the proposed peripheral parking system. The following assumptions were tested:

1. Parking cost—The CBD was divided into different areas, based on estimated future employment densities, and 3 levels of parking cost conditions were developed, based on the current situation. Figure 5 shows the areas and sets of conditions tested. The cost of peripheral parking was assumed to be $1.25 in all cases, and that amount included the round trip to the CBD on the people-mover system.
2. Service level of people-mover system—From the viewpoint of the parker, the perceived time would consist of the time necessary to park and board the people-mover system plus the actual travel time on the system. Depending on the design of the system and the frequency of service, it was determined that the transfer time could vary as much as 15 min. That range was, therefore, tested in the analysis. Allowance for the reduced automobile travel time was also made by deducting this from the system travel time.

To determine the use of peripheral parking sites, a special procedure was used that distributed parkers among all the various available facilities. That allocation procedure based the distribution of parking demand on the observed behavior of CBD employees with respect to their trade-offs between parking cost and distance from place of work. The peripheral parking facilities were introduced as additional parking opportunities, and, depending on their cost and time-distance to each block in the CBD, a certain proportion of drivers were shown to be attracted to them.

RESULTS

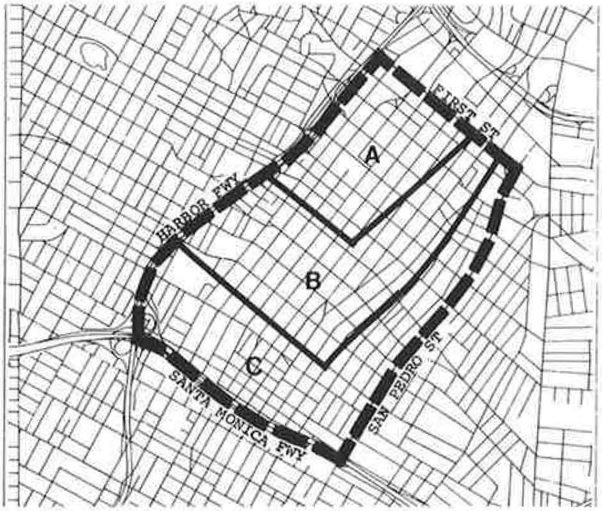
Several runs of the allocation procedure were made, and the results were used to develop sensitivity relations for the peripheral parking facilities. Curves were developed that related the service level of the peripheral parking system and the level of CBD parking costs to the diversion of parkers to peripheral parking. These curves are shown in Figure 6.

The service level measure is shown in terms of the transfer time at the peripheral facilities. For a delay of 4 min, a level could be obtained of 10,400 daily users with the parking costs in the CBD equivalent to cost condition II and 13,000 daily users with costs equivalent to cost condition III.

A summary of the parking patronage by site for the 3 CBD parking cost conditions is given in Table 1. The figures in this table are based on a 4-min transfer delay time. The main factor contributing to the differences in estimated usage among peripheral sites is the travel time from each peripheral site via the people-mover system to the high-density area in the CBD. The influence of that factor is most pronounced in the patronage estimates for the Hollywood Freeway site. That site is ideally situated with respect to the core area, where potential peripheral parkers are destined. The Hollywood Freeway site is less than 10 min via the people-mover system to most destinations in the core area. The effect of that proximity is to attract a considerably higher number of parkers to the Hollywood Freeway site.

The central component of the ultimate peripheral parking system is the network of the transit system in the CBD. If there is a basic transit network in the CBD, the

Figure 5. Parking-cost test conditions.



ASSUMPTIONS	AREA A	AREA B	AREA C
Cost Condition I	Current Costs*	Current Costs	Current Costs
Cost Condition II	50% increase	50% increase	25% increase
Cost Condition III	100% increase	75% increase	25% increase

* amended to account for new developments presently under construction

Figure 6. Total peripheral parking facility use.

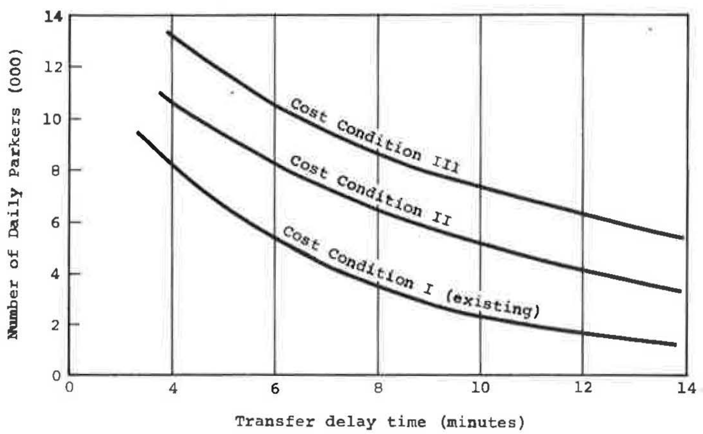


Table 1. Estimated daily parkers at peripheral parking sites.

Site Number	Location	Cost Condition I	Cost Condition II	Cost Condition III
1	Santa Monica Freeway	650	1,050	1,600
2	Hollywood Freeway	2,700	4,200	4,500
3	Pasadena Freeway (Dodger Stadium)	1,100	1,750	2,200
4	San Bernardino Freeway	650	1,100	1,100
5	Fourth and Los Angeles St.	825	1,350	2,200
6	Washington and Broadway	575	950	1,500
Total		6,500	10,400	13,100

Note: Avg all-day parking costs are $1.60 for cost condition I, $2.25 for cost condition II, and $2.90 for cost condition III.

individual peripheral sites can be added independently. The recommended program for Los Angeles involved several development phases and stressed the advisability of implementing those sites, such as the Hollywood Freeway site, that would serve the most parking demands.

CONCLUSIONS

The projected patronage at all peripheral parking sites would be a significant portion of the 90,000 daily parking demands by CBD employees estimated for 1980. With suitable parking cost policies, 10 to 15 percent of the needed parking supply could be successfully provided at the periphery. That represents a significant amount of land area that would otherwise be devoted to automobile parking in the CBD. In addition to relieving the congestion within the CBD, a successful peripheral parking system could allow greater flexibility in development plans; there would be no need to plan so extensively for automobile circulation and parking. The evaluation in this study does, however, indicate the importance of the system design—peripheral parking locations and connected transit system—and of parking policy in the achievement of this objective.

ACKNOWLEDGMENTS

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