118-134

DEVELOPMENT OF A DOWNTOWN PARKING MODEL

Gökmen Ergün*, Turkish Highway Department, Ankara

Provision of adequate downtown parking is a serious problem facing most urban areas. In this study, probabilistic models have been built to explain the behavior of people in choosing among parking places. The effects on parking choices of parking system characteristics and socioeconomic factors have been investigated. The analytical tool used was logit analysis. In the study, implications were drawn and an example worked out for an application of the models. Methods were devised for finding the value of time saved walking from parking place to destination. The methods were applied to data, and values of time were established that are suitable for cost-benefit analysis of downtown parking facility investments. The behavioral models developed can be used to investigate expected parking costs and parking cost changes, and it is possible to assign persons to different parking distances from destinations.

THE ANALYSIS of downtown parking behavior investigates what determines where people park. The basic trade-offs involved are essentially those of choosing between parking closer to destinations at higher money cost and lower walking time and parking farther away at lower cost but with a longer walk. From the analysis of actual parking decisions made, it is possible both to predict what persons would do given alternative future situations and to infer traveler values associated with choosing between walking farther and paying more. These predictions and values can then be used in planning and evaluating parking projects and policies.

Some of the particular questions that the analysis of downtown parking behavior can be helpful in answering are as follows:

1. What are the effects of changes in parking price policy? As prices change, how do drivers correspondingly change where they park?
2. Given the costs, what are the benefits of investments in new parking facilities? Where should parking be located to best serve needs? What kind of parking facilities should be provided? What should parking fees be?

In this study, an analysis of downtown parking behavior has been made in which a number of probabilistic models were built to help explain traveler choices among parking places. Explanatory variables investigated included system characteristics (e.g., parking cost and parking distance), socioeconomic factors (e.g., income, age, and sex), and trip purpose (work and nonwork). The analytical tool used was logit analysis.

In the study, implications have been drawn and some examples worked out for applications of the models. Methods were devised for finding the value of time saved walking from parking place to destination. The methods were applied to data, and values of time were established that are suitable for cost-benefit analysis of downtown parking facility investments. The behavioral models developed can be used to find expected parking costs and parking times to investigate the effects of parking cost changes, and to assign persons to different parking distances from destinations.

For development of the models, data collected for the Northwest Chicago Corridor Modal-Split Project were used (6). These statistics include data on 226 downtown

---

*Mr. Ergün was with the Chicago Area Transportation Study when this research was performed.

Sponsored by Task Force on Value of Travel Time.

automobile trips and information on socioeconomic factors, alternative parking costs, downtown destinations, and trip purposes. The trips from which these data were derived originated in 2 areas of the northwest Chicago travel corridor. The first area is suburban Park Ridge and a small portion of northwest Chicago. The second combines the contiguous suburbs of Arlington Heights and Rolling Meadows.

Of the total sample of 226 downtown automobile trips, 41 involved company-paid drivers, 7 involved riders, and 13 had unreasonable or miscoded information.

For analysis purposes, data for only 165 individuals were used after data involving company-paid drivers, riders, and unreasonable or miscoded samples were eliminated. Of the net sample of 165 individuals making trips, 113 involved work trips, and 52 involved nonwork trips. The data analyzed included both persons who drove by choice (i.e., who could have taken the train) and those who needed to drive.

STATISTICAL METHOD

Although both probit (2, 5, 9) and logit (8, 10) methods were suitable for the statistical analysis, logit analysis was used. To understand the logit method as it relates to the parking problem, assume that the objective is to build a model that finds the probability, p, that a driver will choose to park at a given distance from his destination. Assume also that $X_1, X_2, \ldots X_n$ are the variables influencing the choice. Then, in a very simple form, it can be hypothesized that

$$p = a_0 + a_1X_1 + a_2X_2 + \ldots a_nX_n \tag{1}$$

But this form is inappropriate because it can take values between $-\infty$ and $+\infty$, whereas probability p is constrained to values between 0 and 1. This can be avoided by using another functional form:

$$\frac{p}{1-p} = e^{a_0} X_1^{a_1} X_2^{a_2} \ldots \tag{2}$$

Note that as $p \to 0$, and as $1 - p \to 1$, $p/(1 - p) \to \infty$. Taking the logs of both sides, we get

$$\text{Log}\left(\frac{p}{1-p}\right) = a_0 + a_1 \log X_1 + a_2 \log X_2 \ldots \tag{3}$$

Also note that for the different values of $p/(1 - p)$, $\log p/(1 - p)$ varies between $-\infty$ and $+\infty$ and is a monotonically increasing function of the probability p. The expression $\log p/(1 - p)$ is known as the logit of the probability p.

If the right side of Eq. 2 is replaced by a function G(X), it becomes

$$\text{Log}\left(\frac{p}{1-p}\right) = G(X) \tag{4}$$

hence,

$$\frac{p}{1-p} = e^{G(X)} \tag{5}$$

and

$$p = \frac{e^{G(X)}}{1 + e^{G(X)}} \tag{6}$$

This expression yields a sigmoid (or S) curve that is symmetrical and is similar to the cumulative normal curve, diverging from it at the extremes only (Fig. 1). The coefficients of Eq. 3 can be found by maximum likelihood estimation (8).

PROBLEM FORMULATION

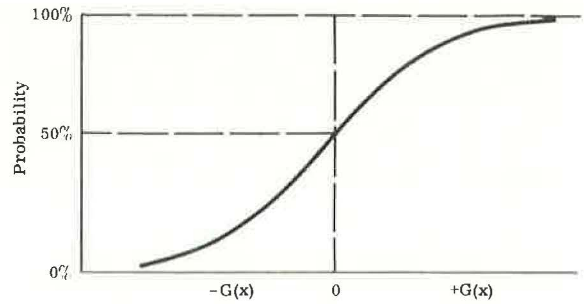

Figure 1. Sigmoid curve.

The basic analytical assumption used in this study was that a person will always choose the parking location that best satisfies his needs and desires. He evaluates parking locations on the basis of parking fee, distance of the parking from his destination, and slope of the parking cost profile. Trip purpose is also relevant.

Based on the preceding assumption, the approach used was to consider parking separately for each block distance and to find the probabilities of using such parking for each individual. When there were multiple parking places within a block, the cheapest one was considered. In other words, a binary-choice model was built for each parking distance, the choices being to use or not to use parking at the distance under consideration. This approach may be a good simulation of the real choice procedure. It seems reasonable to assume that an individual first considers the nearest parking location, and, if it is convenient from his point of view and compares favorably with other choices, he will use it. If not, he will go to the next nearest location and value it. This process will continue until he finds the location that has the greatest value to him.

In the analysis of choices made, 2 types of possible explanatory variables were investigated. The first type that represented system characteristics included parking cost, parking distance, slope of the parking cost profile, and number of parking hours. The second type of explanatory variable investigated was socioeconomic characteristics of the individual choosing parking. Characteristics analyzed were income, age, and sex. Analysis was conducted separately for work and nonwork trips.

Each of the variables considered in the analysis and the way individual variables were handled are discussed in the following sections.

Parking Cost

Parking cost is perhaps the most obvious variable to investigate. As the parking cost increases at a certain location, one would expect that it becomes less likely for persons to park there. Presumably, if the parking cost is high enough, people will prefer to walk a longer distance rather than to pay a higher price to park.

Parking Distance

The distance variable may be expected to have a negative effect on the choice in the sense that, as distance from a parking location to destination increases, it becomes less likely for people to park there. This variable was taken into account by building a separate logit model for each distance interval. Through so doing, the effect of distance was reflected in the constant terms of the logit functions.

Slope of Parking Cost Profile

The variable of the cost-profile slope represents the effect of parking cost differences on people's choices. To see this more clearly, consider the 2 parking cost profiles given as follows:

	Block				
Profile	First	Second	Third	Fourth	Fifth
1	\$2.50	\$2.45	\$2.40	\$2.40	\$2.35
2	\$3.75	\$3.00	\$2.00	\$1.00	\$0.25

In the first profile, the parker must walk 5 blocks to save 15 cents. In the second, if he walks 5 blocks, he will save $3.50. Naturally, if the saving is small compared to the parking cost (as in the first example) and is also small with respect to the individual's value of time, it is reasonable to expect that he will not walk very far. However, if he can save considerable amounts (as in the second example), presumably he will walk farther. In the final models of the analysis, the slope of the parking cost profile was taken as the parking cost difference between the distance of the first and third blocks.

Duration of Parking

It may be expected that, when duration of parking is shorter, people will park closer to their destinations (e.g., when making short business calls, keeping appointments, and so forth).

Income

With higher incomes, people may become more indifferent to parking costs. Dummy variables were used for income.

Age

Older people may be expected to walk shorter distances; walking may become very inconvenient for the elderly.

Sex

It may be that females walk less than males and respond differently when choosing parking locations. This variable was also a dummy.

Other Factors

In the analysis, parking lot capacity was not considered because it should have little effect on the choice process. The reason for this is that market prices will arrange themselves so that parking lots will be almost full without exceeding their capacities. If the capacity is exceeded or if the demand increases, then by the basic rules of economics prices will rise. This creates a balance, and capacities are not exceeded. Public parking facilities are sometimes underpriced and, therefore, they become congested. In general, however, their role in the overall structure of prices is not very important. Furthermore, the congestion itself has the effect of making the price higher. In the data set analyzed in this study, underpricing of public parking facilities was not an important factor.

Model Input

An example of the actual input to the analytical models developed is shown in Figure 2. It should be noted that the choice variable shown in Figure 2 (which is the dependent variable in the logit models) is one for the distance at which parking is accepted and for all greater distances. For shorter distances, it is 0. The models therefore give cumulative probabilities. Clearly, in the longest distance category, all

Individual Number	Actual Walking Time(sec.)	Actual Parking Cost(in cents)	Cheapest Parking Cost at Block						No. of Park. Hrs.	Age	Sex 0 = Male 1 = Female	Choice at the Block 1 = taken 0 = not taken						Income Group Dummy Variables			
			≤1	>1 ≤2	>2 ≤3	>3 ≤4	>4 ≤6	>6 ≤8				1	2	3	4	6	8	3	4	5	6
XXXX	350	175	325	275	225	175	125	50	8.0	40	0	0	0	1	1	1	1	0	0	1	0

Figure 2. Form of data input.

individuals have a choice variable of one. This indicates that all have accepted parking at or before that distance. The logit function is of the following form:

$$
\begin{aligned}
G(X)_{i^{th}\,block} = {} & a_0 + a_1 \text{ (parking cost at } i^{th} \text{ block)} \\
& + a_2 \text{ (slope of the parking cost profile)} + a_3 \text{ (age)} \\
& + a_4 \text{ (sex)} + \sum_{i=5}^{8} a_i \text{ (income dummies)} + a_9 \text{ (number of parking hours)}
\end{aligned}
$$

PARKING BEHAVIOR OVERVIEW

An initial picture of downtown parking behavior can most readily be gained by viewing a map showing parking costs, trip destinations, and actual parking places chosen. Figure 3 shows parking isocost lines in downtown Chicago derived from actual parking rates charged at the time of the northwest corridor travel survey. The map also shows the trip destinations of all the sampled persons who drove to downtown Chicago. For persons who walked a block or more from parking to their destinations, arrows extend from the trip destinations to the parking locations.

For those people who did walk, there was a definite pattern of parking and walking from lower parking cost areas to higher cost destinations. There is no obvious difference in distances walked from 1 part of downtown to another. The proportion of persons choosing to walk is higher where parking is expensive.

ANALYSIS OF WORK TRIPS

The general patterns of parking behavior shown in Figure 3 can be broken down in various ways and shown more precisely in tabular and graphical form. For work trips, Table 1 gives the number of drivers by distance of chosen parking from the trip destination. The majority of drivers (61.1 percent) park within 1 block of their destinations. The remaining 38.9 percent are spread throughout the remaining distances, the percentage of people parking at successively greater distances decreasing approximately linearly. The maximum distance for work trips is 6 blocks; in the sampled population nobody walked farther.

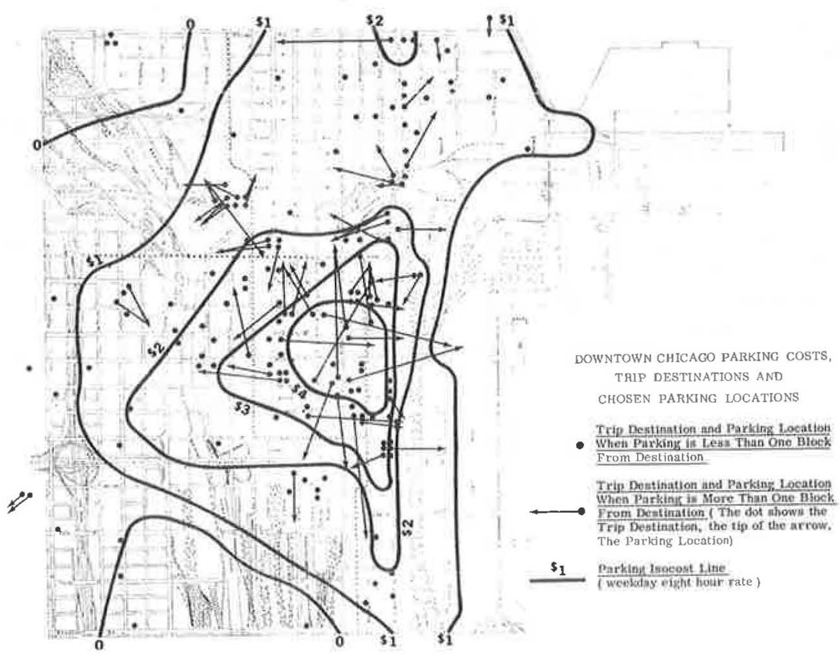

Figure 3. Locations in downtown Chicago of parking costs, trip destinations, and chosen parking locations.

TABLE 1

DISTRIBUTION OF PEOPLE AMONG PARKING PLACES FOR WORK TRIPS

Distance (1/2-mile blocks)	Drivers		
	Number	Percent	Cumulative Percent
> 0 and ≤ 1	69	61.1	61.1
> 1 and ≤ 2	17	15.0	76.1
> 2 and ≤ 3	14	12.4	88.5
> 3 and ≤ 4	8	7.0	95.5
> 4 and ≤ 6	5	4.5	100.0
> 6 and ≤ 8	0	0	
Total	113	100.0	

Parking costs, average parking costs, and average walking time are given in Table 2. There was only 1 person from the $5,000-to-7,999 income group who drove downtown, and thus data from this group are not included in Table 2. The threshold income group is therefore the $8,000-to-11,999 group. Average parking cost for this group is very low (68 cents), implying that people in this income range will not park downtown unless they can do so at low cost. The average cost of the next group ($12,000 to 16,999) is almost twice ($1.30) that of the preceding group. Subsequently, there is a small increase in the average costs paid by higher income groups. As overall averages, drivers walk 1.34 (1/12-mile) blocks and pay $1.34.

Relationships between walking time and other variables are shown by scatter diagrams. There was no observable relationship between the dependent variable (walking time) and variables of income and age. The scatter diagrams for first parking cost and parking cost difference are shown in Figures 4 and 5. Although variances are quite wide, there is, as expected, a relationship between these variables and walking time. Figure 4 shows that walking time increases with increasing parking cost in the first block, and Figure 5 shows that walking time increases with greater parking cost differences.

There were only 5 females among the 113 drivers in the sample. Because this variable could not be significant in the model, it was dropped.

ANALYSIS OF NONWORK TRIPS

As seen from data given in Table 3, a considerable portion of drivers making nonwork trips (42.3 percent) also park within 1 block. Unlike drivers on work trips, however, some drivers in this group park more than 6 blocks from their destinations (7.7 percent.

Of 52 nonwork drivers, 31 are male and 21 are female. On the average, males walk 229 sec and females walk 205 sec, with the overall average being 219 sec. This is substantially different from average walking time for work trips (134 sec) and corresponds approximately to 2.2 blocks.

The parking costs for different income groups are given in Table 4. Contrary to work trips, there are drivers in the lower income groups who make nonwork trips. The overall average cost paid ($1.38) is approximately equal to that of work trips ($1.34).

Similar scatter diagrams (walking time versus various other variables) were drawn for nonwork trips as for work trips. There were, however, no observable relationships

TABLE 2

PARKING COSTS BY INCOME GROUP FOR WORK TRIPS

Parking Cost[a]	Drivers										
	Income Group										
	$8,000 to 11,999		$12,000 to 16,999		$17,000 to 24,999		$25,000		Number	Percent	Cumulative Percent
	No.	Percent	No.	Percent	No.	Percent	No.	Percent			
$0.00 to 0.49	7	41.1	5	12.2	2	5.1	0	0.0	14	12.5	12.5
$0.50 to 0.99	2	11.8	4	12.2	2	5.1	3	20.0	12	10.7	23.2
$1.00 to 1.49	4	23.5	11	14.9	9	23.1	0	0.0	24	21.4	44.6
$1.50 to 1.99	4	23.5	14	33.2	15	38.5	6	40.0	39	34.8	79.4
$2.00 to 2.49	-	-	2	4.9	7	17.9	3	20.0	12	10.7	90.1
$2.50 to 2.99	-	-	2	4.9	3	7.7	3	20.0	8	7.2	97.3
Over $3.00	-	-	2	4.9	1	2.6	0	0.0	3	2.7	100.0
Total	17	15.2	41	36.6	39	34.8	15	13.4	112	100.0	
Avg parking cost, dollars	0.68		1.30		1.55		1.70		1.34		
Avg walking time, sec	128		120		155		128		134		

[a]Excluding company-paid trips.

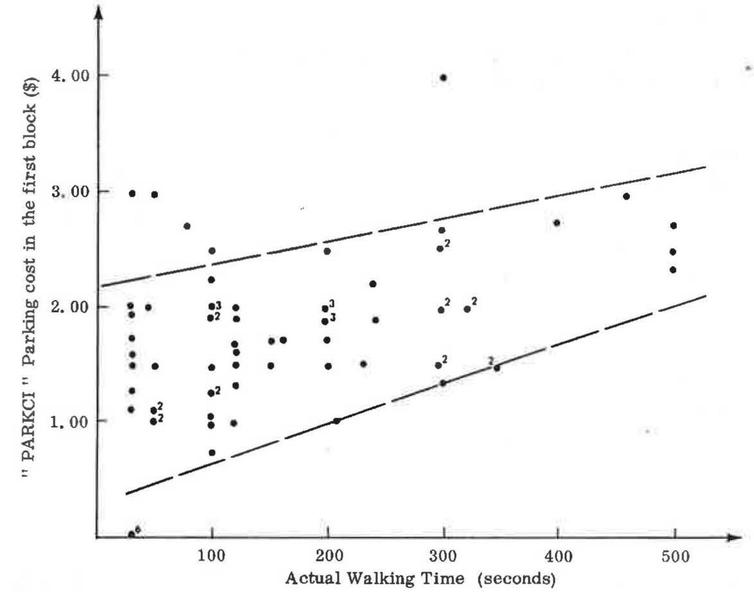

Figure 4. Walking time versus parking cost in first block.

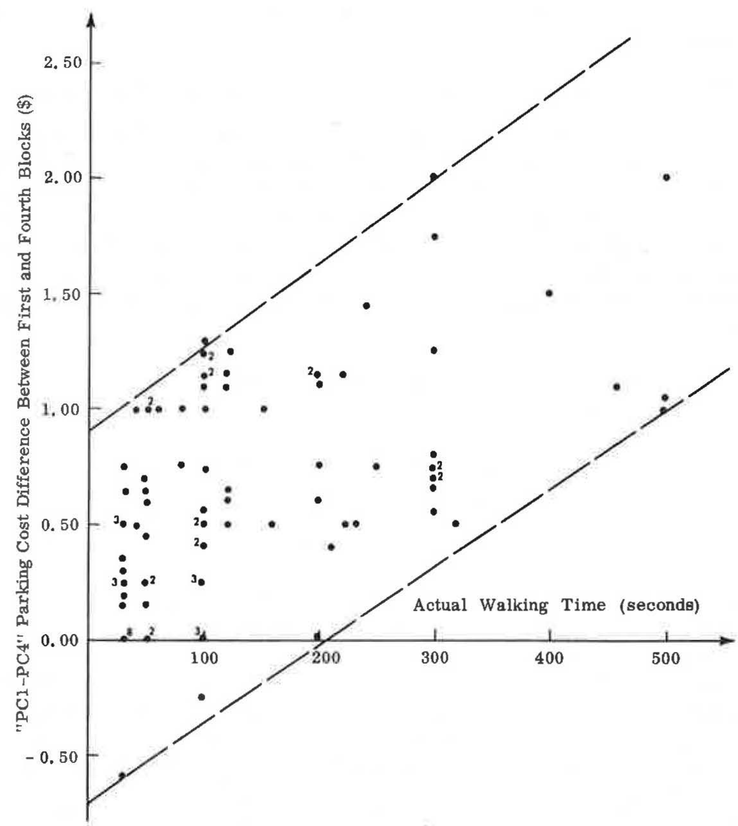

Figure 5. Walking time versus parking cost difference.

TABLE 3

DISTRIBUTION OF PEOPLE AMONG PARKING PLACES FOR NONWORK TRIPS

Distance (1/2-mile blocks)	Drivers		
	Number	Percent	Cumulative Percent
>0 and ≤ 1	22	42.3	42.3
>1 and ≤ 2	12	23.0	65.3
>2 and ≤ 3	8	15.4	80.7
>3 and ≤ 4	3	5.8	86.5
>4 and ≤ 6	3	5.8	92.3
>6 and ≤ 8	4	7.7	100.0
Total	52	100.0	

between the variables. Seemingly, people making nonwork trips walk longer distances while paying similar amounts, but their choices do not fall into patterns as clear as those observed in work trips. This may be because the knowledge of nonworkers about parking availability and costs is limited.

Because of these factors, the small sample size (52), and the very random nature of the scatter diagrams, none of the variables might have been expected to be significant in logit regression models. In spite of this, some logit models were tried. The results were insignificant.

CALIBRATION OF LOGIT MODELS FOR WORK TRIPS

As stated previously, a model for each distance was built. However, because in the work trip sample all persons had accepted a parking place by the sixth block, all of the choice variables were one for the distance between the fourth and sixth blocks. Therefore, only 4 models were built for the first 4 distances: one each for ≤ 1 block, for ≤ 2 blocks, for ≤ 3 blocks, and for ≤ 4 blocks. Because these models give the cumulative probabilities (i.e., the choice variable was coded as 1 for the distance at which parking was accepted and for all greater distances), the individual probabilities are as follows:

$$
\begin{aligned}
P(4 < X < 6) &= 1 - P(X \leq 4) \\
P(3 < X \leq 4) &= P(X \leq 4) - P(X \leq 3) \\
P(2 < X \leq 3) &= P(X \leq 3) - P(X \leq 2) \\
P(1 < X \leq 2) &= P(X \leq 2) - P(X \leq 1) \\
P(X \leq 1) &= P(X \leq 1)
\end{aligned}
$$

where $P(i < X \leq j)$ is the probability of parking at less than or equal to j blocks and more than i blocks. Hence, although there were 4 models, the $P(4 < X \leq 6)$ could also be found as given previously.

The models and associated statistics are given in Table 5. Successful work-trip models were developed for all distances up to 4 blocks from the destination. In all of the models, parking cost, parking cost difference, and distance affected the behavior of individuals in determining their likelihood of choosing a parking location. Also, in all models, the independent variable coefficients had the right sign and were of reasonable magnitudes. In all cases, the higher the parking cost was, the smaller the

TABLE 4

PARKING COSTS BY INCOME GROUP FOR NONWORK TRIPS

Parking Cost[a]	Drivers														
	Income Group												Number	Percent	Cumulative Percent
	$5,000		$5,000 to 7,999		$8,000 to 11,999		$12,000 to 16,999		$17,000 to 24,999		$25,000				
	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent			
$0.00 to 0.49	-	-	-	-	-	-	-	-	1	6.3	1	12.5	2	3.8	3.8
$0.50 to 0.99	-	-	1	33.3	2	18.2	4	33.3	4	25.0	1	12.5	12	23.1	26.9
$1.00 to 1.49	1	50	2	67.7	2	18.2	4	33.3	5	31.2	3	37.5	17	32.7	59.6
$1.50 to 1.99	1	50	-	-	6	54.5	-	-	2	12.5	1	12.5	10	19.2	78.8
$2.00 to 2.49	-	-	-	-	1	9.1	4	33.3	2	12.5	1	12.5	8	15.4	94.2
$2.50 to 2.99	-	-	-	-	-	-	-	-	-	-	-	-	0	0.0	94.2
$3.00 +	-	-	-	-	-	-	-	-	2	12.5	1	12.5	3	5.8	100.0
Total	2	3.8	3	5.8	11	21.1	12	23.1	16	30.8	8	15.4	52	100.0	
Avg parking cost, dollars	1.37		1.03		1.35		1.28		1.51		1.43		1.38		
Avg walking time, sec	140		420		172		227		186		280		219		

[a]Excluding company-paid trips.

TABLE 5

SUMMARY OF LOGIT MODELS FOR WORK TRIPS

Model	Variable	Estimate	Standard Error	t-Ratio	Likelihood Ratio[a]	Pseudo R^2
1 block	PARKC1	-0.00745	0.00385	1.93	25.76	0.276
	PC1-PC3	-0.01526	0.00672	2.26		
	CONSTANT	2.2571	0.55919	4.03		
2 blocks	PARKC2	-0.01099	0.004156	2.64	23.82	0.285
	PC1-PC3	-0.01444	0.005654	2.55		
	CONSTANT	3.4553	0.69	5.00		
3 blocks	PARKC3	-0.01504	0.00549	2.74	10.13	0.168
	PC1-PC3	-0.00943	0.00552	1.71		
	CONSTANT	4.3893	0.94553	4.64		
4 blocks	PARKC4	-0.01519	0.00872	1.71	6.451	0.182
	PCI-PC3	-0.01454	0.00733	1.98		
	CONSTANT	5.5711	1.3202	4.22		
6 blocks[b]						

[a]With 2 degrees of freedom.
[b]No model was built since P (X 6) = 1.

probability was of an individual choosing to park at the given distance. Similarly, the greater the parking cost difference was between the first and third block, the more likely people were to walk farther. Third, the simple effect of distance, as seen in the constant term, was that the greater the distance was, the less likely people were to walk that distance.

In addition, the sensitivity of the models to the parking cost and parking cost difference variables decreases as the distance increases (Table 5). A large portion of the probability is derived from the constant term. When other variables are 0, the constants give a probability of 0.9053 for the first model, 0.9694 for the second, 0.9878 for the third, and 0.9916 for the fourth. This makes sense because, when parking costs are 0, people can be expected not to walk. It is also seen that the first 2 models are more sensitive to parking cost differences than to parking costs. The sensitivity to these variables becomes approximately equal in the third and fourth models.

A number of tests were conducted to assess the statistical validity of the models. The results of several of the tests are given in Table 5. A brief discussion of each of the tests and their results are included in the following sections.

t-Test

The t-test is a test for significance of the coefficients. As seen from data given in Table 5, all coefficients are significant at the 0.10 level because all of the t-ratios are greater than the table values.

Likelihood-Ratio Test

To test for significance of the logit G(X) function, the likelihood ratio test was performed. This test works by proposing a null hypothesis that the probability, p_i, of an individual accepting parking at a given location is independent of the value of the parameters in the G(X) function. If this is true, the coefficients are 0. It can be shown that 2 times the log of the probability is approximately distributed as a χ^2 distribution with as many degrees of freedom as the number of variables in the equation (3). The value of χ^2 for 2 degrees of freedom (number of variables in the equation) at 0.05 level is 5.991. Because all the likelihood ratios are greater than this value, the relationships are significant at 0.05 level.

Pseudo-R^2 Test

The pseudo-R^2 test was developed mainly for discriminant analysis with a regression analogy. This measure tends to understate the effectiveness of the technique. The various statistics given in Table 5 give an overall and relative notion about the comparative efficacy of the 4 models.

APPLICATION OF THE FINAL MODEL: EFFECTS OF CHANGES IN PARKING PRICE POLICY

The effects of a particular type of change in downtown parking pricing policy were observed by changing all of the parking prices by given factors and by calculating the resultant expected proportions of persons parking at different locations, average expected costs, and average expected walking times. Table 6 gives the relevant statistics.

The percentages of people accepting the parking place and parking cost change factors were used to draw Figure 6. From the curves shown in Figure 6, the distribution of people at different locations, with a given parking price policy, can easily be found by drawing a vertical line at the desired factor and reading the percentages from the intersection of this vertical and the curves.

It is interesting to note that, if the original parking costs were to be increased proportionately about 1.5 times, 45 percent of the people would park in the first block and the remainder would be almost evenly distributed among the other block distances, as shown in Figure 6.

VALUE OF WALKING TIME FROM PARKING PLACE TO FINAL DOWNTOWN DESTINATION

Value of time may be expressed as an amount of money per unit of time (dollars/hour or cents/minute). As long as people can save at a rate greater than their value of time, they will walk from parking to destination; if they cannot, they will prefer not to walk. Thus, when the rate of savings becomes more or less equal to the value of time, people become indifferent to walking. Some will walk whereas others will not, the split presumably being 50:50. Based on the concept of indifference, a method was used for finding the value of walking time.

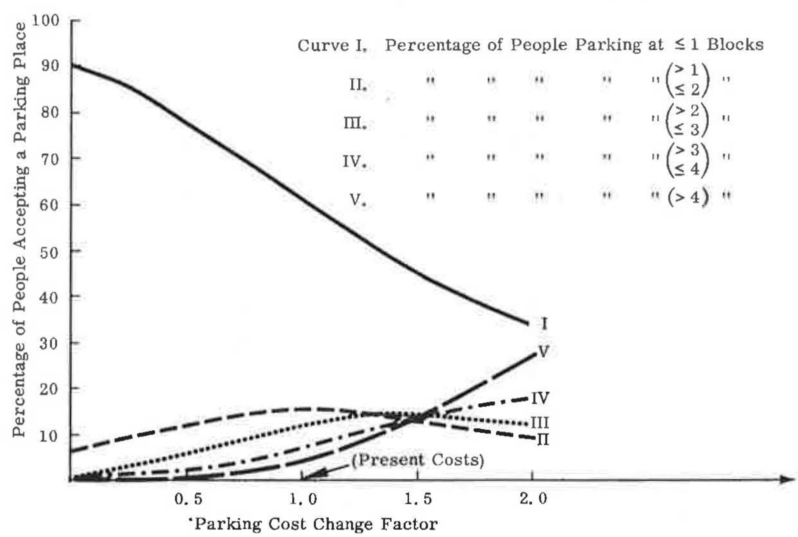

Figure 6. Effects of proportional changes in parking costs on distribution of people parking at different distances from destinations.

TABLE 6

EFFECTS OF CHANGES IN PARKING PRICE POLICY: WORK TRIPS

Parking Cost Change Factor	Average Expected Cost	Average Expected Walking Time	Expected Number of People at Blocks									
			1		1 and 2		2 and 3		3 and 4		4	
			No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent
0.0	0.0	64.3	102.3	90.5	7.3	6.4	2.1	1.8	1.0	0.8	0.4	0.4
0.3	41.80	74.61	95.5	84.5	11.0	9.7	3.9	3.5	1.8	1.6	0.8	0.7
0.5	67.39	85.81	88.9	78.6	13.8	12.2	6.22	5.5	2.77	2.4	1.3	1.2
0.8	100.93	110.36	76.9	68.1	16.6	14.7	11.1	9.8	5.4	4.8	2.96	2.6
1.0[a]	119.2	131	69	61.1	17	15.0	14	12.4	8	7.1	5	4.4
1.1	126.7	141.6	65.7	58.1	16.8	14.8	14.7	13.0	9.5	8.4	6.4	5.7
1.3	141.4	166.9	58.0	51.3	15.9	14.1	16.3	14.4	12.7	11.2	10.1	9.0
1.5	153.15	190.94	52.3	46.3	14.5	12.8	15.9	14.1	15.5	13.7	14.8	13.1
1.7	163.76	216.54	46.8	41.4	12.9	11.4	15.2	13.5	17.7	15.7	20.4	18.1
2.0	177.33	255.91	39.1	34.6	10.1	8.9	14.1	12.5	19.3	17.1	30.3	26.8

[a]Present.

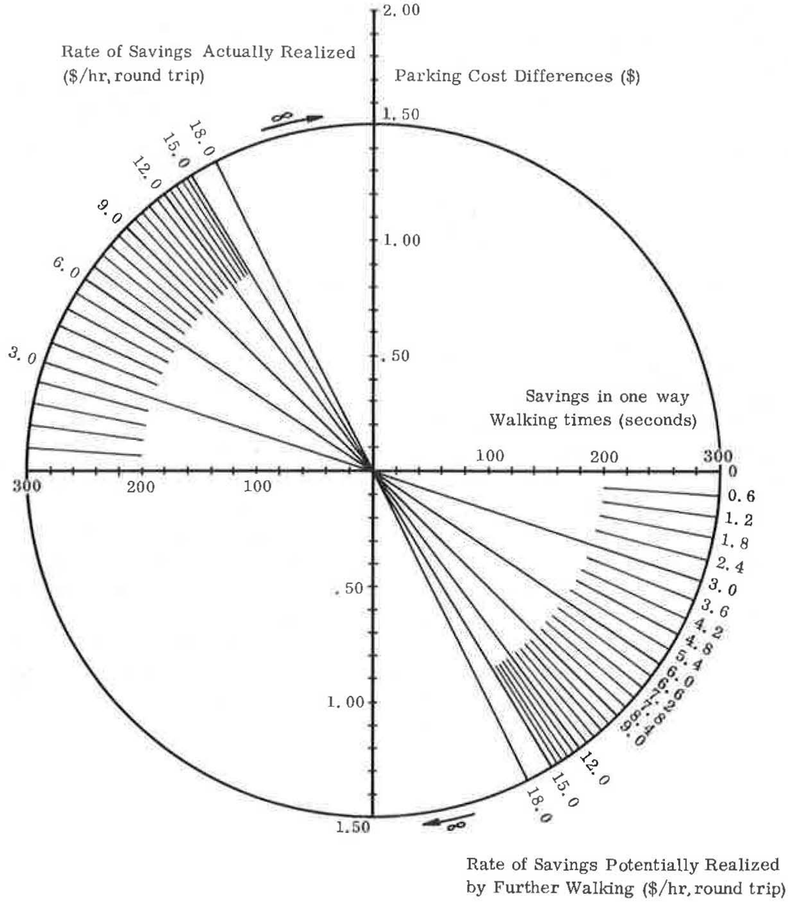

Figure 7. Walking time value indifference circle.

The tool used for finding the value of walking time is a circle, called a walking time value indifference circle, as shown in Figure 7 (11). When a person prefers not to walk to save time (even though he could save money by walking), a line, the slope of which represents the maximum value that saving time could have to him, is drawn in the fourth quadrant. The values around this portion of the circle represent the rates of savings that are potentially realized by further walking. However, if he actually walks to save money, a line is drawn in the second quadrant. In this portion of the circle, the values represent the rate of savings actually realized and are a minimum value of walking time for that individual.

In theory, if the value of time is a constant for all persons, the lower bound of "rate of savings actually realized" and the upper bound of "rate of savings potentially realized" should lie on the same line. The slope of this line will represent the value of walking time (Fig. 8) and will be called the "indifference line". In this case there should be no lines below the indifference line in either the second or the fourth quadrant. To the extent that different persons have different time values, there will be individuals with actual or potential savings below the indifference line.

This method was applied to the work trip data in the following manner. It was earlier established in this study that people are biased in favor of parking within 1 block of their destinations. For people who parked in this block, only the lines in the fourth quadrant representing rates of potentially realizable savings could be drawn because these parkers do not walk to save on parking cost. For these persons, the maximum rate of savings available within a 6-block radius was used. The potential savings available to these persons (Fig. 9) ranged from 0 to a maximum of $11.50/hour. The mean rejected saving was about $5/ hour. The fact that a considerable fraction of the total sample rejected possible savings ranging from $5 to $11.50/hour walking is an indication of the bias for parking within the first block.

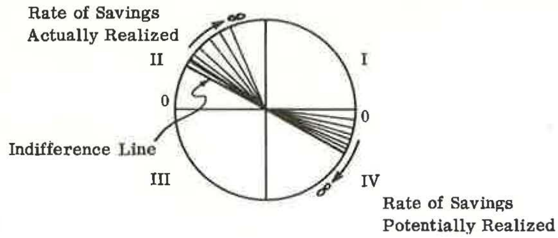

Figure 8. Walking time value indifference circle: theoretical data plot.

A second analysis was performed on the drivers who parked at more than the 1-block distance. For these people, the value of time was found by dividing the money saved by the time spent, and a line was drawn in the second quadrant. Also, because many of these people were subject to still greater savings by walking farther, a line was drawn in the fourth quadrant to represent the further potential savings that they did not choose to gain. Because of the difficulties of establishing reliable indifference lines for individual block distances, an indifference circle, including all individuals who parked more than 1 block from their destinations was drawn (Fig. 10). A clear indifference line for all except only a few people was established at a value of time of $4.50/hour, which represents the value of time for roughly 40 percent of the population (those persons who did choose to walk). As indicated previously, for the approximately 60 percent of the population who did not choose to walk more than a block, higher time values could be derived due to the bias in favor of the first block.

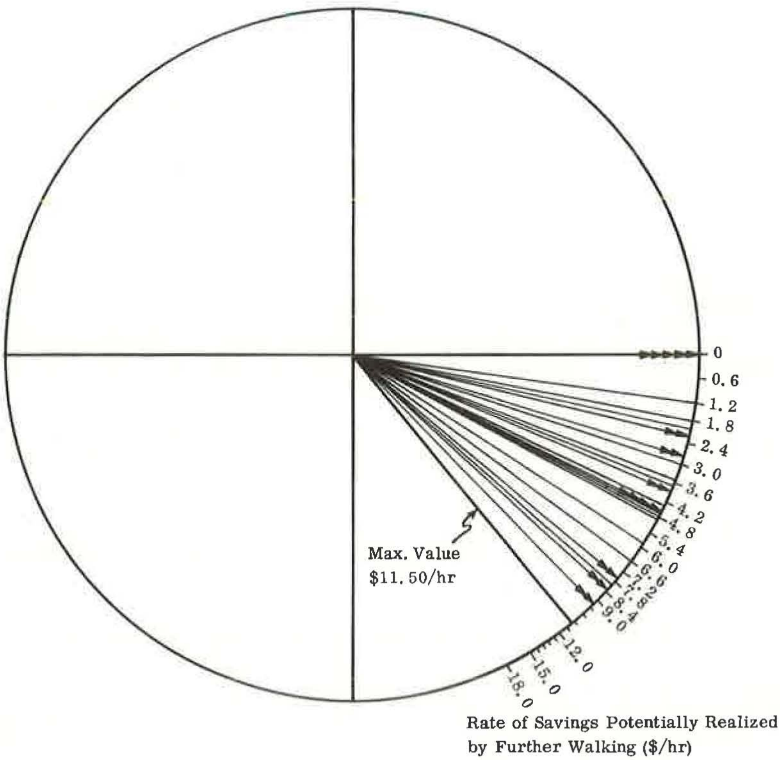

Figure 9. Walking time value indifference circle for first block.

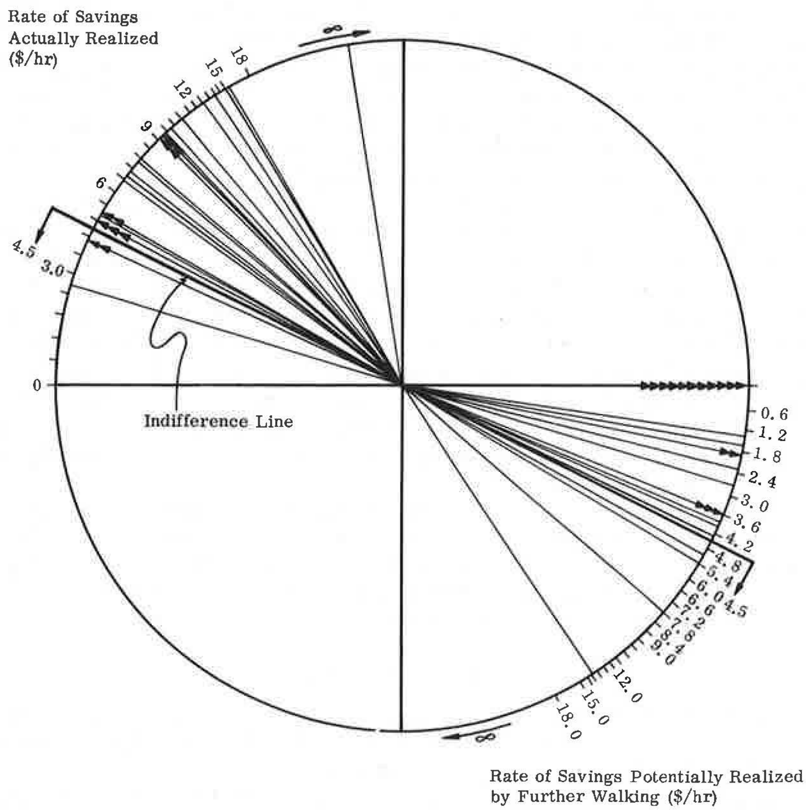

Figure 10. Walking time value indifference circle for more than one block.

CONCLUSIONS

It was observed that drivers have a strong bias for parking in the first block for work trips to Chicago's downtown area. It was also found that commuters are sensitive in their parking and walking behavior to absolute parking costs and to available savings through walking. The higher the parking costs are at the destination, the far-

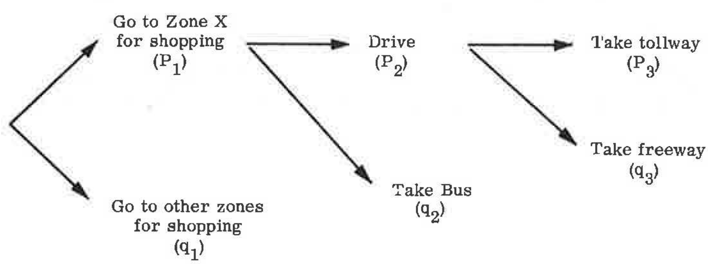

Figure 11. Example of multiplicative probabilities for multinomial mode choices.

ther people are likely to walk. Also, the greater the available savings are through walking, the more likely commuters are to walk farther.

In the models, income was found to be insignificant. This is apparently because its effect is largely taken care of in the overall travel mode choice. To make decisions to drive downtown, people first must consider parking costs and walking distances and make comparisons with their incomes. Once the decision to drive downtown is made, income apparently becomes an insignificant variable.

Another reason for the insignificance of the socioeconomic factors may be that northwest corridor modal-split data were biased toward high-income groups. Even in the transit user sample, there were very few people having incomes less than $8,000.

The value of time was found to be $4.50/hour for persons who did walk from parking places. However, this value of time is only for persons with incomes over $8,000. This should be kept in mind when this figure is applied for cost-benefit analysis.

The final probabilistic model was virtually multinomial. Therefore, this approach may well be applied to other problems requiring a multinomial solution. In parking problems, the probabilities are additive. However, this approach can be applied to problems where the probabilities are multiplicative as well. An example of such a situation is given in Figure 11.

The probability that a person will drive to zone X via a tollway will be $p = p_1p_2p_3$. Notice that the only requirement is that the choices are binary at each stage. For this example, models may be built for the 3 stages given and then combined to give cumulative probability. This approach has numerous applications toward finding solutions to transportation modal-choice problems.

REFERENCES

1. Beesley, M. E. The Value of Time Spent 24th May 71. Economica, May 1965.
2. Finney, D. J. Probit Analysis: A Statistical Treatment of the Sigmoid Response Curve, 2nd Ed. Cambridge Univ. Press, England, 1962.
3. Draper, N. R., Smith, H. Applied Regression Analysis. John Wiley and Sons, New York, 1966.
4. Ehrenfeld, S., and Sebastion, L. Introduction to Statistical Method. McGraw-Hill, New York, 1964.
5. Lisco, T. E. The Value of Commuters' Travel Time: A Study in Urban Transportation. Univ. of Chicago, PhD dissertation, 1967.
6. Lisco, T. E. Project Statement: Northwest Chicago Corridor Modal Split Project. Chicago Area Transportation Study, 1969.
7. Lisco, T. E., and Stopher, P. R. Modelling Travel Demand: A Disaggregate Behavioral Approach—Issues and Applications. Proc., Eleventh Annual Meeting of Transportation Research Forum, 1970, pp. 195-214.
8. Stopher, P. R. A Probability Model of Travel Mode Choice for the Work Journey. Highway Research Record 283, 1969, pp. 57-65.
9. Stopher, P. R. Course Notes of Transportation Analysis Methods, Northwestern Univ., Evanston, Winter 1970.
10. Theil, H. A Multinomial Extension of the Linear Logit Model. Center for Mathematical Studies in Business and Economics, Univ. of Chicago, Report 6631, 1966.
11. Warner, S. L. Stochastic Choice of Mode in Urban Travel. Northwestern Univ. Press, 1962.