

PARKING PATTERNS AND PRICES IN THE CBD

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This paper shows how the flow of automobile traffic from residential areas is allocated among downtown parking facilities by a pattern of prices that acts to minimize the total driving and subsequent walking costs for the drivers as a group. These prices also provide the maximum revenue that can be collected by each parking facility when competing freely. A set of data from a central business district with more than 10,000 parking spaces demonstrates the validity of the analysis and shows that the parking patterns and prices can be determined inexpensively by computer. The model should be useful to traffic engineers and urban planners in their design of more efficient urban transportation systems.

•THE allocation of demand for parking space to the available supply customarily is regulated in large cities by a system of user fees. The automobile driver searching for a parking space selects a location that he feels minimizes some combination of driving time, cost of parking, and walking distance to his ultimate destination. Drivers who value their time most highly will tend to select locations close to their destination, while others will save money by parking in peripheral lots and walking longer distances. The parking lot manager, on the other hand, in attempting to maximize his revenue, sets his fees at the highest level that competition will permit without significant loss of patronage. The parking price therefore acts to ensure that virtually all spaces are used and that they are allocated to those parkers who value them most.

The foregoing principles represent the extension of a model by Brown and Lambe (1) to include the effects of driving distance; they belong to a growing body of literature on parking models (2-5). There are two advantages from this extension. The first is that the inclusion of driving distances provides a clearer view of the flow of traffic from the suburbs to the central business district (CBD) and back. The second is that the presence of this secondary cost factor improves the accuracy of the model in its prediction of parking prices.

The effect of driving distance on the choice of parking location can be illustrated by a simple example of two persons destined for the same office building, where one person lives to the east and the other to the west of the building. Clearly, if there only are parking spaces available at 1,000 ft from the building in each direction, the person from the westerly suburb should use the west one and the other person should use the east one. However, if the westerly parking facility was 3,000 ft away from the office building, the first person probably would prefer to drive an extra 4,000 ft to the eastern parking facility to save 2,000 ft of walking if both lots were free. If he valued his time and traveling expenses at \$0.05 per 1,000 ft for driving and \$0.20 per 1,000 ft for walking, he would theoretically prefer the eastern lot (to save \$0.20 per trip), all other things being equal.

The foregoing example can also demonstrate the effect of driving distance on the maximum price that each person is willing to pay for a parking space at his office building. The person from the east would be willing to pay \$0.15 to save 1,000 ft of walking by driving the extra 1,000 ft to his office, while the person from the western suburb (and parking in the eastern facility) would pay \$0.25 because of the additional

saving in driving. On a daily basis, each would be willing to pay double the figures because of the savings on the return trip to his home. Clearly, if only one space were available at the office building, the westerly person theoretically would get it in a free market by being willing to pay a higher price. Furthermore, he should get the space if total driving and walking cost is to be minimized for this combination of drivers. The value of an additional space for the eastern driver, incidentally, would be twice \$0.15 per day. Consequently, the manager of a parking facility at the office building could charge twice \$0.25 per day if he had one space available, but only twice \$0.15 per day per space if he had two spaces available and could not charge the customers different amounts.

Finally, the example can illustrate the effect of parking duration on the value and choice of parking facility. If the person from the eastern suburb went home for lunch, a parking space at the office building would save him four walking trips per day, and consequently would be worth \$0.60 per day to him. Therefore, if only one space was available at the office building, he would be able to bid a higher price than the westerly person who stayed at his office all day. The value of an additional space (for the westerly person) would be \$0.50 per day. Additional spaces at either outlying facility obviously would yield no revenue because the facility already has ample capacity that is free.

These examples conform to the classical transportation problem (6), where the object is to allocate a set of demand quantities (the parkers) to another set of supply capacities (the parking spaces) in such a manner as to minimize the total transfer (driving and walking) cost. The advantage of this representation of the problem lies in a very efficient mathematical procedure that not only determines the allocation of parkers to minimize total driving plus walking costs in the city but also determines the optimal set of parking fees to achieve this end. Furthermore, an extremely fast computer program has been developed for finding these solutions (7).

The algebraic representation of the transportation problem determines the specific (non-negative) number of drivers $X_{i,jkp}$ who drive from a point (i) to a parking facility (j), then walk to a building (k), and repeat the trip a specific number of times (p) per day. The transportation cost $C_{i,jkp}$ for each of these drivers depends on their driving and walking distances per day. The solution obviously cannot assign more people to a parking facility (j) than its total spaces S_j . It also must satisfy the demand D_{ikp} of people traveling from point (i) to destination (k) with frequency (p). The optimal solution therefore is

$$\text{Minimize } \sum_{ijkp} X_{i,jkp} C_{i,jkp} \text{ by adjusting } X_{i,jkp}$$

subject to

$$\sum_{ijkp} X_{i,jkp} \leq S_j \text{ for all } j$$

$$\sum_j X_{i,jkp} = D_{ikp} \text{ for all } i, k, p$$

$$X_{i,jkp} \geq 0 \text{ for all } i, j, k, p$$

As an illustration, the last version of the previous example consists of two drivers, one from the west ($i = 1$) and the other from the east ($i = 2$). Both of them have the same destination ($k = 1$), but one makes one round trip per day ($p = 1$) and the other makes two round trips per day ($p = 2$). Therefore $D_{111} = D_{212} = 1$, and $D_{211} = D_{112} = 0$. Each person has a choice of three parking facilities, a large free one having, say, 100 spaces located 3,000 ft to the west ($j = 1$), a single space at the destination ($j = 2$), and another large free one located 1,000 ft to the east ($j = 3$). Therefore S_1 and S_3 present

no capacity constraint, but $S_2 = 1$. If each person's home is 10,000 ft from the office, the transportation costs in dollars per day are $C_{1111} = 1.90$, $C_{1211} = 1.00$, $C_{1311} = 1.50$, $C_{2112} = 5.00$, $C_{2212} = 2.00$, $C_{2312} = 2.60$. The algebraic representation of the problem finds the combination of non-negative values for all of the X_{ijkp} to minimize

$$(1.90X_{1111} + 1.00X_{1211} + 1.50X_{1311} + 5.00X_{2112} + 2.00X_{2212} + 2.60X_{2312})$$

subject to

$$\begin{aligned} X_{1111} + X_{2112} &\leq 100 \\ X_{1211} + X_{2212} &\leq 1 \\ X_{1311} + X_{2312} &\leq 100 \\ X_{1111} + X_{1211} + X_{1311} &= 1 \\ X_{2112} + X_{2212} + X_{2312} &= 1 \end{aligned}$$

By inspection, the solution is $X_{1311} = 1$, $X_{2212} = 1$, and $X_{1111} = X_{1211} = X_{2112} = X_{2312} = 0$. In practical terms, the first variable states that a person drives from the western suburbs ($i = 1$), parks at the eastern facility ($j = 3$), walks to his office ($k = 1$) one round trip per day ($p = 1$). The second variable states that another person drives from the eastern suburb ($i = 2$) directly to a parking lot ($j = 2$) at his office ($k = 1$) two round trips per day ($p = 2$). The remaining variables confirm that no one else drives and parks elsewhere. The correspondence between the theoretical and the practical observations (for the idealized model) indicates the usefulness of the theory for predicting the basic flow of traffic in a large city from a multitude of possible trips.

The maximum daily rental R_j that the manager of a parking facility (j) can charge without losing customers is given by the dual formulation of the transportation problem. This version states that the maximum amount P_{ikp} per day that each person making (p) trips from origin (i) to destination (k) is willing to pay for any space is the smallest of all available combinations of driving, walking, and parking fee. The algebraic representation finds P_{ikp} and R_j to

$$\text{Maximize} \left[\sum_{ikp} P_{ikp} \bar{D}_{ikp} - \sum_j \bar{R}_j \bar{S}_j \right]$$

subject to

$$\begin{aligned} P_{ikp} &\leq R_j + C_{ijkp} \text{ for all } i, j, k, p \\ P_{ikp} &\geq 0 \text{ for all } i, k, p \\ R_j &\geq 0 \text{ for all } j \end{aligned}$$

The dual version of the previous example selects non-negative values for P_{111} , P_{212} , R_1 , R_2 , and R_3 to maximize

$$(P_{111} + P_{212} - 100R_1 - R_2 - 100R_3)$$

subject to

$$\begin{aligned} P_{111} &\leq R_1 + 1.90 \\ P_{111} &\leq R_2 + 1.00 \\ P_{111} &\leq R_3 + 1.50 \\ P_{212} &\leq R_1 + 5.00 \\ P_{212} &\leq R_2 + 2.00 \\ P_{212} &\leq R_3 + 2.60 \end{aligned}$$

By inspection, the optimal solution is $P_{111} = 1.50$, $P_{212} = 2.60$, $R_2 = 0.50$ and $R_1 = R_3 = 0$. The practical implication of the first number is that an additional person traveling from the western suburb to the same building in the CBD and back per day would have a total daily outlay of \$1.50 for the cost of time and travel expenses. These consist of \$1.10 for driving 11,000 ft each way and \$0.40 for walking 1,000 ft each way from the eastern parking facility. The second number states that an additional person from the

eastern suburb would pay \$2.60 per day for his two round trips while using the eastern parking facility. The remaining three numbers repeat the earlier conclusion that an additional parking space at the destination building would rent for \$0.50 per day, while additional spaces at either outlying parking facility would yield no revenue because the facility already had extra spaces that were free. Thus the solutions R_j to the dual formulation of the transportation problem correspond to the fees that can be charged for extra spaces, and consequently they also should correspond to the rentals at large public facilities where everyone pays the same price for the same parking service.

APPLICATION OF THEORY TO DATA

In May 1962 the City of Vancouver, British Columbia, carried out a survey of the existing parking situation in order to plan for future space requirements (8). The survey consisted of a compilation of the available parking spaces and their use. The survey encompassed less than 1 square mile of the CBD. Closely following the procedures outlined by the U.S. Bureau of Public Roads (9), the team of 75 men involved in the survey collected data from different city blocks each day and recorded, among other things, the location, size, and fee schedule for all parking facilities. They also recorded the arrival and departure times of all the commuters parking in public facilities between 8:00 a.m. and 6:00 p.m. each day, their home address or last stop, their walking destination, and whether they paid by the hour, the day, or the month. Included in the survey also were parkers at unrestricted curb spaces and public parking facilities in areas adjoining the CBD who were destined for the downtown area.

The survey showed that of the 17,000 spaces located in the area in 1962, 14,000 were available to the general public. These 14,000 spaces divide into two groups, according to the period they were available for continuous use. The first group, called curb, are 2,000 spaces that have time restrictions of 2 hours or less and charge 10 cents per hour. The second group, called commercial, can be used for any length of time. They include unrestricted curb spaces and all off-street lots that are rented by the hour, day, or month. The remaining 3,000 spaces that are not available to the general public are excluded from the subsequent analysis. Also excluded are the users of these spaces because they have a special parking privilege.

The demand for parking space varies throughout the day. In general, there is a heavy flow of people into the spaces as commuters arrive at work between 8:00 a.m. and 9:00 a.m. Then shoppers and people making business calls come and go throughout the middle of the day. Finally, the spaces start to be emptied as commuters journey homeward between 5:00 p.m. and 6:00 p.m. Table 1 shows that total demand for the 14,000 public parking spaces increases rapidly until 10:00 a.m. and continues at slightly less than 10,000 cars until 4:00 p.m.

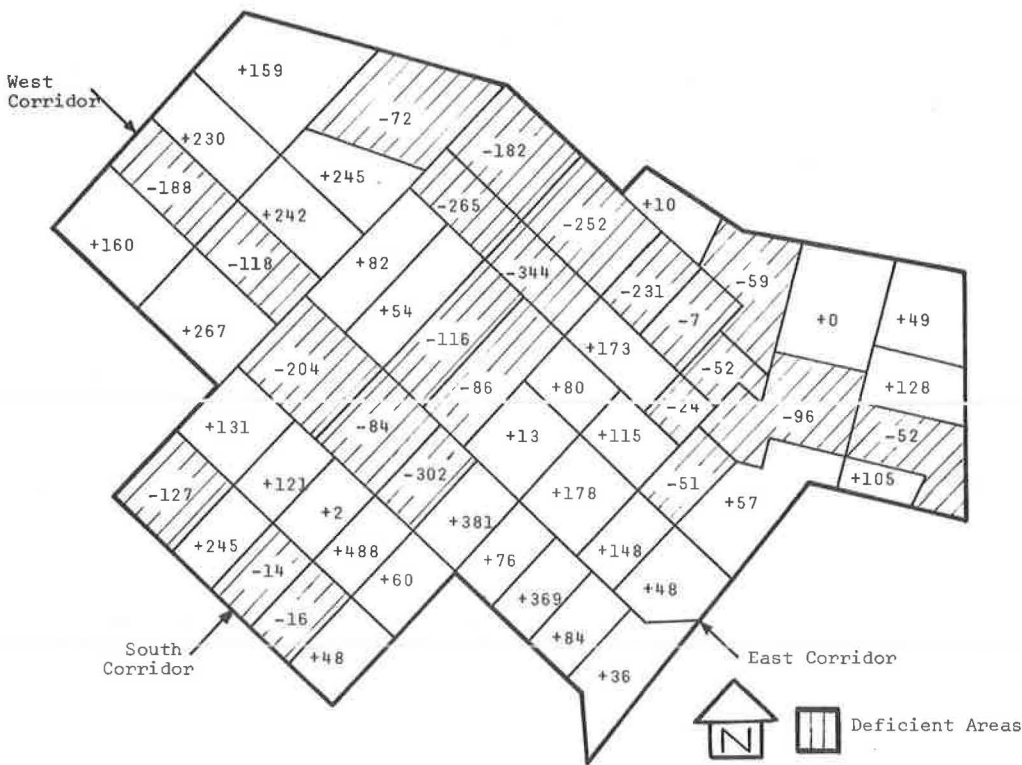
The length of time a person stays at his destination influences his choice of parking facility. Some park for less than 2 hours and legally could use curb spaces. Others stay between 2 and 4 hours and generally pay on a daily basis. The remainder park for more than 4 hours and usually rent parking spaces by the month. The first two groups usually comprise shoppers and people on business calls, while the third group consists of employees and other downtown business people.

The drivers also differ in terms of their home address, their ultimate destination in the CBD, and where they park. Because virtually all traffic reaches the Vancouver CBD through essentially three major corridors (a harbor blocks access from the fourth direction), the classification of home addresses can be considerably simplified by allocating the drivers accordingly. Furthermore, the point where each corridor touches the boundary of the CBD serves as a convenient common origin in determining the relative driving distances to the various parking facilities within the CBD. The classification of ultimate destination also is simplified by dividing the CBD into a number of zones that roughly correspond to 2 city blocks. The same pattern of zones also designates the actual choices of parking location. However, because there are two types of facilities per zone, an additional index (q) is needed to designate curb capacity S_{j1} and commercial capacity S_{j2} . This index also must be added to driver choices X_{ijkpq} and transfer costs C_{ijkpq} .

Table 1. Demand for public parking in the CBD.

Time of Day	No. of Parkers
8:00 a.m.	2,300
9:00 a.m.	7,000
10:00 a.m.	9,200
11:00 a.m.	9,900
12:00 noon	9,900
1:00 p.m.	9,800
2:00 p.m.	9,900
3:00 p.m.	9,900
4:00 p.m.	9,200
5:00 p.m.	7,000
6:00 p.m.	3,300

Figure 1. Supply less demand for parking space.



A comparison of the total demand and supply of parking space per zone shows that there is a severe deficiency near the center of the CBD. This shortage occurs in both short-term and long-term facilities. Figure 1 shows the distribution of the net supply of public parking facilities at 11:00 a.m. after demand and an allowance for the minimum time to change vehicles have been deducted. Table 2 gives the distribution of this demand D_{ikp} by assumed access corridor (i), destination zone (k), and duration class (p). The comparable list for the supply S_{jq} of parking facilities appears in the paper by Brown and Lambe (1). It should be noted that curb and commercial capacities have been reduced by 10 and 20 percent respectively to allow for the normal vacancy rate that occurs in an area of high demand.

The final step in linking the data to the theoretical structure of the previous section is to establish the transfer costs C_{1jkpq} . These depend on the one-way driving and walking distances, their value per foot, their frequency per day, and the direct cost per space for operating a parking facility. The latter is estimated to be \$0.60 per day for maintenance and fee collection at curb and hourly commercial service and \$0.30 per day for monthly commercial services that do not require meters nor parking attendants ($p = 3, q = 2$).

Because of the grid-like arrangement of the city streets, the average driving distance from each corridor entry point to parking facilities in each zone is equal to the sum of the absolute differences between the location coordinates of the entry points and zone centroids when measured along axes parallel to the street alignment. The same procedure determines the average walking distance between zones. Thus, if E_i and N_i are the east-west and north-south coordinates of corridor entry point (i), and Y_j and Z_j are east-west and north-south coordinates of parking zone (j), the one-way driving distance is

$$V_{1j} = |E_i - Y_j| + |N_i - Z_j|$$

A similar formula gives the one-way walking distance to destination zone (k),

$$W_{jk} = |Y_j - Y_k| + |Z_j - Z_k|$$

These relationships greatly reduce the computer storage requirements in the next section. In terms of the location of the zones (as given in the paper by Brown and Lambe), $(E_1, E_2, E_3) = (257, 500, 715)$ and $(N_1, N_2, N_3) = (500, 330, 530)$ in 10-ft units.

The criterion for the choice of one parking facility over another is the value of the commuter's leisure by parking at a conveniently located facility as opposed to more money saved by parking at a cheaper facility. In other words, the driving and walking distances involved in parking at, and walking from, each alternative facility must be assigned values in order to facilitate comparison between the various alternatives. Using data on the prices that people are willing to pay to park closer to their destinations in order to reduce walking distance, Lambe (10) has shown that the difference between driving and walking was valued at \$0.15 per 1,000 ft in 1962 for distances under 4,000 ft. Driving can be valued at \$0.05 per 1,000 ft on the basis of an average driving speed of 20 mph in the CBD, plus maintenance, gas, and depreciation costs of \$0.10 per mile. Consequently, the implicit cost of walking is \$0.20 per 1,000 ft.

The average number of one-way trips per day depends on the parking duration of the driver. Spaces that are occupied by people parking for less than 2 hours at a time ($p = 1$) tend to have three users during the 6-hour period between 10:00 a.m. and 4:00 p.m., and consequently they generate six one-way driving (and walking) trips. In a similar manner, spaces occupied by people parking between 2 and 4 hours ($p = 2$) generate three one-way trips per day on average. Finally, spaces occupied for more than 4 hours ($p = 3$) generate two one-way trips. When combined with the previous data on walking distances and cost rates, the trip frequencies give the following set of transfer costs:

$$C_{1jk11} = 0.30V_{1j} + 1.20W_{jk} + 0.60 \text{ for 2-hour curb users}$$

$$C_{1jk12} = 0.30V_{1j} + 1.20W_{jk} + 0.60 \text{ for 2-hour commercial users}$$

Table 2. Parking demand and prices.

Demand D_{ijk} by Entry Corridor, Duration, and Destination (in spaces)												
Zone (j or k)	West Corridor (i = 1)			South Corridor (i = 2)			East Corridor (i = 3)			Theoretical Price		
	0 - 2 (p = 1)	2 - 4 (p = 2)	4 + (p = 3)	0 - 2 (p = 1)	2 - 4 (p = 2)	4 + (p = 3)	0 - 2 (p = 1)	2 - 4 (p = 2)	4 + (p = 3)	Curb (\$/hour)	Daily (\$/day)	Monthly (\$/month)
910	12	1	18	20	2	49	8	4	24	0.10	0.60	6.00
911	6	1	15	11	3	26	2	4	13	0.10	0.60	6.00
912	6	2	99	13	14	133	12	6	82	0.10	—	9.00
913	11	4	109	24	8	171	17	12	87	0.13	0.75	9.00
914	4	1	39	4	8	82	4	1	29	0.10	—	6.00
915	1	0	25	5	0	41	0	2	39	0.10	0.65	6.90
916	5	7	72	2	10	115	11	8	82	0.10	0.60	6.00
917	3	0	18	3	0	18	0	0	7	0.10	0.75	9.00
918	12	4	111	14	11	192	10	7	135	0.10	0.90	12.00
920	9	9	89	17	19	142	18	9	58	0.15	1.11	16.20
921	16	4	75	21	12	167	21	4	70	0.23	—	22.10
922	4	1	24	12	12	45	1	5	42	0.15	1.13	16.60
923	1	1	5	6	3	21	3	4	13	0.10	1.04	14.80
924	11	10	102	19	18	192	21	3	97	0.21	1.23	18.60
925	9	5	120	30	13	209	15	11	75	0.26	1.57	25.40
926	37	28	46	90	63	119	69	56	80	0.23	1.37	—
927	2	1	5	5	0	8	0	2	15	0.17	—	—
928	2	2	23	9	2	20	6	0	14	0.14	—	—
929	2	1	20	9	2	38	6	2	33	—	1.15	16.90
930	17	5	22	45	16	58	21	16	37	0.20	—	—
931	12	5	34	31	14	117	18	11	43	0.18	1.06	—
932	3	4	51	8	6	155	3	1	150	0.12	0.87	11.40
933	0	0	1	3	1	3	4	0	3	0.10	0.70	7.90
934	15	4	79	30	13	133	12	21	52	0.15	0.87	11.40
935	2	5	26	3	16	71	12	8	37	0.17	0.99	13.80
936	7	4	48	12	18	94	7	5	38	0.13	1.17	17.30
937	32	34	79	121	61	132	64	42	88	0.20	1.19	17.70
938	3	2	9	3	3	30	8	4	16	0.10	0.90	12.00
939	2	1	10	5	6	30	2	0	27	0.10	1.05	—
940	4	3	35	2	10	58	11	3	62	0.10	—	10.50
941	1	0	6	2	0	15	5	1	23	0.10	0.60	6.00
942	6	0	3	6	6	16	3	1	5	0.10	—	9.00
943	0	1	1	5	0	8	2	0	11	0.10	—	—
944	1	1	8	1	0	11	3	2	13	0.10	0.60	6.00
945	0	0	5	0	0	10	2	0	13	0.10	0.71	8.10
946	9	2	15	13	7	12	4	4	10	0.10	0.60	6.00
947	8	1	10	14	1	21	5	0	20	0.10	—	—
948	0	0	3	5	0	10	2	1	8	0.10	0.60	6.00
949	2	0	3	2	0	14	5	0	0	0.10	0.60	6.00
970	0	0	1	1	0	18	0	0	17	0.10	0.61	6.10
971	0	1	3	3	1	9	0	1	11	0.10	0.60	6.00
972	0	0	0	1	0	1	0	2	4	0.10	—	6.00
973	4	1	11	6	2	19	0	1	44	0.10	—	6.00
974	0	0	2	2	0	13	5	0	20	0.10	0.76	9.10
975	2	3	15	10	5	30	2	3	16	0.10	0.62	6.34
976	1	0	0	1	0	5	0	0	2	—	0.60	6.00
977	6	1	16	13	3	40	6	4	40	0.10	0.91	12.10
978	0	1	9	4	2	26	4	5	34	0.10	0.89	—
979	6	0	10	12	2	57	16	6	36	0.10	0.77	9.30
980	30	21	67	128	66	140	130	72	192	0.17	1.01	—
981	0	0	0	0	0	1	1	0	6	0.10	0.71	8.20
983	3	0	3	15	7	25	18	2	25	0.10	—	—
984	1	1	14	14	14	32	7	1	13	0.10	—	—
985	3	0	7	9	3	22	3	0	16	0.10	—	—
986	3	0	1	0	0	10	3	2	7	0.10	0.60	6.00
987	2	0	2	0	0	18	0	0	19	0.10	—	6.00
Total	338	182	1,624	850	483	3,252	613	359	2,153			

$C_{1,jk21} = \text{infinity}$, because not allowed

$C_{1,jk22} = 0.15V_{1,j} + 0.60W_{j,k} + 0.60$ for 2- to 4-hour commercial users

$C_{1,jk31} = \text{infinity}$, because not allowed

$C_{1,jk32} = 0.10V_{1,j} + 0.40W_{j,k} + 0.30$ for >4-hour commercial users

RESULTS FROM THEORY AND DATA

An extremely fast computer program written by Thompson and Srinivasan (7) finds the values of P_{1kp} , R_{jq} and $X_{1,jk,pq}$ for the foregoing transportation problem in 0.32 minutes of processing time on the IBM 370-165 at a cost of less than \$20. Although essentially the same solutions can be obtained in 0.1 minute by pre-assigning the short- and long-term demands when there is sufficient suitable capacity for all of the demand at the destination zone and by combining some of the low demands by corridor, the saving may not be worth the trouble nor the possibility of error. Pre-assignment incidentally reduced the problem from 504 demand and 112 supply equations to 133 and 97 respectively.

The only significant modification to the original computer program was the generation of $C_{1,jk,pq}$ as needed from E_1 , N_1 , Y_j , Z_j , Y_k , and Z_k in order to keep computer storage requirements to a manageable level. Minor modifications to the input and output routines consisted of adjustments for receiving the data by zones and subtracting the row and column multipliers from their largest value to produce the basic measurements of driver expenses P_{1kp} and parking fees R_{jq} . The theoretical parking rate for each zone (j) is then equal to the sum of the net parking charge for that zone and the overhead expense, as follows:

0.167($R_{j1} + 0.60$) for hourly curb
 ($R_{j2} + 0.60$) for daily commercial
 20($R_{j2} + 0.30$) for monthly commercial

The resulting optimal assignment of the 504 types of driver to the 112 types of parking facility agreed reasonably well with observed parking patterns. For those who walked, the average walking distance from the parking zone to the destination was 513 ft for people parking less than 2 hours, in comparison with the observed average distance of 1,227 ft. From theory only 155, compared with an observed 776 (out of 1,795), walked, while the rest parked in their destination zones. For people parking between 2 and 4 hours the corresponding averages were 628 and 1,270 ft, and from theory only 116, compared with an observed 543 (out of 1,025), walked. For people parking more than 4 hours the averages were 855 and 1,360 ft respectively, and from theory only 3,031, compared with an observed 4,718 (out of 7,028), walked. The trend to longer walking distances with increases in parking duration confirms the theoretical assumption that people are willing to walk to save larger sums of money that are charged for parking long periods. Observed walking distances generally are 60 percent larger than theoretical ones because other factors (besides price and distance) influence the drivers' choices of parking facilities.

The effect of the access corridor on the walking direction supports the assumption that driving distance also influences the choice of parking location. For those who walked, long-term parkers from the west in theory walk an average of 652 ft east to their ultimate destination, in comparison with an observed eastward distance of 855 ft. In a similar manner, drivers from the east walk 785 ft west in theory, in comparison with the 1,310 ft observed. Finally, drivers from the south walk 918 and 1,408 ft north respectively. Again, the effect of factors other than driving distance tends to increase the observed walking distance.

The corresponding optimal values for parking prices also agreed reasonably well with observed rates. The standard deviation is \$0.13 for the differences between the observed daily rates ranging from \$0.50 to \$1.50 and theoretical rates ranging from \$0.60 to \$1.57. The standard deviation is \$2.15 for the differences between the observed monthly rates ranging from \$5.70 to \$25.00 and theoretical rates ranging from \$6.00 to \$25.40. Because the curb meter rate of \$0.10 per hour is not determined purely by the interaction of supply and demand, a statistical comparison between the observed and theoretical is not meaningful. Table 2 gives the theoretical rates by

zone, and the paper by Brown and Lambe (1) gives the observed rates as weighted averages based on the capacity of the facilities.

Part of the difference between theoretical and observed parking fees may have resulted from the shape and location of the zone boundaries. For example, a person may park at the edge of a zone and walk across the street to a store in a different zone. His theoretical walking distance from the center of the parking zone to the center of the destination zone consequently is much greater than the actual walking distance, thereby exaggerating the gradient between theoretical parking prices. In principle, the zones should be kept as small as one city block, with the boundaries passing down the middle of the blocks instead of the streets.

Figure 2 shows that the theoretical curb rates are higher than the present \$0.10 per hour in the central 17 of the 54 CBD zones with curb parking. The local government deliberately sets these low prices and at the same time maintains a maximum 2-hour time restriction in an effort to attract business to downtown stores. Consequently, the demand for these spaces is very high as parkers take advantage of this underpricing feature. A fair amount of overcrowding thus results, causing the average utilization of curb spaces in high-demand areas to rise above the average observed across the entire CBD. By classifying the 54 CBD zones with curb parking according to their theoretical rates and their observed utilization, Table 3 clearly shows that underpricing results in exceedingly high use of these spaces.

From a supply-and-demand point of view, it is obvious that the operators of curb spaces (usually the city) are not charging the most that competition will permit and, as such, are not maximizing their revenue. If the 2-hour limits were removed and curb rates were allowed to rise to the levels determined by the interaction of supply and demand, these rates would approximate the going prices at nearby commercial facilities. In general, the central spaces still would be used by short-term parkers, but they would have to pay more for the privilege. Long-term parkers would not be so attracted to the currently illegal practice of adding coins to the meter every 2 hours, even though this practice would then be legal. Finally, street congestion would be reduced because spaces always would be available to those who are willing to pay for them and there would not be the current financial incentive to hunt for a scarce but cheap curb space.

In conclusion, the use of the transportation model to link theory to observation will help city and other transportation planners to understand the behavior of the average parker and to anticipate changes in the pattern of parking with changes in supply and demand. The most useful aspect of this work to such authorities is the systematic way it links the flow of traffic from the major corridors of the downtown area to the optimal traffic parking pattern and the associated optimal parking rates. Future road networks and parking facilities therefore can be planned with greater accuracy.

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