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CONTENTS

FOREWORD

The six papers in this RECORD deal with allocation of parking demand and the location of transportation terminals. Models that make use of computers are common to all six papers. They are expected to be of interest to traffic, transportation, and transit engineers and administrators and of course to parking authorities.

In the first paper, Bates proposes a theoretical, but as yet untested, model for allocating unsatisfied parking demand. The model allows for testing of alternative plans for design of parking facility locations and selection of an optimum solution. It is primarily proposed for use in small urban areas where parking decisions are simplistic.

Ellis, Rassam, and Bennett report on the development and implementation of a parking allocation model that incorporates three basic variables: cost, walking distance, and capacity constraint. Initial testing in an operational application is described as encouraging, and the authors conclude that further pilot applications are warranted. Three separate discussions by Sundaram and Feng, Skinner, and Lathrop are complimentary of the work, and their comments offer proposals to make the model more realistic and useful.

Continuing with the parking space allocation model approach, Gray and Neale describe methods that they used in a parking study in the Seattle CBD. Cost and walking distance were used to calibrate the model to fit actual field conditions of parking supply and demand location. It is stated also that the model can be modified to test various parking program schemes as well as alternate transportation modes.

From France, Lablanche and others describe STOCK, a computer program for localizing parking demand with respect to supply. Rush-hour parking phenomena can be simulated, and the difficulty of parking (generalized cost) can be calculated, thus allowing the testing of plans for a rational parking policy.

Walker and Cummings explain the parking demand forecasting model that they used to study parking needs in Baltimore. Their work forecast the amount of CBD parking needs that could be eliminated by diverting drivers to a planned new rapid transit system and by diverting some work-trip parking demands to CBD fringe and outlying locations.

In the final paper, Yu and Wilhelm developed a theoretically optimum set of characteristics for the location of urban transportation terminals such as parking, bus stops, taxi stands, and others. The solution is suggested as being particularly suited to transportation planning for new towns or new transportation systems for existing cities.

1-4

A GRAVITY ALLOCATION MODEL FOR PARKING DEMAND

John W. Bates*, Metropolitan Atlanta Rapid Transit Authority

This paper proposes a model for the allocation of unsatisfied parking demand. The model is based on the gravity analogy similar to that for trip distribution. Residual or unsatisfied demand in one analysis zone is allocated to other zones on the basis of the parking supply in those other zones and their distance away. The final, "adjusted" demand is the sum of forecast demand and demand allocated "in" from other zones less the demand allocated "out" to other zones. An iterative procedure is followed whereby alternative plans for design of parking facility locations are tested and an optimum solution is selected. The model is theoretical and untested. It is proposed primarily for use in small urban areas where parking decisions are simplistic in nature so that parking costs are consistent and walking distance is the most significant parameter.

•IT IS unreasonable and sometimes practically impossible to provide sufficient parking facilities within an area to satisfy the parking demand in that area. Because of this, the parking demand must shift to adjacent areas that may, in turn, have parking supply deficiencies. To design a parking supply system that can best meet the needs of a large area requires that some means of rationally estimating the diversion between subareas (which will in fact occur) be developed. It is necessary to have some method of judging whether locations selected for new facilities will be close enough to the demand areas so that they will be used by motorists and not be unused while drivers circulate in nearby areas looking for parking space and creating congestion.

In smaller urban areas it is not uncommon to see vacant curb and lot spaces fringing the business district while vehicles are illegally parked or cruising in the center of the area. The expense of providing the fringe parking is wasted, whereas additional investment might have provided a satisfactory solution. If the location of additional spaces is based on a rational analysis, instead of availability of clear areas, the decision-makers can allocate the additional investment but only if the technicians can establish the basis for their decision. A parking demand allocation model is a critical tool in establishing that basis.

This paper discusses a proposed model for the zonal allocation of forecast parking demand throughout an analysis area based on an application of Newton's law of gravity. Everyone who studied high school physics remembers the familiar expression for gravitational force:

$$F = K\ (m_1 m_2)/(r^2)$$

That is, "The force exerted by one body on another body is directly proportional to the product of their two masses and inversely proportional to the square of the distance between them."

For several years planners have been forecasting urban travel patterns by using the following model:

$$T_{ij} = \left(P_i A_j F_{ij} K_{ij} \Big/ \sum_{j=1}^{n} A_j F_{ij} K_{ij} \right)$$

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*Mr. Bates was with the Division of Highway Planning, Georgia State Highway Department, when this research was conducted.

If this expression is rearranged to

$$T_{ij} = \left(K_{ij} \Big/ \sum_{j=1}^{n} A_j F_{ij} K_{ij} \right) (P_i A_j / t^n)$$

then the reason for the name "gravity model" is evident, for the similarity to the general form of the gravity expression is clear. The distribution model assumes that "the number of trips between any two zones is directly proportional to the product of the total number of trips produced at the origin and attracted to the destination and inversely proportional to an exponentially increasing function of the travel time between the zones."

Formulating an expression for parking demand allocation requires the determination of the variables to be included. If the model is to be of the gravity form, then the variables selected should conform to the variables in the gravity expression, i.e., two mass measurements and a distance measurement. Another decision to be made is the type of allocation. Allocation might be made for gross or forecast demand, or allocation might be made for only the unsatisfied or residual demand for each zone.

The model discussed in this paper was formulated to parallel the gravity analogy trip distribution model. The parallel was selected arbitrarily as a basis for testing by the author, who felt that there was sufficient similarity between the distribution of unsatisfied parking demand and trip productions and attractions to warrant the investigation. To state the model, we made assumptions that may or may not prove valid under analysis. The assumptions are as follows:

1. The gravity analogy does apply to parking decisions.
2. Parking costs are significant only in modal choice. Once vehicular mode has been determined, prevailing parking costs will be accommodated.
3. Duration and other legal restraints as well as cost differentials will balance out in application.
4. Only residual or unsatisfied demand should be allocated to adjacent areas.

The behavioral assumption for the model will thus be stated as follows: An automobile driver will attempt to park his vehicle immediately adjacent to his final destination. If he is unable to do this, he will park as nearby as possible. In searching for a nearby space, he will first investigate those areas where larger numbers of parking spaces are provided.

With these assumptions in mind, the model is proposed as

$$Z_i = D_i + A_i$$

where

Z_i = adjusted demand for zone i,
D_i = forecast demand for zone i, and
A_i = net allocation to zone i from all zones, including the subject zone.

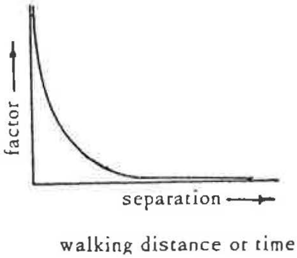
The allocation term A_i is the critical factor in the expression. It is the sum of residual demands from other zones allocated into zone i less the residual demand in zone i allocated out to all other zones. The A_i term is expressed as

$$A_i = \sum_{j=1}^{n} A_{i/j} - \left(\sum_{j=1}^{n} A_{j/i} - A_{i/i} \right)$$

where

$A_{i/j}$ = allocation to zone i from zone j,
$A_{j/i}$ = allocation to zone j from zone i, and
$A_{i/i}$ = residual allocation, that is, the part of the residual demand that remains in zone i.

Figure 1. Marginal propensity to walk from parking space to destination.



The term $\Sigma A_{i/j}$ represents the total allocation into zone i from all other analysis zones. The term $\Sigma A_{j/i}$ represents the total allocation from zone i to other zones and must be a positive number. That is, no allocation of residual demand can be made from a zone if the space supply in the zone is greater than the forecast demand. If there is no residual demand in a zone, then the out allocation $\Sigma A_{j/i}$ will be zero.

Logically, the total residual demand allocated out of all zones must be equal to the residual demand allocated into all zones. Therefore the in allocation for each zone may be accumulated as it is allocated out of other zones.

The gravity analogy is used for the out allocation procedure. The expression is given as

$$A_{j/i} = R_i \left[S_j f_{ij} \Big/ \left(\sum_{j=1}^{n} S_j f_{ij} \right) \right]$$

where

R_i = nonzero and positive value of residual demand in zone i,
S_j = space supply in zone j, and
F_{ij} = proportionality distribution factor between zones i and j, which is of the form $1/d^x$, where d is the distance between zones i and j and x is a varying exponent of d.

The similarity of this expression to the trip distribution model is readily apparent.

The form of the proportional distribution factor is unknown. The exponent is assumed to vary with the value of d because experience has shown this to be the case in the trip distribution application. Also, logically, when the factor is considered to be a "marginal propensity to walk," one might postulate a curve of the type shown in Figure 1 in which the propensity to walk decreases sharply until after a certain distance is reached, at which point the rate decreases less rapidly to a point where walking is totally unacceptable. It might be, however, that the converse is true; that is, the factor may decrease slightly for a certain distance and then begin to decrease rapidly. The shape of the curve cannot be assumed until after experimentation and detailed analysis of behavioral patterns.

Experimental results are also needed to determine the appropriate measure of spatial separation. The most reliable measure might be time or distance quantified in feet or number of block units.

In application, it must also be considered that the peak demand for all zones does not necessarily occur simultaneously. The allocation should be made hourly and analyzed for each separate time period.

Special mention should be made of the fact that the space supply term S_i is a factor in the allocation expression. Because the purpose of a parking analysis is to determine an adequate supply system, it follows that allocation is a convergent or trial-and-error procedure. A space supply system is designed and then tested by allocation, the deficiencies (and surpluses) of that system are corrected, and a new allocation is made to the revised system. The cycle is repeated until an adequate and realistic supply design is attained, one that can be achieved within the policy and physical restraints imposed.

The entire model, then, is represented by the expression

$$Z_i = D_i + \sum_{j=1}^{n} A_{i/j} - \sum_{j=1}^{n} R_i \left(S_i f_{ij} \Big/ \sum_{j=1}^{n} S_i f_{ij} \right) + A_{i/i}$$

with the restriction that, if $R \leq 0$, then

$$\sum_{j=1}^{n} R_i \left(S_i f_{ij} \sum_{j=1}^{n} S_i f_{ij} \right) + A_{i/i} = 0$$

where the allocation is an iterative process, and allocations are made for a given space supply distribution; deficiencies and surpluses are determined and corrected; and a new allocation is made. The cycle is repeated until a practical and satisfactory supply distribution is determined. Because peak demand time varies between zones, allocations should be made over time and by supply system design to serve for all time periods.

This model is theoretical only and, at the time this paper was written, had not been tested. It is possible that during testing it may be found desirable or even necessary to modify the assumptions and adjust the model accordingly.

The model is not so complex in its approach to allocation as other proposed allocation techniques may be. It may be that this simplistic approach will provide adequate or even more reliable allocation in small urban areas where parking decisions are themselves simple, where parking costs are not significant, where there is no modal choice, and where walking distance is the primary factor in the parking location decision.

As stated, this model is theoretical and has not been tested. A proposal is now pending with the Georgia State Highway Department for a research and development project to continue the development of the model and to determine its usefulness in this critical area of need in parking analysis.

5-20

DEVELOPMENT AND IMPLEMENTATION OF A PARKING ALLOCATION MODEL

Raymond H. Ellis, Paul R. Rassam, and John C. Bennett,
Peat, Marwick, Mitchell and Company

This paper develops the underlying assumptions of the parking allocation model and describes the results of its calibration and application in a case study. This version of the model incorporates three of the basic variables influencing parking choice: cost, walking distance, and capacity constraint. The model is embedded in a linear programming context that uses a disutility concept to combine the effects of the trade-offs among cost, distance, and other variables. Parkers arriving during a given time period are allocated such that their joint disutility is minimized, subject to capacity and demand constraints. In general, the performance of the parking allocation model in its first operational application is encouraging. It does replicate the distribution pattern of parkers among facilities and the facility totals. Initial testing suggests that the model captures the dynamics of the parking project. Based on these results, further careful pilot applications are warranted.

• A SYSTEMS ANALYSIS of parking was structured by the authors in a previous paper (1). This parking analysis framework hinges on a parking allocation model (PAM) that simulates the choice of a parking facility by a trip-maker. The objective of this paper is to report on the experience gained in applying PAM in an initial case study.

For purposes of this discussion, it is necessary to situate this model into the broader context of the urban transportation planning process. When we recognize the simultaneous nature of the urban travel process, it is nonetheless necessary, at the present time at least, to assume a sequential process to simulate the urban travel phenomenon. In this context, the parking analysis described in this paper follows modal split and, ideally, precedes assignment. Hence, the parking analysis process assumes a fixed stock of automobile trips; the interaction between the cost and inconvenience of parking on the one hand and the demand for various modes of transportation on the other should be taken into account as part of the modal-split analysis. In other words, aggregate parking demand at a given final destination is explicitly assumed to be an exogenous input to PAM.

The purpose of PAM is to accept a stock of automobile trips to a final destination and to allocate these trips to a set of parking facilities. Given this fixed-demand context, each parker would ideally want to park at his final destination and do so at no cost. As a matter of fact, this is what happens in low-density residential areas or even in the CBD of a small community. However, in higher density centers, it is obviously not possible for each parker to achieve these ideal conditions. Thus, the concept of competition for the available parking spaces is introduced in the analysis. When the competition reaches a threshold level, parking spaces are no longer "free," and either a time limit or a price is imposed.

In this competitive environment, parkers must make choices among alternative facilities characterized by attributes such as (a) the total out-of-pocket cost of parking; (b) the spatial separation between the parking facility and the final destination; (c) the service provided by the facility in terms of waiting time, safety of the user, and protection of his vehicle; (d) the location of the parking facility with respect to the travel routes; and (e) the likelihood of finding a space. It can be hypothesized that, when selecting a facility, a user implicitly or explicitly trades off among these, and perhaps other, attributes and, hence, assigns some disutility to each of the facilities that he considers.

Each parker will attempt to minimize his own disutility. To simulate such a process in which the available choices change as each parker is allocated would theoretically require that a sequential order be assigned to each parker and that the process be repeated until all parkers are allocated to a facility. Changes in the available choices occur when the capacity of a facility is reached. To make the allocation algorithm computationally tractable (in terms of running time) requires some approximation of the process. It can be assumed that a joint disutility minimization performed over a relatively short period of time sufficiently approximates the individual disutility minimization that would occur over the same time span. In other words, parkers are grouped within a given arrival period and assigned simultaneously to parking facilities in a way that minimizes their joint disutilities. For a given time period of arrival a, this can be stated mathematically as follows:

$$\text{Minimize} \sum_j \sum_k \sum_q \sum_d Z(j,k,q,d) \times X(j,k,q,d)$$

subject to

$$\sum_j \sum_q \sum_d X(j,k,q,d) \leq s(a,k) \qquad \text{for each } k$$

$$\sum_k X(j,k,q,d) = T(j,q,d) \qquad \text{for each } (j,q,d)$$

where

j = index identifying a zone of final destination;
k = index identifying a parking facility;
q = index identifying a group of parkers (by purpose or income or both);
a = index identifying a time period of arrival;
d = index identifying a time period of departure ($d \geq a$);
X(j,k,q,d) = number of parkers arriving at time period a, departing at time period d, belonging to group q, destined to zone j, and allocated to facility k;
Z(j,k,q,d) = disutility of each of the parkers;
s(a,k) = supply (number of spaces) available at time period a in facility k; and
T(j,q,d) = number of parkers belonging to group q, destined to zone j, arriving in period a, and departing in period d.

(This formulation assumes that parking duration is not subject to any restriction. Otherwise, the supply constraints must be slightly modified.)

A CASE STUDY

Pittsburgh, Pennsylvania, was chosen as the case study for pilot implementation of PAM. This city was chosen because (a) it is a medium-sized city; (b) it has a well-defined CBD, a feature that facilitated this initial analysis; and (c) an acceptable data base for a parking system analysis was available. A home-interview study was performed in 1967, and a parking study, consisting of an inventory, occupancy counts, and curb-side interviews, was performed in 1969 (2).

This paper will focus on the allocation of long-duration work trips for which it is assumed that workers arrive during a single period and that their durations are stratified in three categories: between 7 and 8 hours, 8 to 9 hours, and longer than 9 hours. This initial focus on the long-duration work trip is logical inasmuch as parkers for this purpose constitute from 40 to 50 percent of the total parkers in cities of greater than 500,000 population, and they consume over 70 percent of the total space-hours. Further, the dynamics of the early-arriving work-trip parkers has significant impacts on the personal business and shopping parkers who generally arrive at later time periods.

The study area (Fig. 1) was divided into 116 zones in which 74 parking facilities are open to the public. Curb parking was not considered in the analysis inasmuch as it represents a very small fraction of available space and is subject to time restrictions.

The data base required to calibrate and validate PAM involved demand data, supply data, and CBD network data. Demand data were obtained from the curb-side interview of parkers; information was obtained on the number of parkers in each facility by final CBD destination, trip purpose, and parking duration. Information on the socioeconomic characteristics of the drivers, the number of people sharing the parking cost, and the arrival time at the parking facility was not available in the survey. Supply information, including the parking rate structure and facility capacities, was available from the inventory work sheets. A detailed CBD walking network was coded in which each zone was represented by a centroid located in the middle of the zone and connected to the street network by four "dummy" walking links. Interzonal walking distances were estimated by skimming this network, whereas intrazonal walking distances were manually estimated. Information on waiting times at the parking facilities was not available; however, the three major factors influencing parking choice, i.e., parking cost, walking distance, and facility capacity, were available in the calibration data set.

DEVELOPMENT OF THE CALIBRATION DATA SETS

The joint distribution for parking cost and walking distance for work trips with a duration of 7 hours or longer is given in Table 1. Although, as might be expected, there is considerable dispersion in the data, a definite trend of decreasing parking cost with increasing walking distance is evident. This dispersion can be attributed to the following factors:

1. The data displayed cover a relatively large geographic area.
2. Low-cost parking facilities are located closer to the final destination in the periphery of the CBD than they are in the central portion.
3. Although not explicitly indicated in the survey, this joint distribution is directly influenced by the effects of available supply, i.e., capacity constraints. For example, in the core of the CBD, there are cases when the closest available facility is about 1,000 ft or more from the final destination, and the cost for this facility is still quite high.
4. Other factors such as the approach route may influence the choice of a parking facility.
5. Consumers generally lack full information concerning the available choices.

The trade-off between walking distance and parking cost is most acutely faced by those destined for the core area of the CBD, as shown in Figure 1 by Liberty Avenue, Grant Street, and Boulevard of the Allies. Plotting the joint distribution of cost and distance only for those parkers whose final destinations are within this triangular area (Table 2) reduces the dispersion and accentuates the relation between cost and distance.

To further reduce the scattering, we stratified the data by intervals of 200 ft for distances up to 3,000 ft and intervals of 500 ft for distances greater than 3,000 ft. The average parking cost for each of the distance intervals is shown in Figures 2 and 3 for the entire study area and the core area respectively. Thus, four calibration data sets, disaggregated and grouped data sets for the entire study area and the core area, were developed.

FORMULATION OF THE DISUTILITY FUNCTIONS

The PAM proposed in this paper does not lend itself to a calibration procedure as generally understood. Because of the structure of the model, the output of PAM is defined implicitly rather than explicitly. This is in contrast to, for example, a modal-split model in which the output variable, modal split, is an explicit function of the input variables. Hence, to exercise PAM requires that an initial estimate of the disutility function be obtained. However, validation must be based on the ability of the model to replicate the observed interchanges between final destinations and parking facilities together with consideration of the quality of the disutility functions.

Figure 1. Study site.

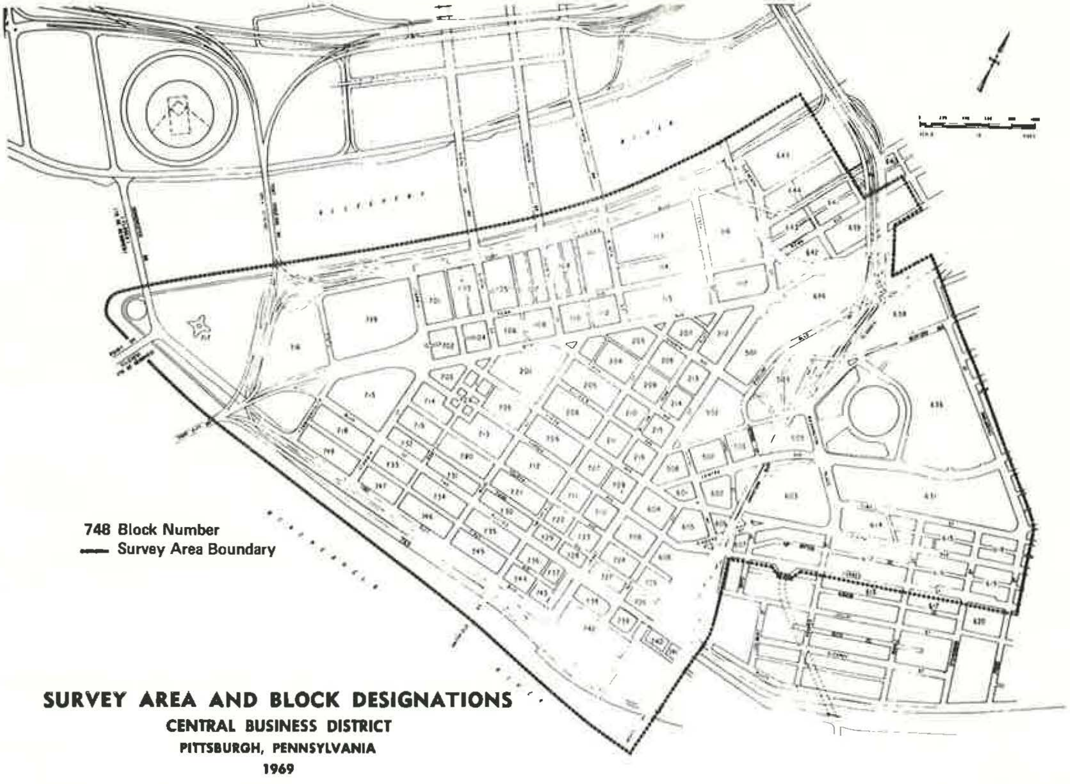


Table 1. Percentage of parkers in entire study area who will walk a given distance from and pay a given price for a parking space.

	Distance (ft)											
Cost ($)	>500	500-1,000	1,000-1,500	1,500-2,000	2,000-2,500	2,500-3,000	3,000-3,500	3,500-4,000	4,000-4,500	4,500-5,000	5,000-5,500	5,500-6,000
>1.00			1.1	1.1	1.0	4.9	7.9	2.4	1.5	0.4	0.3	0.4
1.00 to 1.50	0.2	1.5	1.5	2.5	1.1	0.5				0.2		
1.50 to 2.00	8.9	9.2	12.9	10.9	6.7	2.4		0.1				
2.00 to 2.50	6.3	2.9	6.0	1.8	1.1	0.3		0.1				
2.50 to 3.00	1.2	0.6	2.1	0.6								
3.00 to 3.50	0.6											

Table 2. Percentage of parkers in core area who will walk a given distance from and pay a given price for a parking space.

	Distance (ft)											
Cost ($)	>500	500-1,000	1,000-1,500	1,500-2,000	2,000-2,500	2,500-3,000	3,000-3,500	3,500-4,000	4,000-4,500	4,500-5,000	5,000-5,500	5,500-6,000
>1.00	0.3	2.9	5.5	1.6	2.4	5.3	4.5	1.3	0.8	0.2	0.1	0.4
1.00 to 1.50	1.9	2.9	4.7	2.4	0.7	0.3	0.3		0.1	0.2		
1.50 to 2.00	8.5	9.3	10.2	9.2	3.7	1.4	0.2	0.1	0.2			
2.00 to 2.50	5.2	3.1	4.5	1.2	0.8	0.3	0.1	0.1				
2.50 to 3.00	0.9	0.5	0.9									
3.00 to 3.50	0.3		0.2									

Figure 2. Relationship between cost and distance (entire study area).

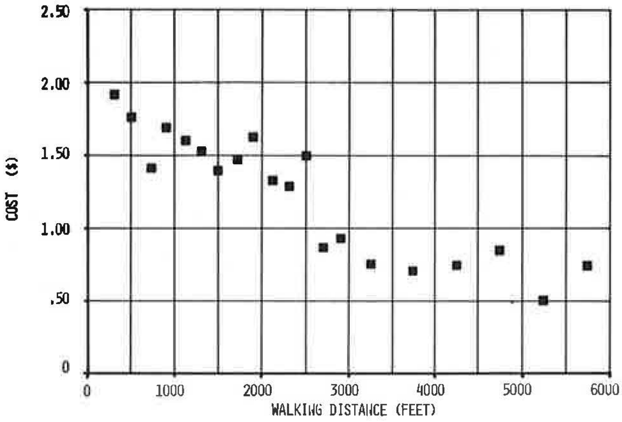


Figure 3. Relationship between cost and distance (core area only).

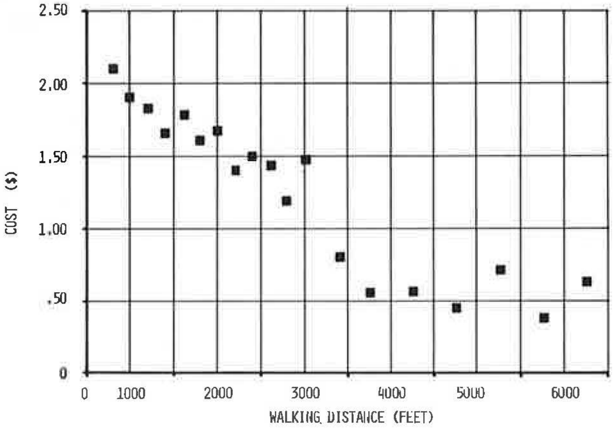


Table 3. Calibrated cost-distance relation and corresponding disutility functions.

Model Number	Cost-Distance Relationship[a]	Standard Error of Distance Coefficient	Correlation Coefficient: Log-Transformed Equation	Correlation Coefficient: Actual Equation	Disutility Function
1[b]	$C = 218 - 4.5*D$	0.001	0.94	0.94	$Z = C + 4.5*D$
2[b]	$C = 45 + \exp(5.587 - 0.067*D)$	0.012	0.80	0.87	$Z = C + 268*[1 - \exp(-0.067*D)]$
3[c]	$C = 45 + \exp(5.157 - 0.041*D)$	0.002	0.88	0.88	$Z = C + 174*[1 - \exp(-0.041*D)]$

[a] Cost is expressed in cents and distance in 100 ft.

[b] Eqs. 1 and 2 pertain to the core area.

[c] Eq. 3 pertains to the entire study area.

Although several variables could be considered, it has been assumed that cost and distance are the two variables that characterize a facility and determine parking choice. It has also been hypothesized that these two variables can be combined into a single measure of disutility. What can be observed by examining a plot of parking cost versus walking distance (Figs. 2 and 3) is that, despite a certain scattering, cost decreases as distance increases. Let $f(C, D) = 0$ be the relationship between cost and distance. This relationship can be readily calibrated by least squares once a functional form has been selected for $f(C, D)$.

The next step of the analysis is to determine how C and D can be combined into a single measure of disutility. When D is equal to zero or very small, disutility is equal to parking cost. If $f(C, D)$ is viewed as a trade-off between cost and distance, then the derivative of C with respect to D can be viewed as a marginal rate of substitution between cost and distance. Hence, the contribution of distance to disutility can be defined as the sum of the "substitutions" made between a given distance D^* and the "ideal" distance, namely 0.

To illustrate this definition, let us assume that $f(C, D)$ is such that

$$C = -\alpha D + \beta$$

where α and β are two positive, calibrated constants. (In other words, a straight line has been fitted to the plot of cost versus distance.) In such a linear formulation, the rate of substitution of distance into cost is equal to α and, therefore, constant. Hence, the contribution to the disutility measure by the distance characteristic D^* of a given facility is αD^*. If C^* is the cost associated with D^*, the disutility of this facility becomes

$$Z = C^* + \alpha D^*$$

A linear model is attractive because of its simplicity. However, it is unlikely that the rate of substitution should remain constant over the range of possible distances. Furthermore, the difference in the disutilities of two facilities located at distances of, say, 500 and 1,000 ft should be greater than the one corresponding to two facilities located at, say, 2,000 and 2,500 ft. To this end, two functional forms are available for $f(C, D)$, namely an exponential function where

$$C = \alpha \exp(-\beta D) \qquad (\alpha, \beta > 0)$$

and a power function where

$$C = \alpha D^{-\beta} \qquad (\alpha, \beta > 0)$$

In both cases, the marginal rate of substitution is a decreasing function of distance as can be seen from the derivatives of these functions:

$$\left|\frac{dC}{dD}\right| = \alpha\beta \exp(-\beta D)$$

and

$$\left|\frac{dC}{dD}\right| = \alpha\beta D^{-\beta-1}$$

It can be seen that the rate of substitution reaches (asymptotically) zero when distance becomes large. According to the definition given earlier, the contribution of a walking distance D^* to the disutility measure becomes in the case of the exponential formulation

$$\int_{D^*}^{0} \left|\frac{dC}{dD}\right| = \alpha\left[\exp(-\beta D)\right]_{D^*}^{0} = \alpha\left[1-\exp(-\beta D^*)\right]$$

This element of the disutility function can be interpreted as follows. At zero distance, the disutility due to distance is zero. At a large or "infinite" distance, this disutility is represented by α. For intermediate distances, disutility is a fraction of α, the fraction being an exponentially decreasing function of distance. Hence, the disutility of a facility characterized by C^* and D^* is expressed as

$$Z = C^* + \alpha[1-\exp(-\beta D^*)]$$

In the case of the power function, the same steps could be followed to derive the expression of the disutility, provided that the "ideal" distance is not zero but is small, say 100 ft (otherwise, the function is not defined). If D_o is such a distance, then the disutility becomes

$$Z = C^* + \alpha\left[(D_o)^{-\beta} - (D^*)^{-\beta}\right] \qquad (D^* \geq D_o)$$

At this point, an observation should be made concerning parking cost as such and the fraction of that cost that can be substituted for in terms of distance. Examination of the data reveals that, for the long-term parkers considered, the minimum cost of parking C_o is 50 cents. Thus, given that a trip-maker has decided to park in the study area, the "substitutable" amount of his parking cost C is $C - C_o$. Alternatively, one could assume that, inasmuch as there is no parking space under C_o available in the study area, the function f(C, D) should yield no value of C under C_o. This condition implies that the asymptotic value of the exponential function should be C_o instead of 0. To this end, the dependent variable in the least-squares estimation of the parameters α and β becomes $C - C_o$. Inasmuch as the logarithmic function is not defined when its argument tends to 0, the value of C_o was set at 45 cents so that the log-linearized relationship could be calibrated by least squares.

CALIBRATION OF THE DISUTILITY FUNCTIONS

Numerical results presented in this paper should be viewed as preliminary inasmuch as application and testing of the model are under way at the present time. Several calibration runs of the cost-distance trade-off function f(C, D) have been performed. However, not all of the corresponding disutility functions have been used as input to the model. As noted earlier, the "quality" of an estimated disutility function depends not only on statistical measures (such as standard errors or correlation coefficients) but also on the extent to which the model using this function reproduces the observed allocations of parkers among parking facilities.

The present discussion focuses on the calibration of the linear and exponential disutility functions, which have actually been used as input to the parking allocation model. The results of the calibration of the cost-distance relationships and the corresponding disutility functions are given in Table 3. The first two disutility functions pertain to the triangular core of the study area, whereas the third one is representative of the entire study area. All three functions have been calibrated on cost data grouped by distance intervals as described earlier. The relatively low standard errors of the coefficients and high correlation coefficient are due, in part, to the grouping of data.

APPLICATION OF THE PARKING ALLOCATION MODEL

The three calibrated disutility functions given in Table 3 were used as input to the parking allocation model. One arrival period and three departure periods, i.e., between 7 and 8 hours, 8 to 9 hours, and longer than 9 hours, were used. To facilitate the comparison of estimated statistics with observed or actual statistics, we aggregated the 116-zone area structure into 10 districts. As shown in Figures 4, 5, and 6, total volumes allocated by each model to each of the 10 aggregate districts are generally in close agreement with the observed totals. The index of determination R^2 between estimated and observed values is 0.95 or better for each of the three models.

Similarly, the estimated aggregate disutilities of the parkers in the 10-district structure exhibit a high correlation with the observed values. These disutilities were

Figure 4. Observed and estimated facility totals (model 1).

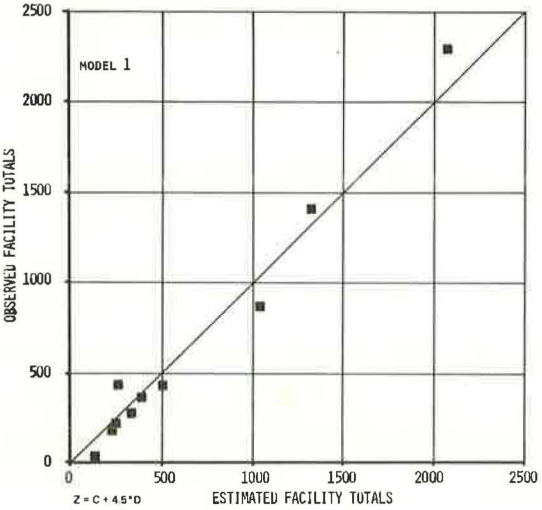


Figure 5. Observed and estimated facility totals (model 2).

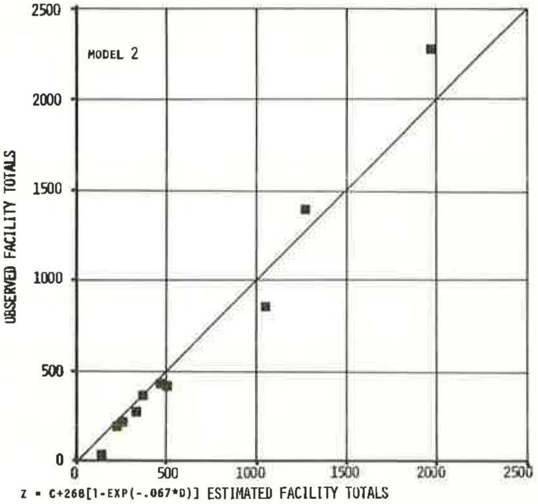


Figure 6. Observed and estimated facility totals (model 3).

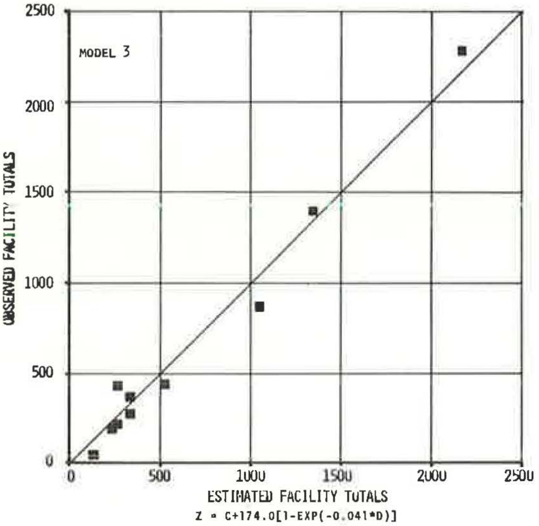
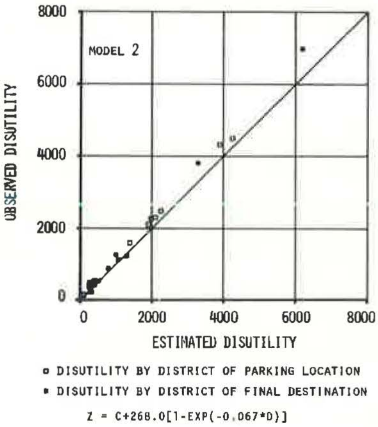


Figure 7. Observed and estimated aggregated disutilities (model 2).



evaluated for each allocated parker by means of the disutility function input to each model. For example, Figure 7 shows the observed versus estimated disutilities at both the facility and final destination levels for model 2.

Finally, it is of interest to compare the interchanges between parking districts and final destination districts. In the 10-district structure, there is a total of 100 such possible interchanges. The observed set of interchanges contains 48 zero cells. Model 2 replicated exactly 47 of these zero cells on a one-to-one basis. Models 1 and 3 replicated 46 zero cells, also on a one-to-one basis. This result is interesting to note inasmuch as it demonstrates the ability of PAM to replicate a parking pattern with reasonable accuracy. The comparison of nonpaired zero cells between actual observations and model estimates are shown for each model in Figure 8 through 10.

For each model, the index of determination R^2 between actual observations and model estimates is relatively high. Specifically, the R^2 values are 0.82, 0.85, and 0.80 for models 1, 2, and 3 respectively.

SUMMARY AND CONCLUSIONS

The present paper develops the underlying assumptions of the parking allocation model and describes the results of its calibration and application in a case study. This version of the model incorporates three of the basic factors influencing parking choice, namely, cost, walking distance, and capacity. Whereas the importance of cost and distance is readily recognized, the importance of capacity should be emphasized in any allocation model.

To negate the importance of capacity would imply in a certain sense that parking supply is always available, which is often not the case. The argument that market forces determine pricing policy is no doubt valid. However, it is when demand exceeds supply that a trader raises his price. Thus, the awareness of the "imbalance" that exists in the real-world cannot be replicated in a simulation model without first noting that capacity is reached and then "raising" the price so as to maintain the parking facility at its peak occupancy. Furthermore, from a modeling standpoint, capacity constraint is certainly a desirable attribute that, everything else being equal, introduces an internal "control mechanism" into the model. Even better, this readily available "mechanism" is neither artificial nor as difficult to define as highway capacity, which is a recognized determinant of route choice in assignment models. Finally, if an allocation model is to become a tool for providing meaningful information to decision-makers, consideration of capacity becomes essential.

The parking allocation model is embedded in a linear programming context in which a disutility concept is used to combine the effect of the trade-offs between cost and distance. It is also a convenient device for incorporating other variables such as those mentioned earlier. Joint or simultaneous minimization of the disutility of parkers is a basic assumption of PAM. It has been noted that PAM is performed as an approximation to individual minimization and that the shorter the time span is within which parkers are grouped, the better this approximation is. In this regard, it is interesting to refer to Figure 7 and observe that, for each final destination district, the total disutility of the parkers allocated by the model is only slightly lower than the corresponding observed disutility. Capacity and demand constraints are easily incorporated in the framework of a linear program. Finally, computational algorithms that are highly efficient are available. (The problem described herein can be solved in approximately 1 min of processing time on an IBM 360/65.)

It should be noted that the results of the model presented in this paper are "uncorrected." Briefly speaking, such corrections or "tuning" of the model results could mainly be performed by examining the final destination-parking facility interchanges in which major discrepancies occur and by adjusting the corresponding disutilities to make the facility more or less attractive, as may be required.

In general, the performance of the parking allocation model in this first operational application is encouraging. It did replicate the distributional pattern of parkers among facilities and final destinations and the facility totals in each district. The close correlations between observed and estimated allocations, shown in Figures 8, 9, and 10 for each of the three models calibrated, suggest that PAM captures the dynamics of the parking process. Based on these results, further careful pilot applications are warranted.

ACKNOWLEDGMENTS

The parking allocation model presented in this paper was developed by Peat, Marwick, Mitchell and Company for the Federal Highway Administration. The authors gratefully acknowledge the assistance and advice of Steiner M. Silence, Leeds Chesshir, Perry Davison, and Robert Stout of the Urban Planning Division.

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DISCUSSION

Swaminathan Sundaram and C. C. Feng,
Department of Civil and Environmental Engineering, University of Colorado

The authors have developed a rational approach to the problem of parking allocation by embedding PAM in a linear programming context. This is acceptable, assuming that the joint disutility minimization is performed over a relatively short period of time. The discussion that follows aims to add information on the linear programming aspects of the paper and the limitations that possibly can be faced in practice.

Linear programming is a process of optimization where the objective function is linear and the constraints are also linear. Any linear programming problem can be expressed in the form of equality relations among the variables, which are nonnegative. This standard form is as follows:

$$\text{Minimize} \quad z = c_1x_1 + c_2x_2 + c_3x_3 + \ldots + c_nx_n$$

subject to the constraints

$$\begin{aligned} a_{11}x_1 + a_{12}x_2 + \ldots + a_{1n}x_n &= b_1 \\ a_{21}x_1 + a_{22}x_2 + \ldots + a_{2n}x_n &= b_2 \\ &\vdots \\ a_{m1}x_1 + a_{m2}x_2 + \ldots + a_{mn}x_n &= b_m \end{aligned} \tag{1}$$

where

$x_1 \geq 0$, $x_2 \geq 0, \ldots x_n \geq 0$, and
$b_i \geq 0$ ($i = 1$ to m).

x_i are the variables, and b_i are the constants.

Generally the problem at hand may not be in standard form as above but may be transformed into one by means of suitable manipulations, introducing slack and surplus variables. For example, if the inequality is of the form

$$a_{k1}x_1 + a_{k2}x_2 + \ldots + a_{kn}x_n \leq b_k \tag{2}$$

it can be put in the equality form as

$$a_{k1}x_1 + a_{k2}x_2 + \ldots + a_{kn}x_n + x_{n+1} = b_k \tag{3}$$

where x_{n+1} is a nonnegative slack variable.

The authors' formulation of the model is as follows:

$$\text{Minimize} \sum_j \sum_k \sum_q \sum_d Z(j,k,q,d) \times X(j,k,q,d) \tag{4}$$

subject to

$$\sum_j \sum_q \sum_d X(j,k,q,d) \leq s(a,k) \quad \text{for each } k \tag{5}$$

$$\sum_k X(j,k,q,d) = T(j,q,d) \quad \text{for each } (j,q,d) \tag{6}$$

where the notations are as defined in their manuscript.

The constraints in Eq. 5 can be transformed in equality form by use of slack variables. For application of linear programming technique s(a,k), the number of spaces available at time period a in facility k should be treated as constants. Hence, theoretically minimization can be performed only over the relatively short period of time during which s(a,k) is reasonably constant. The determination of acceptable variation in s(a,k) is dependent on the sensitivity of the optimal solution to small perturbations in s(a,k).

An important requirement in the linear programming method is that the feasible region formed by the constraint equations be a convex set; i.e., if any two points within the region are connected by a straight line, that line should always lie entirely within the feasible region. This is always true conceptually, even in the higher dimensions, except in the degenerate cases where feasible solutions are nonexistent. In the present linear programming problem of the PAM described by Eqs. 4, 5, and 6, there is a possibility of degeneracy, even though this situation may rarely be faced in practice. For example consider a very simplified representation of constraints in Eqs. 5 and 6 for only two variables, X_1 and X_2. The point brought out can of course be generalized. The constraint equations, Eqs. 5 and 6, take the simplified form

$$\begin{aligned} X_1 &\leq S_1 \\ X_2 &\leq S_2 \\ X_1 + X_2 &= T \end{aligned} \tag{7}$$

The region enclosed by the constraints and the process of minimization of the objective function can be geometrically illustrated as shown in Figure 11.

The region that includes the sets of x_1, x_2 fulfilling the constraints is called the feasible region. In this figure, the straight line AB representing the equality constraint is the feasible region. Any point in AB is a feasible solution, and the optimum occurs either at A or at B. Depending on the values of the constants S_1, S_2, and T in Eq. 7, the graph may take the shape shown in Figure 12 where the feasible region is the line CD and the optimum occurs at C or D. Some values of S_1, S_2, and T, may result in a degenerate case as shown in Figure 13.

Obviously no point can be found that can simultaneously satisfy all the constraints; hence, no feasible region or solution exists. In the model under study, s is the supply available, and T is the total number of parkers. Hence under certain circumstances, when the number of parkers outstrips the supply considerably, there is a possibility of a degenerate case where no feasible solution exists.

A linear programming problem can also face a case of unbounded solution, but in the present model there seems to be no possibility of this occurrence due to the equality constraints in Eq. 6.

Figure 8. Observed and estimated allocation in the 10-district structure (model 1).

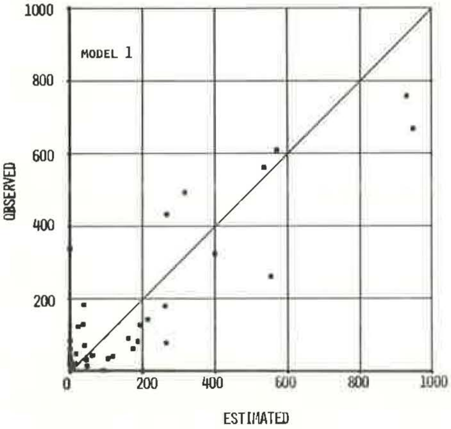


Figure 9. Observed and estimated allocation in the 10-district structure (model 2).

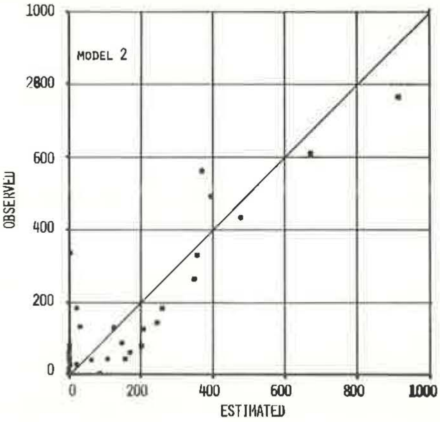


Figure 10. Observed and estimated allocation in the 10-district structure (model 3).

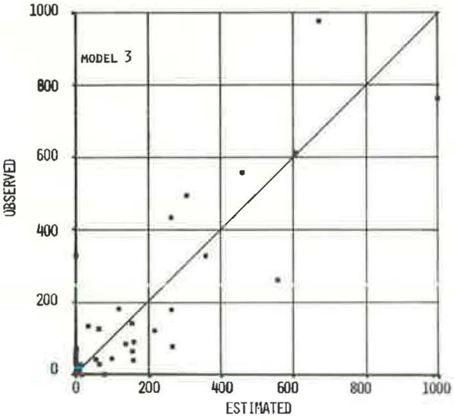


Figure 11. Convex set with feasible region within constraints.

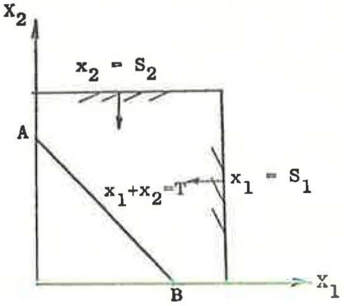


Figure 12. Feasible region partially within constraints.

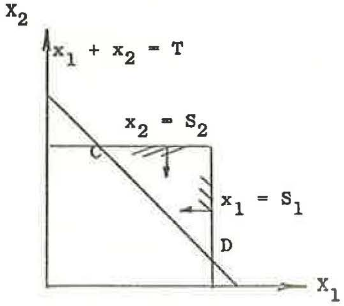
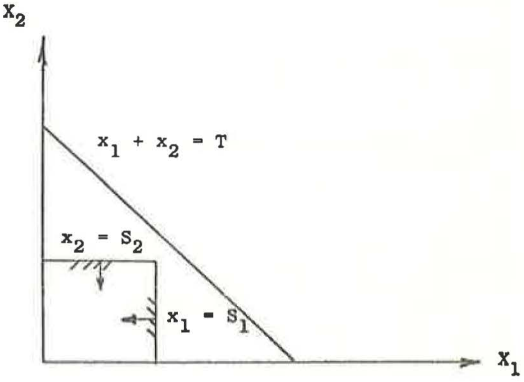


Figure 13. Degenerate case with feasible region outside constraints.



Another observation with respect to the formulation of the objective function is of importance. The authors assume functional forms for f(C, D), where C and D are cost and distance; e.g.,

$$C = \alpha e^{-\beta D} \qquad (\alpha, \beta > 0) \tag{8}$$

Then the contribution of distance to the disutility function is defined by the authors as the sum of the substitutions made between a given distance D* and the ideal distance, namely 0. Thus, the disutility of a facility characterized by C* and D* is expressed as

$$Z + C^* + \alpha(1 - e^{-\beta D^*}) \tag{9}$$

If the functional forms assumed for f(C, D) are indeed a close approximation of the real situation, then, for a facility characterized by D*, the corresponding C* is given as

$$C^* = \alpha e \tag{10}$$

Substitution of Eq. 10 into Eq. 9 yields

$$Z = \alpha e^{-\beta D^*} + \alpha(1 - e^{-\beta D^*}) = \alpha \tag{11}$$

This implies that the disutility is constant for all facilities under consideration. This does not appear to be true as can be seen from Tables 1 and 2, which describe joint distribution of cost and distance. It can be calculated that more than 55 percent of the parkers park closer than 1,500 ft from their final destination, and more than 80 percent park closer than 2,500 ft from their final destination. From this it appears that parkers find distances of more than 2,500 ft to cause more disutility, even at the reduced cost. Hence, the disutility function characterized by Eq. 9 requires some modifications. It is suggested that some form of relative weightage be attached to cost and distance, giving more weightage to less walking distance after 2,000 ft as depicted by the joint cost and distance distribution tables. It is hoped that this modification will add to the work done by the authors and help create a more realistic model.

Harry B. Skinner, Federal Highway Administration, Denver

The information in this paper represents an excellent and innovative approach to the problem of parking allocation. This procedure will surely serve as a basis for an important parking planning tool.

Through PAM the authors treat parking supply and demand as deterministic commodities. The resultant allocation of parking demand to the supply is subject to a fixed facility capacity and a disutility objective function. It would appear that a more appropriate approach would have been to assume a stochastic character to supply and demand because (a) parking supply is, to some extent, a function of demand and demand, to a certain extent, a response to, inter alia, the availability of space; (b) the planning process that generated the input statements of demand is acknowledged to be a less-than-perfect projection of future need; and (c) the allocation output is merely a tool to guide the decision-maker.

The computational effort in treating this problem stochastically would not be significantly increased, and the result would serve as a better tool because it would not be rigidly fixed to a given demand and a given supply. A probabilistic element of the objective function would allow the demand to respond to the supply, and a probabilistic supply constraint would allow the supply to respond to the demand. The resulting allocation would be improved in the following two ways:

1. Establish a supply-demand relation, and
2. Establish a probabilistic demand (rather than merely assign demand deterministically to supply, set the likelihood of accomplishing an occurrence).

This, in turn, should more nearly optimize a system of parking facilities of projected size and location and represent a more valuable tool to the decision-maker.

It may also be beneficial to the decision-maker if a sensitivity analysis were performed on the final parking allocation. The purpose would be to guide the decision-maker in answering such questions as the following: What would be the resultant usage of the facility or system of facilities if a change in pricing policy were implemented? How would a change in location affect usage of a facility?

Also, PAM uses a disutility function that is derived from a cost to park and distance to walk relationship. This is reasonable when considering the accommodation of long-duration work-trip parking. Work-trip parking is an important element of the total parking consideration in any community. For many parking facilities, this is the "bread and butter" of the operation. However, the measure of success of many operations is the accommodation of the short-term parker on a shopping trip, a business call, a professional visit, and the like. Surely, the derivation of a disutility function for nonwork-oriented parking would have to consider parameters other than cost and distance. Experience with the idiosyncrasies of parkers indicates that it may be necessary to take account of such things as self- or attendant-park operations and the character of the neighborhood through which the parker must walk to arrive at his final destination.

For a projected allocation a uniform set of conditions can be assumed. This is not so for current conditions and, therefore, not so for the derivation of the disutility function. For instance, a parking facility on the periphery of a renewed section of the city may be used by parkers having destinations in only half the set of possible destinations in the region of possible influence of the facility. Or a facility one block removed from a renewed area and separated from that area by an economically depressed and despoiled neighborhood will probably demonstrate a different disutility relation than a comparable facility completely surrounded by a renewed and vital setting.

These brief comments are intended only to stimulate consideration of techniques that may make the basic model more useful and should in no way be interpreted as questioning the credibility of the concept or the technique.

George T. Lathrop, Department of City and Regional Planning,
University of North Carolina

In general the authors have presented a potentially useful technique for accomplishing their stated objective: to simulate the choice of a parking facility by a user traveling to a given final destination (within the context of a concentrated travel destination area). They are to be complimented particularly on the simplicity of the model and its assumptions and the success of the simulation, given that simplicity. It goes without saying that one of the self-defeating aspects of many urban simulation models of all types in the past has been the complexity in parameters and mathematics, which have been necessary to make them "work," but which have made them so complicated that they are almost impossible to use (by normal humans).

If I have areas of concern about the model, they might be grouped under two headings: technical concerns and concerns about application.

In the technical area, I would have appreciated a more extensive review of the linkage matches. As the authors note with proper caution, the linear programming algorithm provides a system minimization that is accepted as a reasonable model of the grouped behavior or choices of individual decision-makers. They also note the disparity between the simultaneous behavior assumption of the linear programming format and the sequential nature of the actual process. Clearly, if the objective of the model is to be realized, to even a reasonable extent, there should be some strong correspondence between the choices actually made and the choices simulated or predicted by the simulation.

In the same vein of technical comments, the authors are also quite properly cautious in their claims for applicability of the model. Without replication independent of the data used for calibration, the "utility" of the coefficients of the disutility function must remain unknown. Of course, this question in no way addresses the use of the linear programming model; the specific parameters of the disutility function and the cost-distance aggregations are the application-specific values.

Along those same lines, it is interesting to note that the results of a linear disutility model apparently approach the quality of the results of the more complex functions. Given the nature of the linear programming algorithm itself and the earlier observations on the merits of simplicity, this is most encouraging.

Turning to concerns about application of the model, it must first be noted that, beyond their introductory statements concerning the objective, the authors refrain from suggesting potential uses other than by inference.

I think it is reasonable to raise the question of what might be called the "black-box syndrome." To elaborate, the presumption must be that the model will not be used by the devisors of the model alone. In the long run, assuming that other testing and validation leads to reasonable results, it may be further assumed that the technique (and even perhaps a computer program packaged and distributed for the purpose) will be used by many other persons to accomplish exactly the objective stated: to simulate individual choice. The computer program will be written to accept input of parkers by final destination, parking facilities by capacity and cost, and distance from all destinations to all origins. Output will be a listing of parkers versus capacity and a set of linkages between the final destination and parking locations. Instructions for fitting curves (or straight lines) to minimize variation between the actual and simulated situation will complete the package. Forgotten will be the authors' careful precautions about aggregation of data and grouping of origins and destinations and warnings about simultaneous versus sequential decisions and system versus individual optimization.

My concern about this eventuality should in no way reflect on the authors. They have done a careful job both of developing their technical work and of couching their conclusions about that work in thoughtful, well-chosen, and cautious reservations. My concern is rather with the creation of simulation models and their implementation on the computer, inasmuch as it is apparent that one of the frailties of human nature is to forget what is in the "black box" and to begin to accept the output as infallible. Unfortunately, there does not seem to be much that can be done. Perhaps in this case careful explanation of the assumptions inherent in the model and clear statements of exactly what goes on inside might help. The authors have done this to a large extent. It is up to the distributors and users to continue.

In summary, Ellis, Rassam, and Bennett are to be congratulated for a potentially useful application of a straightforward technique to a nagging problem. The simplicity of the assumptions and procedure will encourage others to both use their particular application and attempt similar applications in the same spirit. We may all look forward to the examination of alternative parking facility location strategies that use the model.

AUTHORS' CLOSURE

The authors would like to thank Sundaram and Feng, Skinner, and Lathrop for taking the time to comment on the paper.

Sundaram and Feng's comments focus on two points: theoretical considerations relative to the transportation problem and interpretation of the disutility function. Regarding the first point, we would like to note that, for lack of space, we deliberately avoided a theoretical discussion of linear programming. We certainly agree with Sundaram and Feng about situations arising in which total parking demand outstrips total supply. In the computer program, requisite cells are introduced if demand and supply are not equal. The second point that they made, namely that disutility remains constant for all facilities, is probably a misinterpretation. In the relationship defining the disutility of a facility characterized by a cost C* and a distance D* to a given destination, namely

$$Z = C^* + \alpha[1 - \exp(-\beta D^*)]$$

C* and D* are actually observed values. Specifically, C* is not derived from the relationship

$$C = \alpha \exp(-\beta D)$$

Thus, we believe that their second point may not be founded.

It should be noted that discontinuities may exist in the disutility function; for example, a parker may be unwilling to accept a walking distance greater than 1,500 ft. Consideration of such discontinuities can be accommodated within the current formulation of PAM. Estimation of the disutilities would require in-depth studies of the attitudes and perceptions of parkers, an alternative to the calibration strategy used in the current study.

We agree with Skinner that the problem could be cast in a stochastic programming framework. His comments regarding the stochastic nature of demand and supply are most appropriate. We envisaged such an approach but wanted to proceed by steps; therefore, we initially cast the problem in a deterministic framework. Also, we feel that the data acquisition and processing necessary to define the stochastic functions, not to mention computer running time, would require significant additional resources.

One of the reasons we chose to cast this problem in a linear programming framework was the relative ease of treating post-optimality problems. It is often possible to analyze the effects of changes in the price and supply vectors without re-solving the problem. For example, the operator of a given garage could determine how much he could raise his price (in the absence of a Phase II Price Board) without losing customers. Parametric programming techniques would be a most useful addition to the current computer package.

We certainly agree with Skinner on the desirability of introducing other variables into the disutility function. The general formulation of the problem does not preclude considering other factors such as waiting time, approach route, or whether a facility is attended or not. However, we wanted to proceed cautiously inasmuch as this was the first operational application of the model. One might also add that consideration of these other factors would require a substantial amount of data, which at present are not easily available. The main difficulty would probably be to find one single data source so that all the factors defining parking choice are compatible, which is not the case when the data base is assembled from secondary sources with all the ensuing definitional and sample size problems.

Lathrop raises two technical issues, namely, the linkage matches and the parameters of the disutility functions. Linkage matches have been one of our primary concerns in testing the model, as shown in Figures 8, 9, and 10. We fully agree with Lathrop that "if the objective of the model is to be realized, to even a reasonable extent, there should be some strong correspondence between the choices actually made and the choices simulated or predicted by the simulation." In this sense, we were particularly encouraged by the near replication of the zero cells (47 and 46 out of 48 on a one-to-one basis). We believe that, by more closely examining the nonzero linkages and by introducing (selectively) more variables into the disutility functions, we might obtain improved linkage matches.

In addressing the issue of the parameters of the disutility functions, Lathrop raises a critical question, the answer to which has eluded us for the time being inasmuch as we have not had the opportunity to test the model in other cities. Ideally, one would seek a set of so-called universal coefficients. However, transportation is a field in which such an optimistic outlook has always been tempered, willingly or not, by reality. Thus, we would rather seek to identify a set of variables and ranges of their associated coefficients that an analyst could easily adapt to a specific situation. In other words, keeping in mind that models, albeit useful tools, are not panaceae, we would attempt to narrow, to a reasonable degree, the options left to a field practitioner.

In conclusion, we would like to state how much we agree with Lathrop about the "black-box" syndrome. Modeling, and especially computer modeling, can easily become misleading whenever the proper caveats are cast aside. Should we conclude by saying that the myth of Icarus has often been forgotten? His "black box," if we dare say, offered great promises until.... He really should have listened to Daedalus' warnings!

PARKING SPACE ALLOCATION BY COMPUTER MODEL

Victor O. Gray, Victor O. Gray and Company, Inc.; and
Merritt A. Neale, Hunnicutt and Neale

This paper describes methods used in conducting a typical parking study of a central business district and points out the shortcomings of traditional methods used to assign and locate future parking demand. It outlines a method developed in a recent parking study of the Seattle CBD wherein a computer model was calibrated to fit the actual field conditions of parking demand and supply location. The principal characteristics used to calibrate the model were parking cost and walking distance, which were determined by extensive field surveys. The use of the computer model eliminates the need to manually adjust or balance parking demand against supply on a block-by-block basis in the determination of locations for future parking facilities. The model can also be modified to test various schemes in the planning of parking programs as well as alternate modes of transportation. To the authors' knowledge, the computer model developed in the Seattle study is unique in that this method has not been used and tested heretofore in a large metropolitan area.

• THE continually increasing use of the automobile as a personal transportation mode for more than 2 decades has created mounting and vexing problems for the individual motorist. This situation has been most acute in the central business districts of our large urban population centers. In spite of spiraling costs and efforts on the part of federal, state, and local governmental agencies to keep pace with the country's expanding highway and local street improvement needs, the three basic elements of an automobile transportation system, the vehicle, the roadway, and the terminal facility, are still far from being in balance with each other.

Terminal facilities for automobile and truck parking (and loading) are as much a part of a sound, comprehensive transportation system as are the streets and highways that carry moving traffic. To provide adequate service, not only must the system accommodate travel efficiently from origin to destination, but also it must provide for temporary storage of the vehicle, if the trip must be completed on foot. Time lost in parking and walking from the storage location more often than not offsets any increase in service resulting from improvement of the street system itself.

Regardless of local practices and policies with respect to development and operation of off-street parking facilities, the municipality or some other local political jurisdiction has the obligation to provide leadership and overall planning guidance in creating a comprehensive network of strategically located off-street parking facilities to serve the needs of all motorists in an urban area. It should be mentioned that curb parking serves a majority of the parkers in all but the nation's largest cities, and, by virtue of this fact, the municipality generally assumes the major role in establishing a city-wide parking system, along with the necessary cooperation from private business, civic, and other interests.

PARKING STUDY PROCEDURES USED IN THE PAST

The steps heretofore used in conducting a parking study generally are well known. Depending on the study's objective and the results desired, the methods employed in data collection, analysis, and development of a parking program based on the study's findings are quite similar. The size and scope of the study and area to be surveyed depend on the nature of the study. Comprehensive parking surveys usually cover all of a central or secondary business district. More limited studies may be appropriate in sectors of these business areas. Finally, special-purpose studies usually are made for specific parking generators, such as new office building complexes, hospitals and medical centers, recreational facilities such as sports stadiums and convention centers, airports, university campuses, and industrial plants. Because a comprehensive study designed to investigate and analyze the parking problems of the CBD generally is the most costly in terms of data collection and analysis, this discussion will be confined to such a survey. However, the same procedural steps, on a more limited basis, can apply to a more confined or special-purpose study area.

After information is gathered on the supply of existing on- and off-street parking spaces within the survey area, field studies are conducted at selected parking locations and at major generators of parking demand to determine parker habits and characteristics. These consist of trip purpose, parking duration, space accumulation and turnover, extent of illegal parking at the curb, walking distance, and relative parking costs. Usage patterns are observed for defining both short-term and long-term parking demand. Generally, the dividing line between these two demands occurs at about 3 to 4 hours.

Usually, the most costly and difficult data to gather relate to location of parking demand. For example, the shopper would like to be able to park in front of the department store counter if this were physically possible. However, in nearly every downtown area with a critical parking shortage, people often find themselves parking at locations inconvenient to their destination. Even with higher parking costs at facilities adjacent to major generators, such as department stores, office buildings, and the like, the average motorist weighs the greater walking distance from his parking place to his destination against the higher cost and greater convenience of a close-in location. These two factors, walking distance and cost, are considered to be the most significant variables in determining the location as well as allocation of parking demand.

Other factors affecting choice of parking location, though extremely difficult to quantify, are capacity of parking garage or lot, accessibility, topography, environment, type and quality of service, socioeconomic level of parker, trip purpose, type of demand served, number and type of passengers, weather and seasonal climatic conditions, other available travel modes in CBD, and arrival and departure times. A combination of thorough knowledge of the local community and experienced engineering judgment is essential if the foregoing factors are to be taken into account with any degree of reliability.

For many years, zoning ordinances throughout the United States have recognized a relationship among land use, amount of floor space, and parking demand. In recent years, quantitative results from comprehensive parking studies have allowed a more definitive evaluation of parking generation by land use and building size. A comparison of peak accumulation of parker destinations (demand) and gross or net rentable areas of selected buildings leads to a determination of the ratio of demand per 1,000 sq ft of floor space.

The number of parkers destined to a particular block and the accumulation of parked vehicles at any given time are dependent on the various generators located within the block. For example, a block consisting primarily of commercial or retail establishments will be visited by many parkers, but they park at different intervals throughout the day. The actual accumulation of parkers destined to a block containing many retail outlets may be less than that of a block that has an office building because the majority of employee parkers remain all day. Therefore, it can be seen that unit parking ratios can vary widely, depending on the types of parking generators and trip purposes of those parkers using the available spaces. However, as stated previously, walking distance and parking cost still remain the two most important determinants in allocating demand.

Next, parking demands for each block in the study area are derived by tabulating arrival and departure times of parkers destined to the block. Parking accumulations at private facilities are assigned to the block of parker destination, and total parking demand for each block is determined. Because the peak demand for each block does not occur simultaneously, parker accumulations are evaluated by parking type and duration. From these calculations, the peak parking demand for the study area is determined.

To arrive at parking space surpluses and deficiencies, on a block-by-block basis as well as for the total study area, requires consideration of ingress and egress of vehicles and fluctuations in usage because these factors reduce the effective capacity of parking facilities. Therefore, existing parking supplies are adjusted to reflect reduced efficiency of the facilities. Generally, efficiency factors of 90 percent for curb parking spaces and 85 percent for all off-street spaces are applied to existing facility capacities. Application of these efficiency factors to all spaces in the survey area produces an adjusted parking space supply.

When the adjusted supply is related to existing parking demands, parking requirements in terms of surplus and deficient spaces can be derived. Block-by-block surpluses and deficiencies usually are classified separately for short-term and long-term parking supply and demand. The resulting surplus or deficiency is determined for each block independent of all others. This approach is appropriate if it is assumed that each block is self-sufficient and contains adequate parking space to accommodate all of its parking demands. However, this condition does not normally occur in actual practice, and field studies often reveal that many parkers leave the block in which they have parked and walk to their destinations. This makes it necessary to introduce the element of pure judgment to take into account parking space utilization in nearby blocks to offset excess demands. Without additional field studies, which involve more cost, there is no real degree of certainty that parkers actually are utilizing nearby spaces that still may be convenient to their destinations. At this stage of analysis, the exercise of judgment based on the experience of the individual analyst means that the final allocation of parking space demand is subject to the expertise of the person analyzing and interpreting the data. A more intensive application of the parking cost variable, coupled with the variable of walking distance, in the opinion of the authors, should result in a more precise assignment of parking demand.

In forecasting future parking demand the application and development of a computer model for more accurate allocation of parking space demand has very promising potential. Such a model was developed and utilized in the Seattle CBD parking study conducted in 1970. It can be applied, with minor adaptation, to cities of less than 50,000 population involving a CBD of a minimum of 12 to 15 blocks and to cities with a population in excess of one million. The decision to use the computer model would depend on field data available, availability of the program, and degree of accuracy required.

BASIC DATA

The basic data required for any CBD analysis include a study area definition, block or block face identification, determination of land or access restraints, a basis for generating parking demand, a parking inventory, knowledge of parker characteristics, and a means of projecting these components to the design year. The study area should be large enough so that parking activities on the study boundary will have a minimal effect on the data developed within the retail, general office, governmental, or other activity areas.

The Seattle study area included 321 blocks covering an area of 842 acres. Each block was identified by a block number, with all data collected in the study referenced to this numbering system to establish complete parking information for each block. Freeway location and topographic characteristics of Seattle limit parking-related activity to three general regions. Blocks were coded by these three areas to initiate special procedures for parkers walking between them.

Parking demand in the Seattle study area was generated by applying unit demand factors to land use square foot area, producing long-term and short-term parking demand for each study area block. The inventory of parking supply is similarly categorized by unrestricted time stalls (long-term supply) and restricted time stalls (short-term supply) on study blocks.

Parker characteristics to be identified for each study area block consist of the distance people walk to park and the parking cost paid. Projections to design years were based on local forecasts of employment and population growth prepared by city and state agencies, along with an examination of relatively firm CBD building commitments.

FIELD SURVEYS

To supply the above information for the allocation model, we made extensive field studies. Figure 1 shows the overall Seattle CBD. Dominant land uses include the retail core, the office district, the hospital area, the waterfront, and major access facilities such as I-5 and I-90. In the Seattle CBD area, selected blocks representing various types of parking activity were surveyed, providing sample parking characteristics to be projected to similar land use blocks in the study area. In the course of the study, some 47 buildings were surveyed for long-term usage, and eight major activity centers were examined for their short-term usage. We distributed 13,798 questionnaire forms, and 9,726 were returned (70.5 percent response). We conducted 3,640 detailed interviews at selected short- and long-term parking generators. The high return indicated not only great interest in finding a solution to the parking requirements, but also citizen cooperation with the approach utilized. Here the approach emphasized the needs of people and their desires as contrasted to counting cars, curb violations, and space utilization. Figure 2 shows the overall long-term (4 hours or more) and short-term demand on a block-by-block basis developed from the analysis of the field survey results.

PARKING SPACE ALLOCATION MODEL

Data Input

The technique the parking space allocation model uses is to simulate the entire study area, parking characteristics intact, with a computer program. The model is constructed by establishing the unique parking characteristics of each block in the study area. This is provided by data categories in which parking information generated from the field survey is located. Each study area block is associated with a list of block characteristics and deals with input data required for the model. A block is given a "block number" for general identification. X and Y coordinates providing block positions are stored in the "location" category. A "region" identification indicates topographic area in which the block lies. "Bridge" coordinates provide the shortest walking distance across topographic barriers. The cost of parking on the block is noted in relative units, and short- and long-term parking supply is specified in number of parking stalls. The parkers on the block are represented in the remaining categories. Both long-term parkers and short-term parkers are classified into nine walking distance and parking cost categories. This classification identifies a particular block's parking demand by the walking distance parkers desire and parking rates they are willing to pay when parking spaces are available (Fig. 3). For simplification, three distance categories are shown: a one-block walking distance, a two-block walking distance, and a three-block walking distance. Corresponding to these distance categories are parking rate values expressed in relative terms. A block's parkers are represented by the number desiring parking in each category. For example, 50 individuals desire parking within one block and will pay a relative parking cost or a rate of 7 units (Fig. 3).

Computer Operations

The model now has all the required information to control the distribution of parkers in the study area. The actual computer operation parallels the decision processes made by an actual parker: The space must be available, it must be within the proper walking distance range, and the cost of parking must be acceptable.

The distribution of parkers to the supply involves an incremental technique, where one parker increment in a block is "parked," and the parking space meets his walking distance and parking cost criteria. Each time this occurs, the parking supply and demand of the affected blocks are adjusted. Figure 4 shows a parker increment taken from the demand category being distributed to find a suitable parking space, in this case one having a walking distance within one block and a rate of 7 units.

The acceptability of a parking stall to a potential parker is determined by a series of computer checks on the supply stall under consideration. The walking distance from the destination block to the parking location is calculated by comparing coordinate data

Figure 1. Seattle central business district.

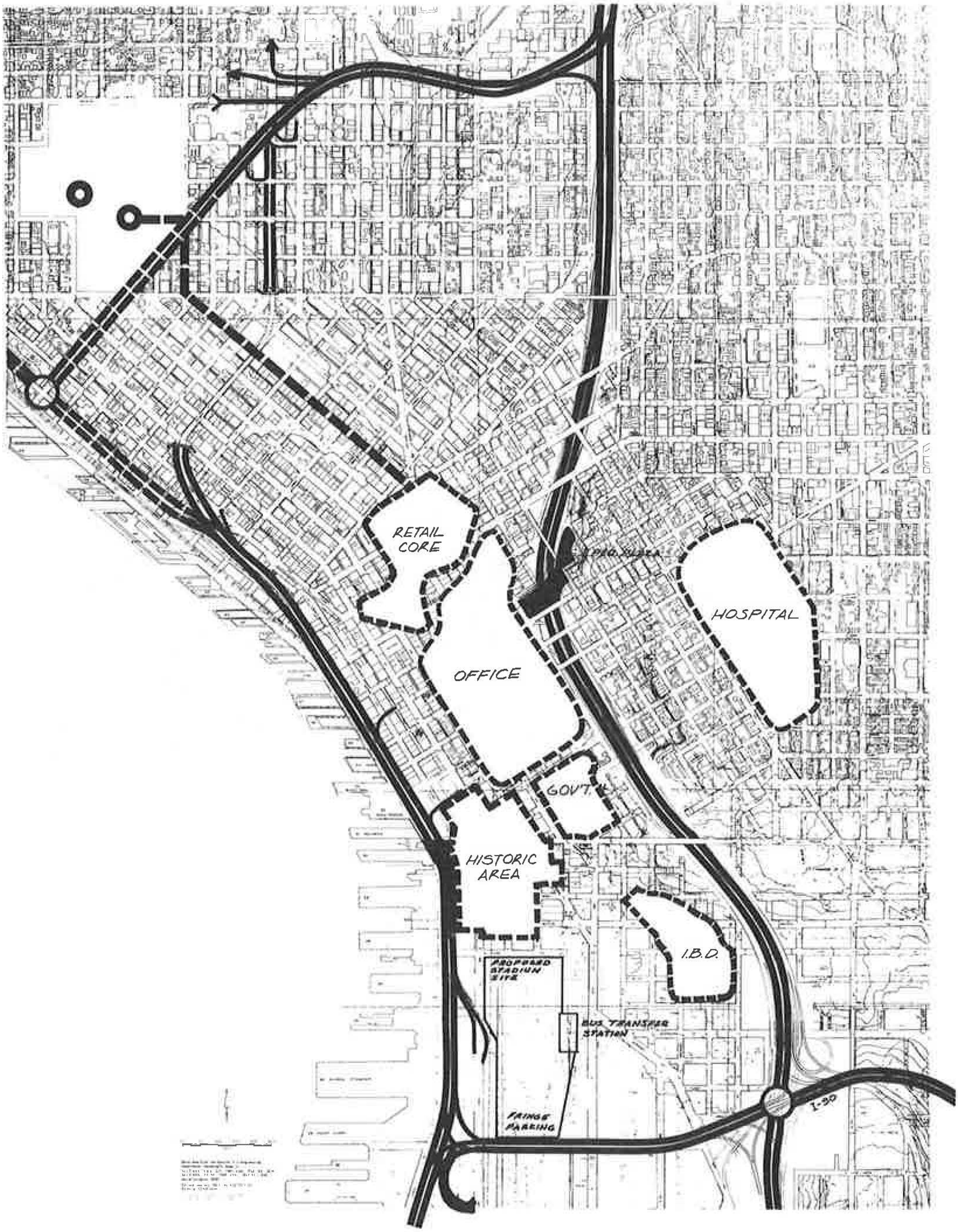


Figure 2. 1970 parking demand.

Figure 3. Demand categories.

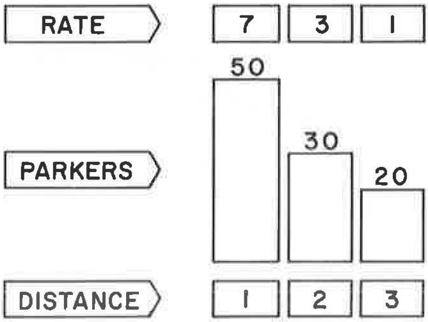
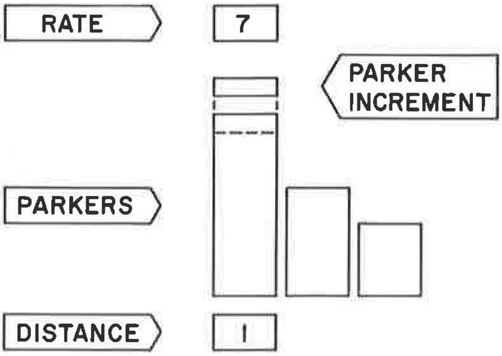


Figure 4. Parker increment.



of the demand and supply blocks. In addition, "region" identification is compared to detect a barrier between the two blocks that would alter the normal rectangular coordinate walking pattern of the parker. If this exists, a routine to "bridge" the barrier and calculate an adjusted walking distance is called.

When a supply block is found that meets the parker's distance criteria, the rate of the block is checked. If this check is passed, the supply block is identified as a "qualifying supply block." This procedure continues until all qualifying supply blocks that meet the parker's qualifications are found in the study area (Fig. 5). This indicates a demand block D where a group of parking supply blocks S have passed the parker's distance and rate criteria. From this group of blocks, those blocks that contain parking supply receive an equal proportion of the parker increment as shown in Figure 6. This figure shows the same group of supply blocks, with 10 parker units divided between two blocks. In this case, the remaining qualifying supply blocks S had all stalls filled in prior operations. When the condition exists where the supply has been filled on the qualifying group of blocks, the parker increment is proportioned to these blocks, creating an equal additional deficiency on each of the qualifying blocks (Fig. 7). With all qualifying supply blocks filled, the 10 parker increments are proportioned to all qualifying supply blocks, and an equal additional deficiency is created on these blocks.

The next parker increment to be distributed is selected from a new block, thus rotating the study area to prevent one block's parkers from having a sequence advantage over another's (Fig. 8). By distributing parking demand in small increments and rotating the study area blocks after each operation, we minimize sequence advantage between blocks in relation to available parking supply. These techniques are performed for each parker increment until all parking demand has been distributed. In actuality, more than 40,000 parkers in the Seattle analysis were distributed to the parking supply in 10 parker increments, which required 12 hours for each run on an IBM 1130 computer.

Results of the parking space allocation model are read from a list of block identification numbers corresponding to a value indicating the status of that block's supply. A positive value represents parking stalls remaining, or a surplus of parking on the block, and a negative value indicates deficiency, or a shortage of parking stalls.

Short- and long-term supply and demand are maintained in separate categories. In the program operation, short-term parking demand is distributed first and has priority in locating suitable supply. Once short-term supply has been consumed, short-term demand is "parked" in long-term supply. Long-term demand is distributed into remaining long-term supply. Thus, deficiencies are recorded, primarily, in the long-term supply column as follows:

Block Number	Long-Term Supply	Short-Term Supply
8	-10	3
9	2	0
10	-15	0

The results of this distribution are recorded by altering the status of each block's parking supply. As an assignment is made to the block, a corresponding value is subtracted from the supply. A positive value indicates stalls remaining, a zero value means supply is filled, and a negative value indicates a parking deficiency. Location and magnitude of parking deficiencies within the study area were plotted on a map of the study area as shown in Figure 9.

INTERPRETATION, CALIBRATION, AND VARIATIONS

The general utilization of the parking space allocation by computer model involves developing a synthetic representation of an existing field condition, and calibration of the model to produce these conditions. This prepares the model for future projections and variations offering investigations of parking conditions.

To investigate future parking conditions with the model, we converted population, employment, CBD building projects, and other parking activity-related indicators into

Figure 5. Qualifying supply blocks.

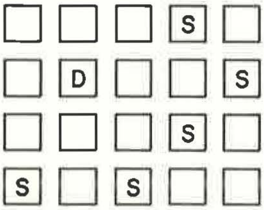


Figure 6. Assignment of parkers.

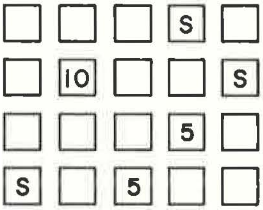


Figure 7. Parking deficiency.

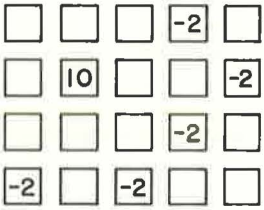


Figure 8. Block rotation.

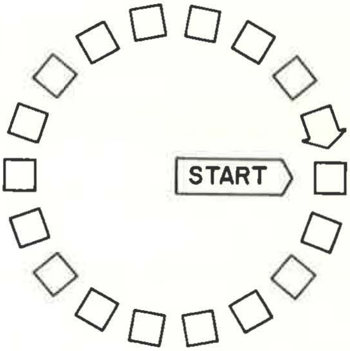
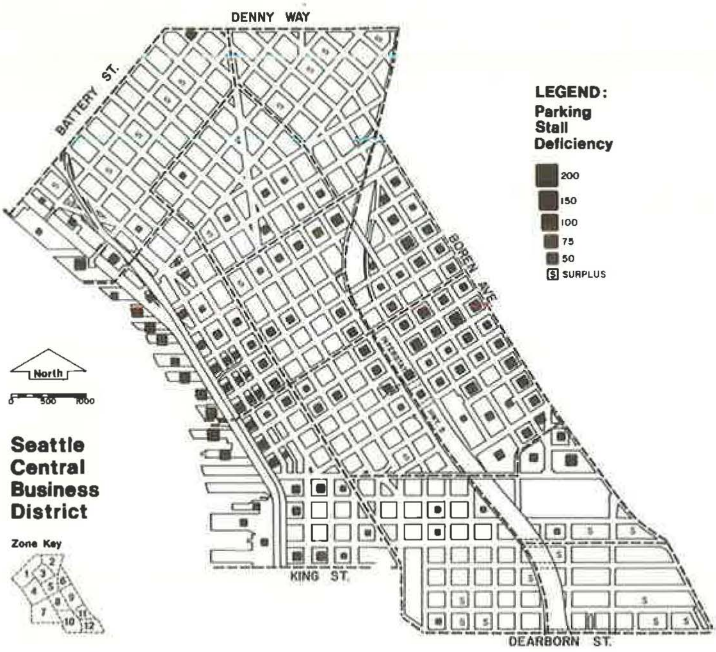


Figure 9. Parking deficiencies within study area.



parking demand and parking supply adjustments for the affected blocks. The computer program and distribution then provide a simulation of future parking demand. This approach provides a simple method of updating data on a block-by-block basis. As land use changes, affecting either demand or supply, it is necessary only to revise one card, and the program can be rerun and the results analyzed. This program gives the administrators in a city the ability to test proposed or planned projects for their relative parking impact on adjacent areas. The relative attraction for parkers can also be compared on a block-by-block basis.

Another aspect of the program, and perhaps its most important feature, is that adjustments in parking cost can be studied as required. The program can be modified to limit the deficiency generated to a minimum parking cost. For example, to make preliminary judgments of where to locate a municipal parking facility requires that a minimum parking cost be assumed and the resulting deficiency for the particular area be determined. This provides the first step in the economic feasibility study of a proposed facility. In the Seattle study, a minimum parking rate of \$15.00 per month was established (Fig. 10). Those parkers who, by survey results, will not pay that rate are simply dropped out of the analysis.

As a further variation on the model, the program can be simply modified to study the effects of parker walking distance in most CBDs. The retailers, particularly, have been hard hit by competition from the suburban shopping centers. In the suburban center, the shopper literally drives up to the front door, whereas in the CBD the shopper must pay a direct parking cost besides walking a considerable distance. The program can also determine parking deficiencies based on different walking distance restrictions. Figure 11 shows parking allocated with a maximum walking distance of 500 ft for shoppers or visitors and 1,500 ft for employees or all-day parkers.

OTHER APPLICATIONS OF SPACE ALLOCATION

The program can also be linked up to tie in parking supply locations with arterial and freeway access routes. In the original Seattle CBD study, this was not done because of the limited scope of the study. However, without question, this step should be completed inasmuch as parking space allocation is fundamental to an overall transportation network. In the final recommendations to the city of Seattle, the relationship of parking facility location to the access routes was given top priority in line with city planning policies, which require a minimum of pedestrian-automobile conflict in the core area.

The block characteristic data and computer program were also used in a study of the impact of Interstate 90 on the traffic distribution within the Seattle CBD. As part of the I-90 facility, a transportation center providing a fringe parking area immediately south of the CBD is being proposed. This transportation center with fringe area parking is to be connected to the Seattle CBD by means of a shuttle bus system. The shuttle bus headways and frequencies were converted to time and cost, and this cost was added to parking cost at the proposed transportation center. Using the access routes determined from field studies and converting them to travel time costs, the computer program then determined the probable parkers assigned to the transportation center for a given design year, based on competitive comparison with existing parking supply (Fig. 12). This figure shows the overall Seattle CBD with I-90 and the transportation center shown at the bottom of the figure and a shuttle bus line through the CBD. In this case, the motorist is given the option of using the freeways and downtown streets to arrive at his parking location or of using the proposed transportation terminal for parking and riding a shuttle bus to his final destination. The assignment to either option is made on a time and cost basis by the computer program with many different variables tested. The influence area shown for the shuttle is typical of the results obtained.

CONCLUSIONS

This paper has outlined procedures used in conducting a typical parking study. Attention has been called to the fact that in such studies, in spite of the data accumulated, the final analysis of demand allocation has been done largely by means of engineering judgment. This judgment can be excellent, merely satisfactory, or substandard, de-

Figure 10. 1975 parking allocation of those willing to pay $15.00 per month.

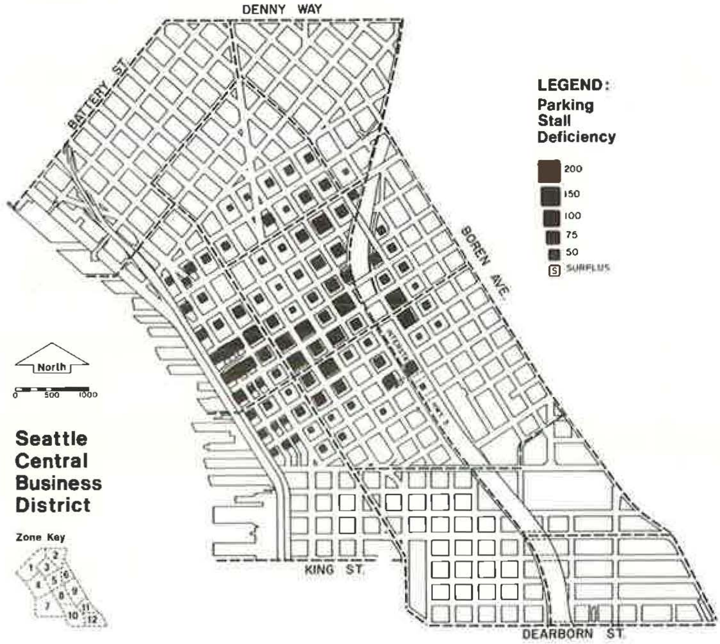


Figure 11. 1975 parking allocation considering limited walking distance.

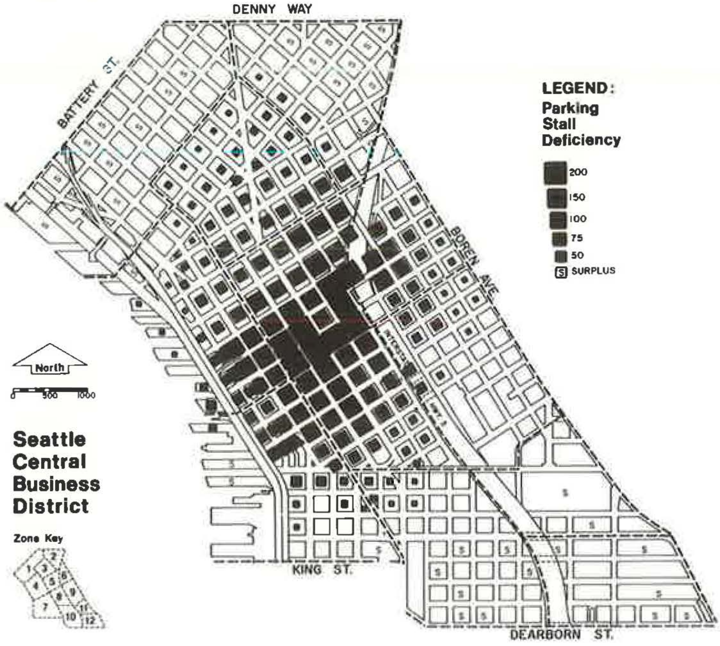
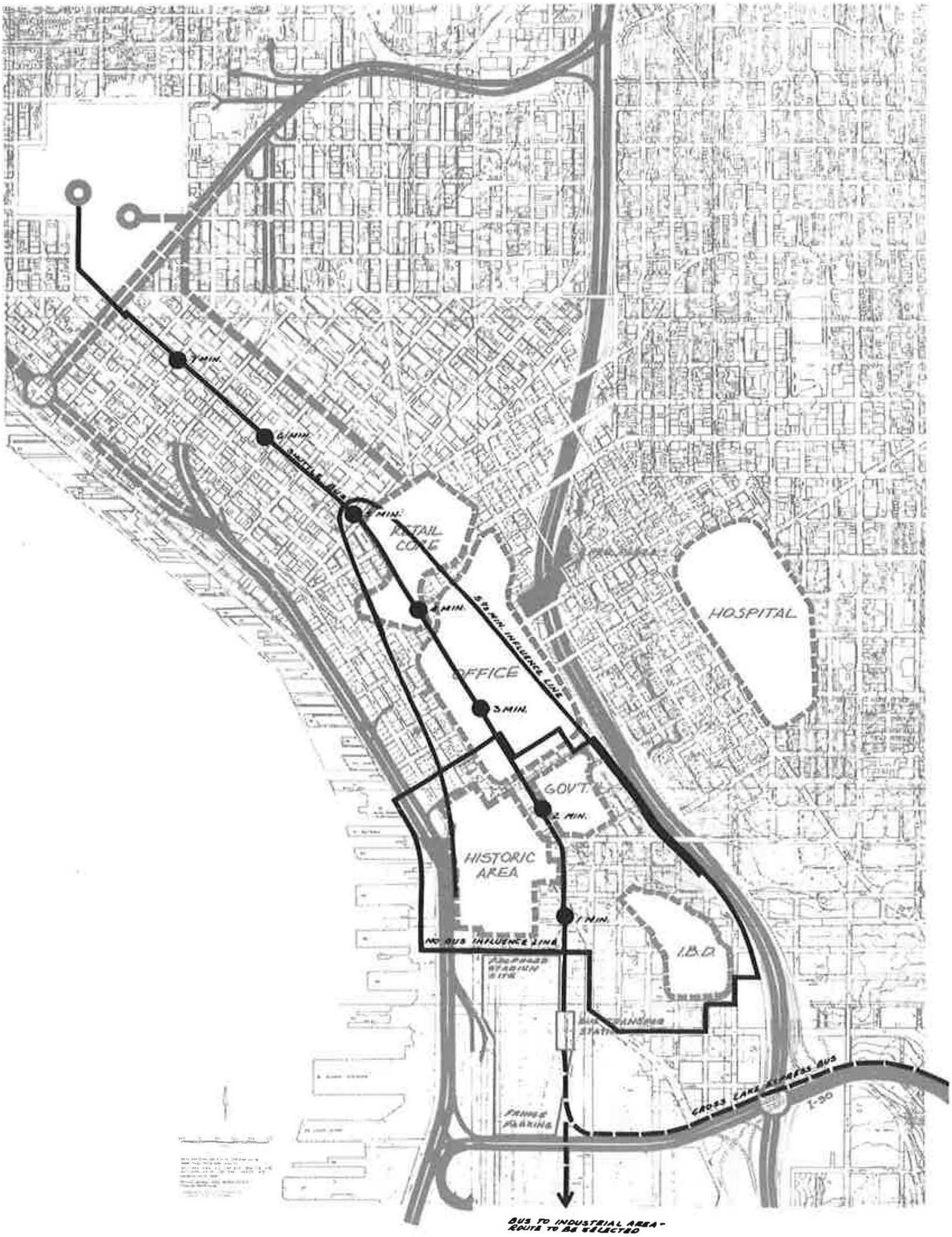


Figure 12. Transportation terminal and shuttle influence area.



pending on the experience of the analyst conducting the study. The parking space allocation by computer model provides a means by which subjective judgments can be reduced to an absolute minimum. By using a combination of walking distance and parking cost determined by field data, the computer model can be calibrated to fit the actual conditions at hand. Parking space demand and location assignment can be determined on a block-by-block basis through use of detailed economic data for the particular study area. The computer program and resulting output provide a realistic and simple basis for updating and testing future parking programs. The program further provides a means by which regional transportation studies and alternate modes of transportation can be analyzed for their effect on proposed parking programs.

PROGRAM STOCK

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STOCK is a computer program for localizing parking demand with respect to its supply. It allows the simulation of rush-hour parking phenomena and the calculation of a global index of the difficulty of parking (generalized cost). Plans for a rational parking policy can then be tested by comparing generalized cost to that of the present situation considering receipts from parking charges to users.

•PROGRAM STOCK is a fairly simple tool that enables the simulation of rush-hour parking phenomena and the calculation of a global index of the difficulty of parking (generalized cost). By comparing generalized cost to that of the present situation and by calculating the receipts from parking meters and other parking places, we can test plans for a rational parking policy (for instance, charging for on-street parking or creating inexpensive car parks for long-term parkers). The calculation of parking demand is assumed to be carried out before the program is run.

The model used has been worked out from an analysis of parking phenomena and therefore can be applied to a fairly long-term problem or to a situation very different from the actual one.

This program is written for CDC 6600 and IBM 360 series computers.

PROGRAM DETAILS

Program STOCK distributes to various car parks the total demand during the rush hour as a function of (a) places available, (b) the risk of committing a minor offense by staying longer than permitted in a "blue zone" (i.e., a zone in which parking is controlled) or by illegally parking, and (c) parking charges.

When places to park become more and more difficult to find, it is possible to transfer parking from one zone to another. The average distance separating these two zones is determined and, from this average, the trouble of traveling by an intermediate route is evaluated as a monetary value of time (and eventually of distance).

It is assumed that in the presence of several solutions users will choose that with the smallest cost (in the widest sense).

The program simulates the arrivals of cars and their occupation of places by parking purpose during the peak hour; purposes for parking include residential, work, and business. The hypothesis is that places are first filled by those parking to get to their homes, then by those going to work, then by those on business, and so forth. The gross assumption is valid inasmuch as purpose is a crude measure of the duration of parking.

Purposes are assigned in order of decreasing stay. That is to say, for example, that at the peak parking hour those on business or shopping trips find it more difficult to find a place than those who have traveled to work or those who are already parked near their homes.

From studies in several French towns average parking durations were found to be about 8 hours for residents, 5 hours for workers, and 1 hour for others. Nevertheless, there are some variations about these averages as there are variations in arrival times. To make the rigid hypotheses given earlier more flexible, one can multiply the demand (by purpose) by a coefficient. (Later, we can divide parking space utilization by this same coefficient to reconstitute the initial demand.) This supposes that we take a larger demand than that at the peak and that we get some places free (some departures occur before the peak).

The "departure coefficient" is introduced as the parameter AMDA, less than 1. It is possible to multiply the calculated occupation of parking spaces by this coefficient to give a figure corresponding to the peak. (AMDA is therefore the inverse of the multiplicative demand coefficient.)

Specifically, the study area is divided into zones. Parking spaces are represented by a network consisting of the following (Fig. 1):

1. n centroids representing the zones;
2. One "injector" centroid representing the total desire for parking in the zones (this centroid must have the number 1);
3. Arcs connecting centroid 1 to all others, representing the possibilities of parking in the corresponding zones (street parking, legal or illegal, and charging car parks); and
4. Chords joining pairs of centroids, representing walking distances between the various zones.

This structure is shown in Figure 1. The choices open to a person wishing to park in zone 7, for example, are as follows:

1. He can park directly in 7 in a pay car park (cost C_1),
2. He can park illegally in zone 7 (cost C_2),
3. He can park in 5 and walk to 7 (cost C_3), and
4. He can park in 12 and walk to 7 (cost C_4).

The program calculates the costs of each solution and gives the cheapest, for example, C_3. A place is then filled in zone 5, and a walk route is chosen between 5 and 7.

Then the program calculates the costs of several routes (those from 1 to 5 and 5 to 7) as a function of the traffic already using them. The cost on an arc increases with the traffic on it and becomes infinity as the capacity is exceeded. This prevents more and more people from going to an already saturated zone. However, so that the excess is minimal, it is advisable to eliminate certain purposes, thus reducing subsequent arrivals.

So as not to unduly lengthen the time for solution, we note the following points:

1. Parking demand is treated in increments. Demands smaller than that of residents will be treated in one increment and at least 10 increments of 10 percent will be necessary for the other purposes.
2. Smaller capacities must be defined most precisely. They are very important inasmuch as illegal parking is due to pressures of demand.

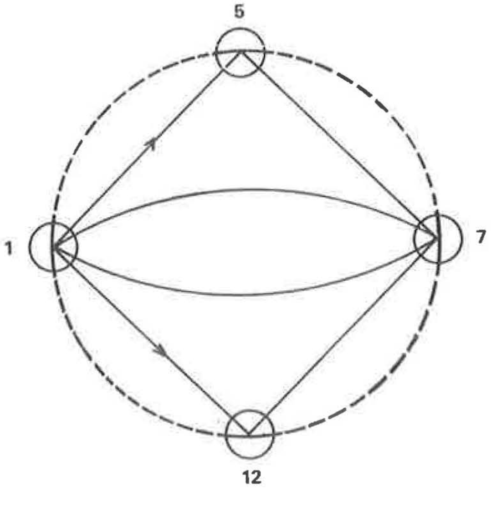
In the program the number of increments is introduced in the parameter IFRAC.

As the work progresses the results of the simulation for each purpose are printed in the form of a table that gives the levels for each type of parking in each zone in the column "traffic estimate"; also printed are the initial cost (i.e., with zero level of parking), the capacity, and the traffic-capacity ratio.

The letter R or an asterisk in the cost column indicates infinity, i.e., saturation. For the walking links, the program indicates the volumes between one zone and another. Zero flows or parking volumes are not printed.

This table is followed by a printout of results in terms of generalized costs. The method is used as follows: To compare two situations corresponding to two dif-

Figure 1. Parking network.



ferent hypotheses (of supply or demand), one calculates the sum of the costs to each user (comprising various penalties, risks of contravening the regulations, and so forth) initially for the rush hour. These results for each purpose and each flow are multiplied by the cost before saturation and the vehicle occupation factor, parameter OCCUP. By dividing this sum by the appropriate total number of users, one obtains an average cost per user for each purpose. This cost represents the average difficulty of parking for this purpose. It is therefore possible to compare this with the average costs for other purposes or with that for the same purpose in a different situation.

The comparison is made by calculating the generalized cost for all journeys and all users. For this the rush-hour levels are multiplied by the parameter TAU, the peak factor, which computes all journeys from the peak figures. The total cost thus obtained is added to the total costs for other purposes already calculated.

Having obtained the total accumulated cost, we divided it by the total demand and thus obtain an individual journey cost, summed for all purposes. This cost can be taken as an indication of the difficulty of parking for a given situation. Compared with the cost of another situation it will indicate the relative advantages and disadvantages of the two. To get the journey costs for any purpose only requires that the two successive cumulative costs be subtracted (similarly for the demand).

The program first needs to be given the values of the parameters IFRAC, TAU, AMDA, and OCCUP. Then it prints the total demand (drivers and passengers) at peak hour and individual cost for the purpose being considered. Finally, it prints the demand and journey cost summed for all purposes.

A remark on this process is warranted. It is fundamental to give a forecast of the "reserve zones" (eventually fictitious), which will serve to provide the increased demand in the study area.

Table 1. General structure of punched-card deck.

Name	Card	Definition
Data Control	One	Integer value given to variable LAGE written in first 4 columns (if LAGE = 9876, all network and demand data will be written on disc; if LAGE ≠ 9876, it is not possible to write on disc or to modify any networks or demands).
	Two	Job title written in columns 1 to 80.
	Three	Contains two data values: COEF (1), the value of time written in columns 9 to 16, and COEF (2), the value of distance written in columns 17 to 24.
Network Data	One	Network number written in first column (this reference number is that of the scheme if it refers to a parking network and is equal to 9 if the network is the walking network; schemes are numbered sequentially from 1 to 8).
	Two	Network title written in columns 1 to 80.
	Subsequent	Defines arcs joining pairs of centroids; network description is terminated by blank card.
Demand Data	One	Number indicating the demand set (which is also number of corresponding scheme network) written in first column.
	Two	Title written in columns 1 to 72; figure 1 written in column 76; number of zones plus one written in columns 79 and 80.
	Subsequent	Describes demand for parking in each zone, and data are terminated by blank card.
Parameter Data		Each card refers to a scheme, and each card contains four parameters: IFRAC, number of loading increments, written in columns 1 to 8; TAU, peaking factor, written in columns 9 to 16; AMDA, departure coefficient, written in columns 7 to 24; and OCCUP, car occupancy factor, written in columns 25 to 32.
Network Cards	Parking network	Consists of arcs going from centroid No. 1 to other centroids, each arc representing a particular parking possibility, written as follows: origin, column 6; destination, columns 10 and 11; C, column 20; cost, columns 21 to 24; capacity, columns 56 to 60; and centroid No. 1, column 68.
	Walking network[a]	Consists of chords joining pairs of centroids, each chord representing a possible walking route, written as follows: origin, columns 5 and 6; destination, columns 10 and 11; distance, columns 16 to 19; S, column 20; speed, columns 21 to 24; S, column 35; speed, columns 36 to 39; capacity of chord from origin to destination, columns 56 to 60; capacity of chord from destination to origin, columns 62 to 66; and centroid No. 1, column 68.
Demand Cards		A demand figure is given to each destination; nine demand values per card; coded as follows: title, columns 1 to 72; number 1, column 76; and number of centroids, columns 79 and 80 (demand expressed as number of cars that wish to park in zone).

[a] Instead of walking link, data could represent minibus or shuttle bus between peripheral zones and central area.

Overall, the total demand must not exceed the supply because the program will continue to assign the residual demand to saturated zones. Because the calculation of generalized costs is made with the aid of parking costs before occupation, the results will not make any sense.

On the contrary, with the reserve zones, an indication will be given of the number of walking trips that go toward increasing the general cost. One, therefore, needs a means of reducing the demand; it is sufficient to do so in proportion to the additional cost above that considered normal or maximum.

GENERAL DATA STRUCTURE

For any parking purpose the complete network is composed of parking arcs and walking links. The former are numerous inasmuch as they increase as the square of the number of zones increases. On the other hand, the walking links do not vary much from one scheme to another. One can decide to store parking networks for each purpose and the walking network on separate discs. Similarly the demands can be stored.

The program thus takes charge of reading and matching the complete networks and links with the corresponding demand for the same purpose. This procedure has the advantage of permitting a series of schemes to be tested on the same study area with the same zones; between one purpose and another the walking network will not be modified, but possibly the characteristics of the parking network are printed, which enables the testing of the various hypotheses.

Perhaps it will not be necessary to modify the networks or the demands in some cases, but instead it may be desireable to change the number of loading increments, the peaking factor, the departure coefficient, or the occupancy rate. In this case it is only necessary to change the last data cards. The general structure of the punched card data deck is given in Table 1.

FORECASTING IMPACTS OF TRANSIT IMPROVEMENTS AND FRINGE PARKING DEVELOPMENTS ON DOWNTOWN PARKING NEEDS

E. L. Walker, Jr., and John J. Cummings, Wilbur Smith and Associates

The changing economic role of most downtown areas, with employment becoming the major growth factor, has resulted in a rapid rise in peak-period automobile trips and all-day parking demands and a lower growth rate for short-term (under 3 hours) parking. Few CBD core areas can accommodate all current parking demands or the expected higher demands of the next decade. This paper reviews techniques used in a recent Baltimore study to forecast the number of long-term CBD work-trip parkers who can be diverted to a planned new rapid transit system and to CBD fringe and outlying parking locations, linked to the CBD by improved transit and other people-mover systems. Without these developments, a core-area deficiency of 15,700 spaces is estimated for 1985—double the 1969 deficiency. Recommended programs to divert some long-term work-trip parkers to fringe and outlying locations can reduce the core-area deficit to 10,900 spaces. Also, if the rapid transit system is operational in 1985, most CBD sectors will have surplus parking space. The core area will need only 4,500 more spaces. These needs can be met by recommended 1975-1985 CBD parking programs. This paper explains the parking demand forecasting model and suggests methods for future refinement of the model.

•THIS PAPER reviews techniques used in a recent Baltimore study (1) to forecast the amount of downtown parking that can be eliminated by a planned new rapid transit system and by diverting some CBD parkers to fringe and outlying locations linked to the CBD core area by improved transit and other people-mover systems (1).

The Baltimore study was structured to take into account three transportation trends that have emerged in downtown areas of most large and medium-sized cities over the last 2 decades. These trends create a need to reappraise parking survey techniques with respect to the role of public transit and to provision of new parking facilities. The three trends are as follows.

1. The changing land-use patterns and shifting economic base of downtown areas have produced a sharp increase in morning and afternoon peak work trips, as downtown areas continue to grow in importance as employment centers for financial, governmental, and specialized professional services. They also have caused a reduction in the growth rate (and, in some cases, an actual decline) of midday and evening trips for shopping, entertainment, and other personal and business purposes.
2. Continually but gradually, the proportion of CBD trips made by automobile, for all trip purposes, has increased, and the share of CBD trips made by transit has declined.
3. From the combined effect of these two trends, recent survey findings show an accelerated growth in peak traffic flow within the CBD and in major access corridors and increased demand for more off-street parking spaces within the CBD. Contributing to pressures for more parking spaces is the fact that a higher proportion of existing spaces are occupied by all day work-trip parkers, which reduces turnover.

FOCUS OF PAST CBD PARKING PROGRAMS

Techniques for studying CBD parking supply-demand and for projecting space requirements to a study target year have improved steadily over recent decades, largely because, with the passage of time, projected demands could be checked against actual demands, and refinements could be made in forecast methodology. Survey findings normally are converted into parking programs involving municipal policy decisions that result in more parking spaces being added downtown.

Almost without exception, parking studies in recent years have concluded that the CBD core area, that portion of downtown most intensely developed, has a deficiency in parking supply as measured against demand and that this deficiency would increase in the future. The studies also usually conclude that a parking space surplus exists in fringe areas of the CBD and that a surplus would continue to exist in the study target year.

Although these studies often made reference to the desirability of reducing core-area parking space deficiencies by diversion of some automobile drivers to improved public transit systems and by diversion of some core-area parkers to CBD fringe locations, no methodology existed for quantifying potential effects of improved transit and fringe parking programs in terms of reduced parking demands in the CBD core.

POLICY IMPLICATIONS OF CHANGING CBD FUNCTIONS

The changing role of downtown areas, which has caused a rapid rise in all-day parking and a lower growth rate for short-term parking (under 3 hours), indicates that new techniques aimed at implementing new urban development objectives should be used in CBD parking studies.

The hard fact is that most CBD core areas simply cannot be structured to accommodate all of today's parking demands and the increased demands of the next 10 to 15 years. Even if parking space requirements could be met, the CBD street network and corridor-approach capacity would be limiting factors, as they already are in some large cities.

These remarks are not intended to imply that cities should adopt a policy of banning cars arbitrarily from downtown areas or of prohibiting development of more off-street parking spaces in the CBD core. Such policies would have a negative effect. Downtown areas could not continue to expand as major employment centers, and other CBD growth potentials, primarily as cultural and convention activity centers, would be similarly stifled.

RESTRUCTURING OF CBD PARKING STUDIES

The objective of CBD parking programs should be to encourage maximum person-trip attractions, by all modes of travel. And, because it will not be possible to accommodate all trip-makers who wish to drive to and park within the core area, downtown parking studies should incorporate techniques for exploring alternative methods of serving the trip-makers, alternatives that will not discourage people from making the trip and that may even encourage them to make the trip more often.

Downtown parking programs should be structured to promote urban design objectives that recognize that long-term parking and short-term parking have sharply different impacts on CBD parking needs, its economic growth, its internal streets and approach corridors, and particularly its land use.

For example, long-term parking generates morning and evening travel in peak traffic hours; this means that a parking space is used by only one vehicle for the full business day. Because the long-term parker generally reaches the CBD before short-term parkers arrive, long-term parking conflicts with the objective of the CBD to encourage visits for personal and business purposes. In contrast, short-term parking involves trips made chiefly in off-peak traffic hours when CBD streets and approach corridors normally have surplus capacity; allows each available parking space to accommodate a number of visitors during the business day; and contributes to the economic viability of the CBD inasmuch as short-term parkers are customers rather than employees.

CBD parking studies should include measurement of potentials for some diversion of long-term parkers to fringe and outlying locations, with direct trip linkages and pedestrian connections to the downtown center.

The studies also should quantify anticipated impacts of proposed new or expanded rapid transit systems in terms of reduced CBD parking demands and should emphasize, in developing new CBD parking facilities, provision of short-term parking in buildings that combine multilevel parking with office, hotel, apartment, retailing, and other functions.

FORECASTING CBD PARKING DEMANDS

Because a rising share of downtown trips originate in automobile-oriented suburbs, CBD parking demands will continue to increase in older and newer cities in all population ranges. Even in cities with existing or proposed rapid transit systems, more off-street parking facilities will need to be provided—with emphasis, as stated before, on short-term parking in multiple-use buildings.

Downtown parking demands are a function of desires, needs, and habits of tripmakers. The demands can be related to the number of CBD person-trips made by car, average car occupancy, space availability and cost, and efficiency of parking space usage. These factors are affected by urban population totals, geographical location, and seasonal variations in trip purposes (2, 3).

Steps to Establish Current Parking Needs

Procedures for identifying current parking needs in a particular CBD are relatively standardized. They include a block-by-block inventory of curb and off-street parking facilities; parking accumulation and turnover counts; interviews with parkers to determine trip origin and destination, duration, trip purpose, walking distance to destinations, and other parker characteristics; determination of parking-generation rates (unit demand in spaces per 1,000 sq ft of building floor space) for existing CBD land uses; and, in certain special surveys, determination of the percentage of CBD trips made by automobile and other modes through use of a travel-mode questionnaire survey of persons entering principal trip generators such as large department stores, hotels, government and office buildings, and major banks.

Data from these studies are compiled on a block-by-block basis for the entire CBD and stratified to determine short-term, long-term, and total parking demands.

Demands then are compared with parking supply in each block to determine whether a surplus or deficiency exists. If a parking deficit exists in a specific block but a space surplus exists at a nearby location within an acceptable walking distance and at an acceptable parking cost (which normally are greater for work trips than for other trips), adjustments are made in supply-demand calculations to reduce or eliminate the need for added parking supply at deficiency locations. Techniques for these adjustments range from a parking allocation model to manual clerical data methods.

Surplus spaces also are tabulated for locations beyond acceptable walking distances from space-deficient locations but do not reduce the number of needed additional spaces.

Projecting CBD Parking Demands to 1985

Objectives of the Baltimore CBD parking study were (a) to determine present CBD off-street parking needs and those anticipated in 1975 and 1985, with and without a planned rapid transit system in operation in 1985; (b) to measure the potential for shifting some parking demands to locations outside the core area; and (c) to develop data and recommendations on administrative, legal, and fiscal aspects of the city's parking program.

The study drew on data from previous studies relating to Baltimore-area urban development and transportation planning (4) and various reports and files of the urban design concepts associates who were commissioned in 1967 to develop studies and recommendations on location and engineering design of both the planned rapid transit system and the city's freeway and arterial network, with particular attention to social, economic, and aesthetic effects on the community.

Many techniques for projecting parking demands were considered for use in the Baltimore study. Projection methods of recent years have employed a composite factor to forecast base-year demands, derived from growth trends in employment, retail sales, population, disposable income, motor vehicle ownership, and land use, to a future year.

Mathematical Models—Multiple linear regression analyses also have been developed as a projection technique. A mathematical expression is used to project demand based on changes in such parametric values as employment, population, floor space, dwelling units, retail sales, and automobile ownership. The mathematical formula contains both constants and variables and takes a form similar to the following:

$$\text{Demand}_{(\text{year})} = K_1 + K_2\,(\text{employment}) + K_3\,(\text{population})$$

For the base year, the K_1 or constants are derived, by use of calculated values for demand, with variables such as employment inserted in the equation, based on known quantities of each parameter. The equation would be solved for demands by using the regression method, and only the statistically stable parameters would remain in the equation.

For a future year, projected values for each significant parameter would be introduced into the formula and the equation solved for demands. This method is frequently referred to as developing a model, inasmuch as the equation generally models a future year based on today's known characteristics. Future demands can be estimated by modifying only the parameters that are based on growth characteristics, and the equation can be solved for future-year demand values.

Generation Rate Model—A projection technique increasingly used today employs parking-generation rates in relation to land use. For example, the generation rate for an office use may be expressed as 1.5 parking spaces per 1,000 sq ft. Mathematical equations can be established as follows:

$$\text{Demand}_{(\text{year})} = (R_1)\,(LU_1) + (R_1)\,(LU_2) \cdots$$

where

R = rate of demand per 1,000 sq ft, and
LU = land use in square feet.

The negative aspects of the regression method thus are reduced because both the rate (unit parking demand) and the land use can be varied independently. An additional advantage lies in the fact that use of constants is minimized. The estimated future parking demand in the Baltimore study was calculated by use of the generation rate method.

A summary of parking-generation rates for existing CBD land uses in a number of large cities is given in Table 1. These figures are estimations based on transportation and land-use studies of various cities from 1964 to 1971. As indicated by the wide variations in generation rates by land use, each CBD has its own parking-generation rates for similar types of buildings, so rates applicable in one CBD may not apply to another.

Method Summary—Four steps were followed to obtain the estimated future parking demands in Baltimore. First, existing parking-generation rates were calculated for core and noncore areas. Rates for older land uses were separated from those for newer developments because parking-generation rates for buildings erected in recent years have been found to differ from those for older buildings.

Additionally, these rates were derived for each land use and reported in parking spaces per 1,000 sq ft of gross floor area, spaces per hospital bed, and spaces per dwelling unit.

All land-use data were furnished by the Baltimore Planning Department for 1969, 1975, and 1985, including announced future parking facilities.

Step two involved a reduction of block demands. Many existing buildings are to be demolished by 1975 or 1985. The 1969 demands from these generators were removed from the data set.

The next step was to add forecasts of new land-use developments and to project demands based on generation rates derived for more modern buildings. The 1969 and 1985 rates used for this projection are given in Table 2. Anticipated changes in Baltimore CBD building floor area between 1969 and 1985 are given in Table 3.

A fourth step involved application of engineering judgment to the values obtained. A high-speed computer was used to tabulate demands. These data were edited and evaluated, and judgment was used to establish final values.

The supply-demand tabulations for 1975 and 1985 were compiled in the same manner as outlined for current parking space needs to produce an estimate of needed additional long-term and short-term parking spaces. These estimated needs can be tabulated on a block-by-block or sector-by-sector basis.

REDUCING CBD PARKING DEMANDS THROUGH TRANSIT IMPROVEMENTS

New methodology was applied in the Baltimore study to develop forecasts of the impact on CBD parking demands in 1985 if a planned new rapid transit system is in operation by that time. Following are the steps involved.

Estimating CBD Trip Diversion to Transit

Travel patterns to downtown Baltimore, both current and projected, have been extensively investigated in recent studies (5, 6). Results are given in Table 4. A total of 253,400 person-trips to the CBD is estimated for 1985. If the rapid transit system is not operational at that time, 65 percent of these CBD trips are expected to be made by nontransit modes, mainly by automobile.

These data represent person-trip demands, based on trip-generation rates for anticipated CBD land uses. The important question of whether sufficient street and parking capacity can or will be provided to permit the demands to be fully accommodated is now unanswered.

The effect of improved transit facilities anticipated to be operational by 1985 (including a rapid transit system and extensive expansion and upgrading of service on bus routes) also is given in Table 4.

Under these conditions, daily transit trips to the CBD are estimated at 136,500, or 54 percent of total CBD trips, and also 54 percent more trips than would be made by that mode without the transit improvements.

Daily automobile trips to the CBD are estimated to be reduced 22 percent by the transit improvements. This means that CBD automobile trips in 1985 would be below the level expected in 1975.

Parking Demands Without Rapid Transit

The 24-hour trip data in Table 5 were adjusted to the 8 hours (10:00 a.m. to 6:00 p.m.) used in the CBD parking study, based on screen-line checks made by the city and the Maryland State Roads Commission.

Under the process previously described for projecting parking demands to 1985, long-term and short-term space demands, without rapid transit, were aggregated by CBD sectors. These are given in columns 2, 3, and 4 of Table 5.

The ratio of peak demand to total daily parkers was determined by CBD sectors from 1969 parking study data. These ratios, shown in column 5 of Table 5, were assumed to apply for future years. The ratios were used to expand peak demands to total 8-hour demands in 1985.

Parking Demands With Rapid Transit

By using the trip tables from a 1968 Baltimore study (5) modified to reflect the 8-hour parking study day rather than a 24-hour day, we derived the number of automobile drivers (parkers) destined to each sector after diversion to transit. The difference between parking demand with and without rapid transit represented automobile trips diverted to the transit system.

Table 1. CBD parking-generation rates by floor area and land use.

Use	Spaces per 1,000 Sq Ft Average	Range
Floor area		
General office buildings	1.4	0.2 to 5.3
Banks	1.5	0.6 to 6.7
Department stores	1.4	1.1 to 4.7
Hospitals	1.1	0.4 to 4.0
Bus terminals	4.1	1.5 to 7.9
Government offices	1.2	0.3 to 5.1
Courthouses	1.6	1.1 to 3.7
Post offices	1.1	0.8 to 4.5
Colleges	2.1	1.5 to 3.0
Hotels	0.5	0.3 to 1.9
Medical buildings	3.8	1.1 to 8.6
Utility company offices	1.3	0.4 to 5.6
Libraries	1.5	1.1 to 4.3
Manufacturing and wholesale	0.7	0.2 to 1.4
Furniture stores	0.5	0.3 to 1.2
Restaurants	2.1	0.9 to 6.3
Land area[a]		
Residential		
Single family	0.5	0.1 to 2.5
Multiple family	0.3	0.0 to 4.0
Commercial	1.5	0.2 to 9.3
Industrial	0.6	0.1 to 2.7
Public and semipublic	1.0	0.2 to 6.5
Parks and open space	0.1	0.0 to 1.4

[a] Land area is surface occupied and does not include square feet of building above the ground level.

Table 2. Parking-generation rates for Baltimore CBD, 1969 to 1985.

	Spaces per 1,000 Sq Ft					
	1969			1985		
Land Use	Short-Term	Long-Term	Total	Short-Term	Long-Term	Total
Office	0.4	1.0	1.4	0.4	1.3	1.7
Retail	1.2	1.0	2.2	1.1	1.0	2.1
Hotel[a]	0.1	0.2	0.3	0.1	0.3	0.4
Manufacturing and wholesale	0.1	0.3	0.4	0.1	0.5	0.6
Hospital[b]	0.3	0.5	0.8	0.6	1.0	1.6

[a] Parking spaces per room.

[b] Parking spaces per hospital bed.

Table 3. Building floor area use in Baltimore CBD, 1969 and 1985.

			Change	
Floor Use	1969 (sq ft)	1985 (sq ft)	Square Feet	Percent
Office	15,205,200	21,059,200	+5,854,000	+38.5
Retail	8,733,300	8,610,400	-122,900	-1.4
Hotel	1,610,300	1,709,100	+98,800	+6.1
Manufacturing and wholesale	10,326,300	6,751,500	-3,574,800	-34.6
Institutional	8,205,200	10,899,300	+2,694,100	+32.8
Other	1,015,300	2,527,600	+1,512,300	+148.9
Total	45,095,600	51,557,100	+6,461,500	+14.3

Table 4. Person-trips per 24 hours to Baltimore CBD with and without rapid transit.

		Transit Trips		Automobile Trips		Other[a]	
Year	Total Person-Trips	Total	Percent	Total	Percent	Total	Percent
1962	140,000	53,400	38	56,000	40	30,600	22
1969	171,900	63,600	37	70,500	41	37,800	22
1975[b]	202,800	71,000	35	87,200	43	44,600	22
1985[b]	253,400	88,700	35	109,000	43	55,700	22
1985[c]	253,400	136,500	54	85,500	33	34,600	13

[a] Includes automobile passengers, taxi patrons, and pedestrians.

[b] Without rapid transit operation.

[c] With rapid transit operation.

Table 5. Baltimore CBD parking space demand in 1985 with and without rapid transit.

		Without Transit or Fringe Parking		Without Transit, With Fringe Parking		With Transit, Without Fringe Parking		With Transit and Fringe Parking	
Sector (1)	Space Supply in CBD (2)	Demand (3)	Supply (4)	Demand (5)	Supply (6)	Demand (7)	Supply (8)	Demand (9)	Supply (10)
1	765	1,464	-699	1,291	-526	893	-128	812	-47
2	499	1,129	-630	996	-497	825	-326	735	-236
3	2,639	1,518	+1,121	1,324	+1,315	1,093	+1,546	967	+1,672
4	1,399	1,656	-257	1,394	+5	1,656	-257	1,394	+5
5	2,137	5,633	-3,496	4,751	-2,614	4,168	-2,031	3,549	-1,412
6[a]	10,560	14,841	-4,281	12,841	-2,281	11,279	-737	9,762	+845
7[a]	3,341	9,601	-6,260	8,155	-4,814	7,297	-3,956	6,173	-2,832
8[a]	4,737	9,899	-5,162	8,529	-3,792	7,424	-2,687	6,401	-1,664
9	4,272	4,878	-606	4,291	-19	3,658	+614	3,266	+1,006
10	4,076	3,381	+695	2,853	+1,223	2,975	+1,101	2,520	+1,556
11	1,200	710	+490	623	+577	582	+618	516	+684
12	2,736	4,149	-1,413	3,600	-864	3,319	-583	2,902	-166
Total	38,361	58,859	-22,804[b]	50,648	-15,407[b]	45,169	-10,705[b]	38,997	-6,357[b]

[a] Core-area sectors.

[b] Total for sectors with space deficiences.

Each sector's peak parking demands then were reduced by the percentage of daily parking demand diverted to the transit system. Distribution of diverted car trips between long-term and short-term parking demands is shown in columns 6 and 7 of Table 5. For example, in sector 1, 80 percent of the diverted parkers would be long-term parkers, and 20 percent would be short-term parkers. These percentages were derived from parking-duration data by CBD sector compiled during the parking study.

Remaining parking demands after diversion to transit are shown in the last three columns of Table 5. These sums were derived by subtracting diverted parking demands from peak demands expected without the rapid transit system in operation, as shown in columns 2 and 3.

The analysis concluded that the rapid transit system would reduce 1985 parking space demands by approximately 24 percent within the entire CBD and the three core-area sectors.

POTENTIAL FOR FRINGE AND OUTLYING PARKING PROGRAMS

Regardless of whether a rapid transit system is operational by 1985, the study report recommended development of new parking facilities along fringes of the CBD and at strategic outlying locations with direct person-trip linkages and special pedestrian connections to the downtown center.

Included would be development of reserved freeway and CBD street lanes for use by buses (7), closing of certain CBD streets to all traffic except buses and taxicabs in peak travel hours, use of electronic controls on buses and at selected traffic signal locations so signals can be adjusted to favor bus movement, and development of people-mover systems (such as elevated and enclosed moving walkways) to interconnect CBD buildings and fringe parking facilities.

Results of Travel-Mode Survey

A special travel-mode survey was conducted, by personal interviews, at 13 major CBD trip-generating locations during the parking study. Responses indicated that 25 percent of long-term work-trip parkers would use fringe or outlying parking locations if direct transit service to the CBD core area were provided and if this service involved lower round-trip costs (for the driver and all passengers in the car) than the cost of parking in or very near the CBD core.

Because 84 percent of Baltimore CBD long-term parking is for work-trips, a potential exists for diverting 20 percent of long-term CBD parking demands to fringe and outlying locations, assuming that the park-and-ride trip involves little or no increase in trip time and that the cost requirements can be met.

It is recognized that this type of survey produces only "subjective facts" based on opinions people express on how they would react to a new set of conditions. Although such surveys cannot be accepted as a fully accurate indication of how people actually would react to new conditions, it is important that efforts be made to learn public preferences in considering alternative transportation improvements.

It is probable, for example, that many improvements in urban transportation facilities made in recent years would have been made in a somewhat different manner if users of the facilities had been able to express choices among alternative solutions, each of which was acceptable from a technical standpoint.

Following are the steps involved in forecasting 1985 CBD long-term parking demands that can be diverted to fringe and outlying locations served by low-cost transit facilities or other types of people-mover systems.

Parking Diversion Without Rapid Transit

The 20 percent value, representing long-term parkers who stated they would use fringe or outlying locations under the stipulated conditions, was applied to 1985 long-term peak parking demands, shown in column 2 of Table 5, representing demand without a rapid transit system.

The projected reduction in CBD parking space demand attributable to park-and-ride diversion is found for each CBD sector by comparing columns 3 and 5 in Table 6. Space demand in the CBD and in the core area was estimated to drop 14 percent.

Parking Diversion With Rapid Transit

If the planned rapid transit system is operational in 1985, projected use of park-and-ride facilities is lower than it would be without the transit system because more car drivers and passengers would use transit service for all or most of their work trips.

Projected diversion to park-and-ride locations was determined by applying the 20 percent parking diversion factor to long-term parking demands remaining in the CBD after diversion to rapid transit.

The estimated reduction in CBD parking demand is found by comparing columns 7 and 9 in Table 6. The reduction in demand, beyond that due to the rapid transit system, is 14 percent.

Combined Impact of Transit and Fringe Parking

Anticipated effects of improved transit and park-and-ride programs on 1985 parking needs are shown in Figure 1.

The anticipated Baltimore CBD parking space supply in 1985, based on existing and currently planned expansion of parking facilities, totals 38,361 spaces, as shown in column 2 of Table 6.

Without either the rapid transit system or the fringe-parking program, projected demand totals 58,859 spaces, resulting in a deficiency of 22,800 spaces. The most critical space shortage is expected in the core areas (sectors 6, 7, and 8) where demand is projected at 34,341 spaces, resulting in a deficiency of 15,700 spaces, or double the 1969 deficiency.

If the park-and-ride program is in effect in 1985 but no rapid transit system exists, the anticipated CBD space deficiency will be reduced 33 percent to about 15,400. The core-area deficiency will be reduced 31 percent to about 10,890 spaces.

With both the rapid transit system and park-and-ride facilities in use in 1985, the CBD deficiency is projected at 6,360 spaces, or 72 percent below the deficit expected without the two programs.

In core-area 6, which has the heaviest downtown office concentration and is by far the leading person-trip generator of the entire CBD, the transit and park-and-ride programs are expected to change a projected 1985 deficiency of about 4,300 spaces to a surplus of 845 spaces. In the other two core-area sectors, the projected deficiency is reduced 61 percent to 4,500 spaces.

This remaining core-area deficiency is within manageable levels for elimination by 1975-1985 parking programs. Recommended programs include establishing parking rate structures that will encourage some additional long-term parkers to use spaces outside the locations of heaviest demand.

CONCLUSIONS AND RECOMMENDATIONS

This analysis of the impact on 1985 Baltimore CBD parking space demands expected to result from the planned regional rapid transit system, and recommended park-and-ride facilities in CBD fringe and outlying locations, indicates that these developments will reduce the need for more long-term CBD parking spaces by some 13,000 spaces, or 31 percent, and will reduce the need for added short-term spaces by about 3,500, or 20 percent.

Economic Implications

The average recent cost for a long-term parking space in downtown Baltimore is $3,500 and for a short-term space, $5,500. Thus, the rapid transit system alone can obviate a need for almost $50,000,000 in new downtown parking spaces.

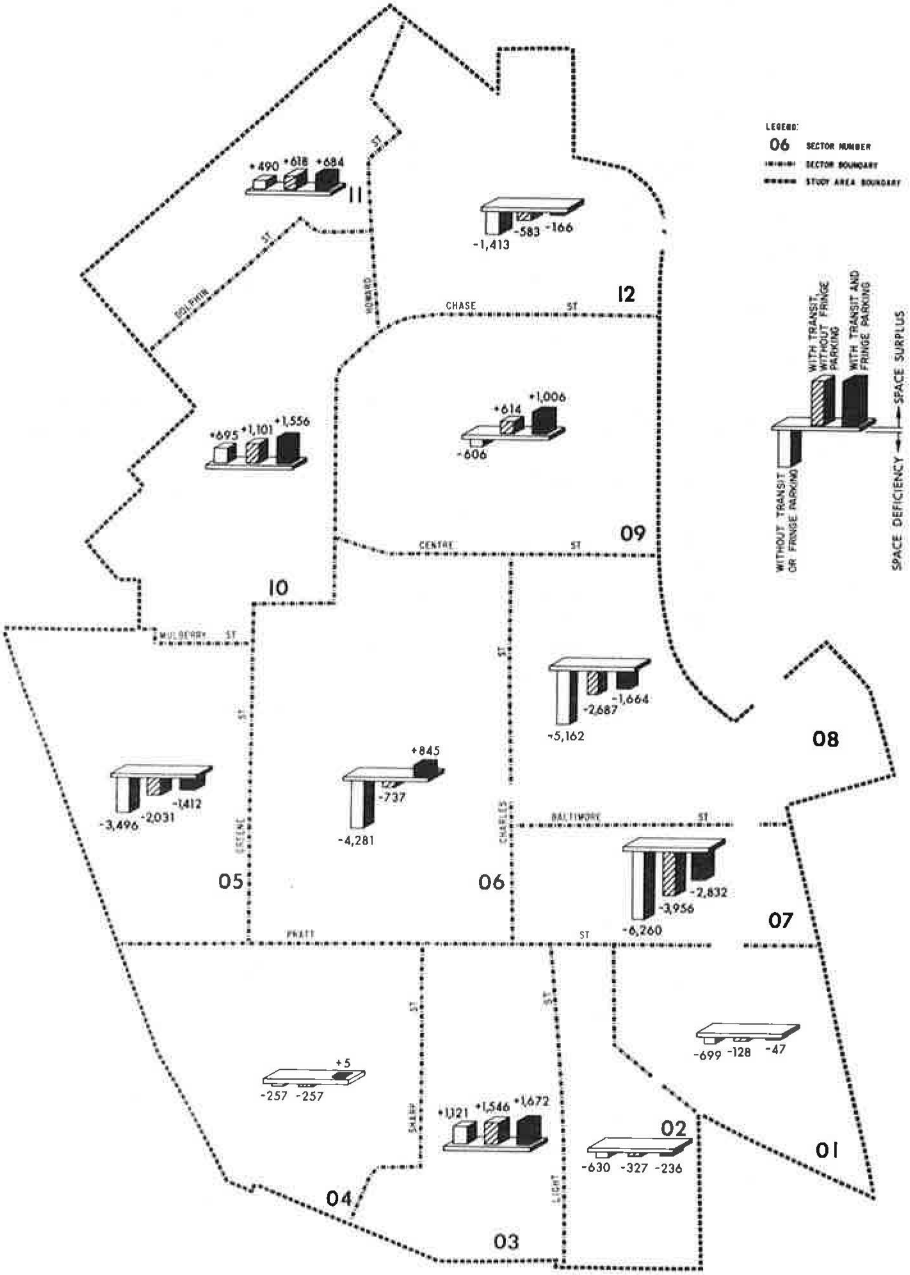
The park-and-ride terminals also will have a substantial impact on capital costs of developing long-term parking spaces. By taking advantage of lower land costs in fringe

Table 6. Baltimore CBD parking supply and demand in 1985 with and without transit and fringe parking.

	1985 Peak Demand Without Transit				Diversion to Transit		Remaining CBD Parking Demand		
Sector (1)	Long-Term (2)	Short-Term (3)	Total (4)	Peak-Hour Factor[a] (5)	Long-Term (6)	Short-Term (7)	Long-Term (8)	Short-Term (9)	Total (10)
1	863	601	1,464	0.95	457	114	406	487	893
2	663	466	1,129	0.47	213	91	449	374	825
3	972	546	1,518	0.66	340	85	632	461	1,093
4	1,309	347	1,656	0.83	0	0	1,309	347	1,656
5	4,412	1,221	5,633	0.81	1,319	146	3,093	1,075	4,168
6[b]	10,002	4,839	14,841	0.56	2,137	1,425	7,865	3,414	11,279
7[b]	7,231	2,370	9,601	0.61	1,613	691	5,618	1,679	7,297
8[b]	6,849	3,050	9,899	0.56	1,732	743	5,117	2,307	7,424
9	2,934	1,944	4,878	0.54	976	244	1,958	1,700	3,658
10	2,639	742	3,381	0.76	356	41	2,274	701	2,975
11	434	276	710	0.57	102	26	332	250	582
12	2,747	1,402	4,149	0.61	664	166	2,083	1,236	3,319
Total	41,055	17,804	58,859	0.60	9,918	3,772	31,136	14,031	45,169

[a] Factor is 1969 peak-hour demand divided by total 1969 parkers; the resulting ratio is assumed to apply for 1985.
[b] Core-area sectors.

Figure 1. Impact of rapid transit and fringe parking on 1985 downtown Baltimore parking needs.



and outlying locations and economies of scale in developing large parking areas, we estimate that each parking space in such locations will represent a capital saving of about $2,000.

This indicates that the recommended park-and-ride facilities can mean a savings of another $8,000,000. If federal grants are obtained to cover part of the fringe-parking development costs, as appears possible under current programs of the U. S. Department of Transportation, the savings to the city would be even higher.

Refining Forecast Models

Although the Baltimore parking study was one of the first to use these new techniques for forecasting impacts of planned rapid transit and new park-and-ride facilities on CBD parking demands, similar techniques are being used in several CBD parking and regional rapid transit studies under way in other cities.

It is anticipated that these techniques will become standard elements in urban transportation planning studies and that the methodology will undergo continuing improvement. Progress in that respect can be furthered by the following four developments:

1. Adoption of a standard data set of urban land uses in as much detail as practical (the data set also should be reasonable in perspective with urban design objectives);
2. New systems for testing parking-generation rates for various land uses including park-and-ride terminals;
3. Refinement of "model" techniques for estimating future demands for each mode of transportation, with emphasis on simplicity and ease of application (parking allocation models also can be used or integrated to assist the analysis work effort); and
4. Further testing of the "public preference" phase of transportation planning to find better ways to measure desires of users of the transportation system in order to accommodate them to the degree feasible.

In this connection, the Urban Corridor Demonstration Program, cosponsored by the Federal Highway Administration and the Urban Mass Transportation Administration of the U. S. Department of Transportation, is designed to test, through actual developmental programs, the potentials for diversion of car trips to improved transit systems and public acceptance of park-and-ride facilities. This program should be of tremendous assistance in measuring demands for such facilities.

It will be impossible in coming years to accommodate in CBD core areas everyone who wishes to drive downtown on work trips that involve long-term parking. The future growth of downtown areas as major employment centers and as centers of cultural and convention activities, therefore, will depend heavily on how well our larger cities meet the problem of providing alternative CBD travel choices to the trip-maker while keeping the alternatives sufficiently attractive so that he will continue to make the trip.

ACKNOWLEDGMENT

The study was conducted for the City of Baltimore in cooperation with the Maryland State Roads Commission and the Federal Highway Administration of the U. S. Department of Transportation.

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A LOCATION PRINCIPLE OF URBAN TERMINAL DISTRIBUTION

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The study was an attempt to determine the optimum spatial pattern of passenger transportation terminals in urban areas with the objective of maximizing terminal accessibility. The concepts of terminal-destination environment used by this study were introduced to manifest the basis of analysis and the generality of the resultant techniques. Mathematics was used to evaluate alternative geometries of terminal location patterns and to investigate the possible effect of location displacement on the service efficiency of terminals. Also, a search procedure provided through computer programs was developed to help establish the optimum location to best serve a particular area. Study results indicate that the optimum location consists of the following: terminal location pattern that forms diamond-shaped service areas centered at intersection with the major axis of the pattern being parallel to the urban streets; border lines of the service areas that are parallel to street block diagonals; and the service area diagonal that is an integer multiple of block sides. The theoretical solution developed by this study appears to be applicable to the transportation mode that has definite locations of users' access in urban areas, particularly transportation planning for new towns or planning of new transportation system for existing cities.

•WITH today's population explosion and increasing travel needs, the urban transportation problem has become serious enough to justify a great deal of effort to determine means for improving urban mobility. Traffic is not, in itself, generated for the sole purpose of movement; instead, it is the result of one's desire to reach a destination. Therefore, the service effectiveness of a mode of transportation, to a great extent, lies in terminal accessibility, particularly for the relatively short urban trip. When travelers must choose among available modes of travel, that system providing poorly located terminals is at a competitive disadvantage. However, most urban transportation terminal facilities in use today have not been located in a systematic manner. It is therefore becoming increasingly important to consider a total system approach in designing transportation media and to include a rational selection of terminal location systems.

A properly designed location system avoids duplication and waste and makes possible the maximization of service effectiveness. Location theorists consistently make use of the concept of regional hierarchy for service area planning. The basic argument supporting the use of central-place ideas is that system access points arranged in a hierarchy provide an effective way of articulating distribution to the area served. By definition, the optimum location system minimizes the average access distance of all users in the service area, and the central-place principle is well suited for application to transportation terminal locations. Under the assumption of an unbounded plane with equal access in all directions, regional scientists suggest that the triangular arrangement of service sites, and hexagonal market areas, represents the optimum (2, 4, 15). This result has been derived by the assumption of the straight-line access distance of customers to and from service sites. However, locating transportation terminals in urban areas by this geometrical arrangement does not appear to be applicable because most urban street systems follow a gridiron pattern (17). In this respect, an analysis of the terminal location pattern based on the rectilinear access distance would be of significance in providing urban travelers with the most effective transportation service.

STUDY OBJECTIVES

The study was intended to define the optimum spatial arrangement of transportation terminal locations for passengers in urban areas. The basic criterion on which optimum characteristics were determined was that of maximizing terminal accessibility. The method first identified urban environmental variables to realistically provide valid assistance in actual application. It is hoped that this method would provide valuable insight in locating such transportation terminals as automobile parking facilities, bus stops, and taxi stands. The theoretical apparoch may also provide assistance in solving other location problems of service facilities in urban areas.

TERMINAL-DESTINATION ENVIRONMENT

The terminal distribution system must be analyzed in terms of the competitive environment within which it operates. It is therefore essential to make explicit some environmental variables and the underlying assumptions considered by this study to help determine the generality of the resulting solutions. All possible efforts have been exerted to produce a theoretical solution that is most representative of a real situation.

Although many environmental variables affect the terminal location of a particular transportation mode, accurate estimation of demand for the mode is the most crucial part of the optimization consideration. The level and distribution of demand depend on population density and other socioeconomic characteristics in the area under consideration. The demand for a specific transportation mode among other alternatives is determined by the relative service performance of the mode in question. Assuming that terminal accessibility is an important factor affecting public choice of mode, few people are willing to walk farther distances to use a given mode of transportation. In other words, other available modes will be more competitive at farther distance if remaining performance factors are equal.

Theodorson (17) found that the grid pattern is characteristic of American cities with few exceptions. Therefore, the rectilinear walking path along the gridiron street network is typical for access to an urban terminal. For a mode of transportation to provide adequate service to a city requires a certain number of terminals so that all points in the city are accessible with reasonable rectilinear walking distances for all customers. Each terminal has associated with it an area that includes a number of destination points served. The imaginary boundaries of a terminal service area are determined by the maximum acceptable walking distance. Because numerous factors are considered in determining an acceptable walking distance for individual passengers to reach a terminal, it is difficult to choose a simple definition for all circumstances.

The cost of walking is a subjective value placed on the walking time and the discomfort and inconvenience of walking. The value of time depends on many factors such as the person, the circumstance, the amount of available time, and the time productivity. There have been some attempts to determine the value of travelers' walking time by statistical methods. More recent work (14) has been based on the theory relating parking cost profiles to commuters' marginal valuing of time and comfort. It has been found that commuters are willing to spend about 12 cents per minute, or 15 cents per $^1/_{16}$-mile block, to save walking time between parking places and work. This 12 cents per minute includes two cost components: value of time and value of comfort. A typical commuter would like to pay about 8 cents per minute at the margin to avoid the discomfort and inconvenience of walking. This figure is significant because commuters appear to be willing to pay a high price to save walking time and thus are very responsive to choosing a mode of travel in accordance with terminal accessibility. For these obvious reasons, determining the optimum terminal location for reducing access walking distance should play an important role in planning the transportation terminal system.

In attempting to resolve the complexities of the terminal-destination environment, we based this analysis on the following important assumptions:

1. The passenger's walking distance to and from terminals is along rectilinear paths corresponding to the gridiron street pattern inasmuch as square or rectangular block configurations are predominant in urban areas.
2. All passengers tend to minimize their walking distance by using the terminal nearest their destinations. This assumption is supported by the economic and psychological make-up of travelers.
3. The number of travelers willing to use a mode of transportation decreases with increased distance between the point of destination and the terminal location.
4. A terminal location is considered to be an area located anywhere along the outer periphery of a city block but not within the confines of a block.

TERMINAL LOCATION PATTERNS

Because the terminal access time is a major criterion in evaluating the service provided by the transportation system, the optimum pattern of terminal locations will be that providing the least access distance for most terminal users within service areas. It first appears that this criterion, minimizing the access distance based solely on the cost of the access walking time, tends to favor a high-density terminal network with a small service area. Ideally, each terminal user would have his own terminal at his point of destination. Practical limitations, however, prevent optimization on such a basis because it is not economically and physically feasible to provide a very large number of terminals to serve a city area.

A complete definition of the necessary conditions that the service area of terminals must fulfill is essential to describing the optimum terminal distribution system. If a single terminal is to be provided, it will serve an area bounded only by the maximum distance people are willing to walk. Because this study was ultimately concerned with the determination of a terminal network to provide service to a larger area or an entire city, a geometry consisting of multiple areas served by individual terminals is formed. Figure 1 shows a multiterminal structure superimposed on the Philadelphia CBD for illustrative purposes.

Many geometrical patterns could be used for the location distribution of terminals, but most of these were ruled out by simple reasoning. To provide complete service coverage for an area would limit the geometrical pattern of terminals to those that neither deprive any portion of the area of service nor create overlapping service areas. In other words, all adjacent service areas must border each other. In this analysis, it was proved that the only possible geometries satisfying this unique requirement are regular polygons, the square, the diamond, the triangle, and the hexagon, as shown in Figure 2.

Single Terminal Considerations

After the limited number of possible geometric configurations has been described, it is necessary to compare the relative values to users of average access distances within each service area in order to determine the optimum geometry. The most accessible location pattern would minimize users' travel (walking) distance along rectilinear routes between the terminal and the destination point. For an analytical treatment, it was assumed that there are an infinite number of demand points within the service area and that all people in the service area, regardless of walking distance, will be willing to use the terminal for travel. Based on an equivalent area for all four geometries, the following function was applied to compute the average walking distance $\bar{D}$:

$$\bar{D} = \iint_A (1/A)\,(x + y)\,dx\,dy$$

Figure 3 shows the diamond configuration. Using the terminal spacing for the square

Figure 1. Philadelphia CBD multiterminal structure.

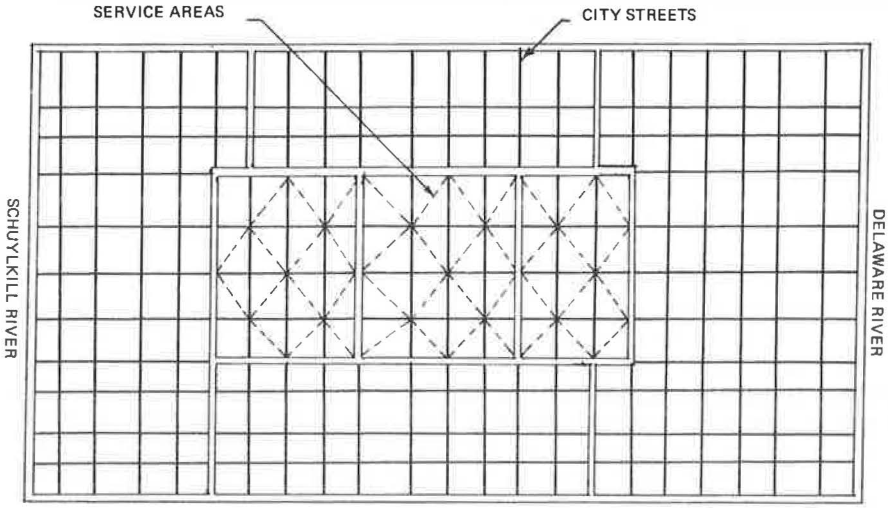
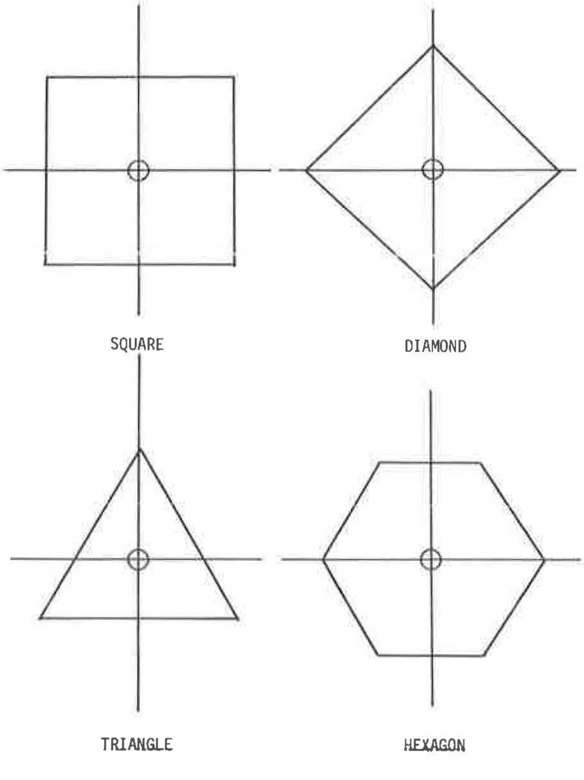


Figure 2. Feasible service area geometries.



pattern S, the resultant, normalized values of the average walking distance for the four geometries are given as follows:

Service Area Geometry	Average Walking Distance
Diamond	0.47 S
Triangle	0.48 S
Square	0.50 S
Hexagon	0.51 S

This comparison indicates that the diamond-shaped service area is superior to other configurations because it provides a minimum average rectilinear distance. The second best is the triangle shape, which approximates the efficiency of the diamond shape and could be used for cases in which natural boundaries constrain service area shape. It first appears that the difference in the average walking distances among various geometries, ranging from 2 to 6 percent, may not be manifested. However, these differences should be greatly magnified by the quantity of daily users over the entire life cycle of the terminal.

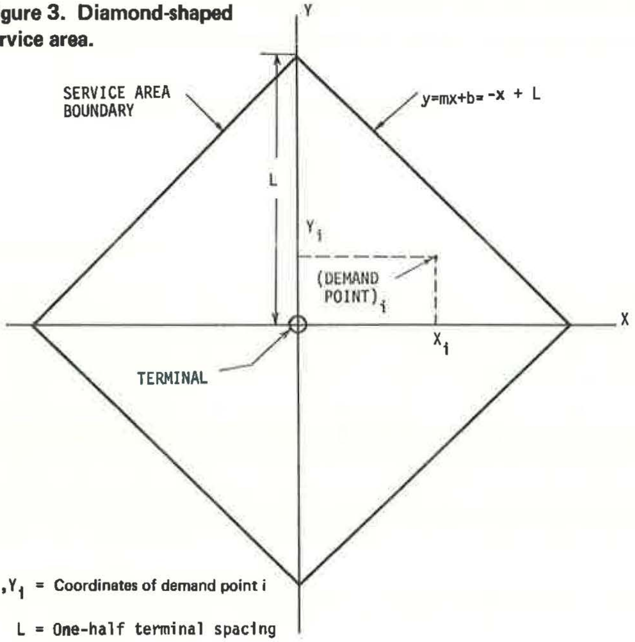
This theoretical treatment developed important principles that are applied to the practical conditions. Hakimi (12) has shown that the absolute median of a graph, a rectangular network with weights attached to each branch and vertex, must be at a vertex of the graph. An intuitive application of this theorem to a terminal location would substitute the demand at each point in a city for the arbitrary weights used by Hakimi. In this context, it would appear that the optimum location of a terminal unit is at the intersection that minimizes the absolute median function. Combining the result derived by this study with the absolute median concept developed by Hakimi indicates that, for a city block-street system, a terminal should be located at the center of an intersection and should serve a number of separate destination points (building entrances) within a diamond-shaped service area; access to and from the terminal would be along a rectilinear walking path. Each building has only some finite number of entrances through which a traveler must pass to reach his actual destination. Minimizing walking distances to these building entrances has the same effect as minimizing the entire route to the actual destinations within.

The theoretical analysis indicated that the optimum geometry of service areas should be the symmetrical diamond shape, which may be superimposed on uniformly square street-blocks. Practically, the configuration of the city block may not always be uniformly square shaped. To extend the optimum characteristics of the diamond-shaped service area requires, therefore, that the relative efficiency of service areas that form a nonsymmetric diamond be examined. For example, for a terminal network superimposed on rectangular city blocks, the geometry of individual service areas would become elongated diamonds as shown in Figure 4. This geometrical deformation is due to an important constraint; that is, the distance from the center of the service area (or the terminal point for uniformity in sense) to the vertexes of the diamond shape must be an integer multiple of block sides. This constraint may be proved by assuming a supposedly nonfeasible terminal-to-vertex distance of a noninteger multiple of block sides, say, one and a half blocks. The adjacent service area must border the test area and must be of equal size for the uniform demand case. The terminal for the adjacent service area therefore would be specified at one and a half blocks directly below (or above) the vertex at the middle of the block. This location at the center of the block violates the rule that a terminal must lie along the outer periphery of a block. This assumption appears to be mandatory because of the extra cost associated with locating a terminal within a block and the need to provide walking routes to all block sides.

The average and total walking distances to an individual terminal in an elongated-diamond service area can be expressed in the following functions:

$$A = 2_{\ell}L$$

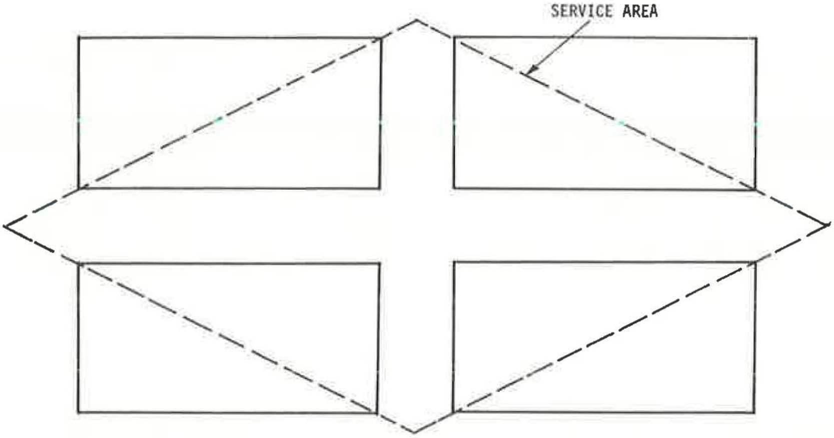
Figure 3. Diamond-shaped service area.



X_i, Y_i = Coordinates of demand point i

L = One-half terminal spacing

Figure 4. Elongated diamond-shaped service area superimposed on rectangular city blocks.



$$D_t = 4 \int_0^{L} \int_0^{(\ell - \ell x/L)} (x + y)\, dx\, dy = \tfrac{2}{3}\, \ell L (L + \ell)$$

$$\bar{D} = (1/A) D_t = \tfrac{1}{3}\, (\ell + L)$$

where

A = size of service area,
D_t = total walking distance, and
$\bar{D}$ = average walking distance.

The comparative efficiencies of the elongated diamonds and the symmetric diamond are graphically shown in Figure 5. Because the difference in efficiency varies with the degree of elongation, an actual block configuration will determine the relative efficiency of various diamond-shaped service areas.

Multiple Terminal Considerations

As discussed previously, a truly optimum transportation mode must provide some level of service to all points within a city; therefore, adjoining service areas must border each other so that the certain area or the entire city is completely serviced (Fig. 1). For the network to operate at maximum efficiency, it is important that service areas be easily discernible and terminals be found easily, even by the inexperienced user. Uniformity of terminal service area boundaries that do not cut across a block side was assumed to contribute to providing these optimum characteristics.

If demand within an entire area served were uniform, a single service area size would prove optimum, and the entire area would be best serviced by a set of equally sized service areas. This is proved by contradiction; there would be nothing to require a different service area size. If demand within the total served area were not uniform, two possibilities exist. First, the area could still be covered with equally sized service areas, or the service area size could be determined on a unit basis so that each area would optimally service the demand peculiar to the area it covers. Second, because customers will most often use the terminal nearest their destinations, the practical service area boundaries will not coincide with those specified by analysis, and optimum characteristics will not be retained. The perpendicular bisector of the (imaginary) line connecting any two terminal locations will establish the service area boundaries between the two terminals. The dotted lines in Figure 6 show this perpendicular bisector effect. Extending this concept across the entire city area served indicates that all service areas should be of equal size. This may force a non-optimum service area size on a particular city section, so a large number of comparisons between different, feasible service area sizes must be made before local improvements can be made.

If demand unexpectedly and radically changes at some future time, an auxiliary terminal could be provided for somewhat improved service without disrupting the entire network. For instance, a large department store attracting many retail customers might be built on a vacant lot near the point where an auxiliary terminal could be located. Central-place theory would indicate that an additional terminal could be located at a point central to all neighboring terminals. However, because of the perpendicular bisector effect, the service area of the auxiliary terminal would become a non-optimally shaped, square pattern.

SERVICE AREA SIZES

Previous studies (16, 22) indicate that the trip density is constant for a constant type of generating area. Accepting the assumption that demand within an area of each section of a city is nearly uniform, we see that there is a unique optimum service area size

Figure 5. Examination of elongated diamond service areas.

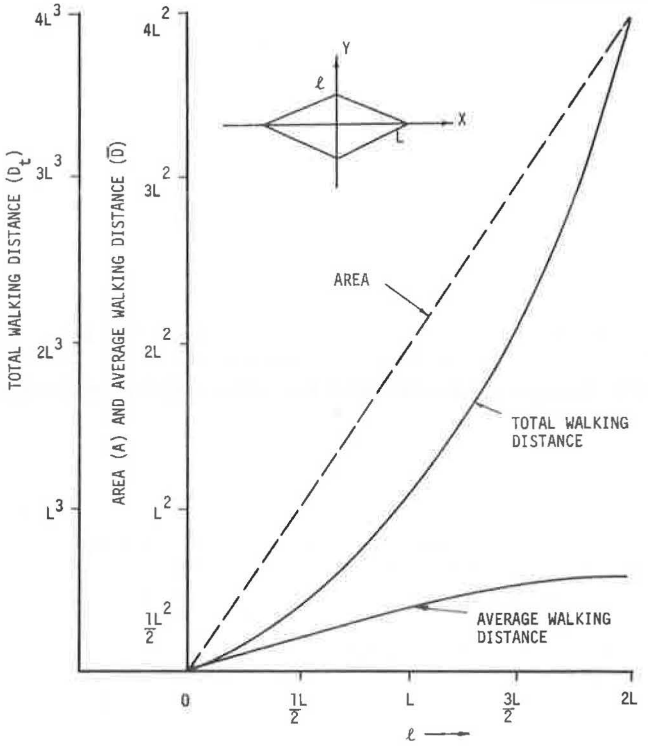
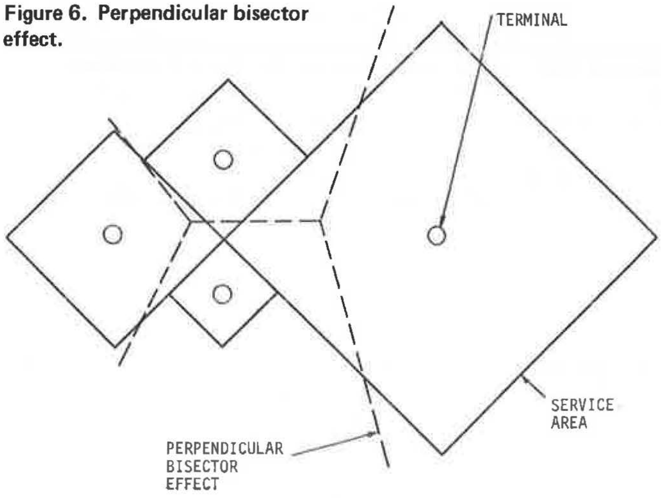


Figure 6. Perpendicular bisector effect.



within each section and that further improvements cannot be obtained by replacing that with equivalent service areas within the section. If the service areas of two bordering localities are of different sizes, the bordering service areas must be analyzed in detail to determine the best geometry of transition between the two service area sizes.

As stated before, the unique optimum size for each area requires that the distance from the center of the service area to the vertexes of the service area be only one block, two blocks, three blocks, and so forth. The upper limit of feasible size is about 1,250 ft (6, 16) inasmuch as this was assumed as the maximum desirable walking distance under the normal condition. Scaling a map of the central part of Philadelphia, for example, and performing the necessary calculations showed the average block length to be approximately 407 ft (19). For this case, sizes larger than three blocks are not feasible. Comparison with the maps of other cities indicated that this size can be considered an upper limit in a great many cases. Indeed, a two-block upper limit would be used in many areas.

One other feasible possibility exists. If the distance from the center of the service area to the vertexes were one-half block, all of the constraints mentioned would be met. However, this would call for a terminal at every intersection in a city. This possibility was not considered further because it was assumed that land for this excessive number of terminal facilities would not be available in a practical application. Therefore, only three feasible service area sizes were considered in this study: size 1, size 2, and size 3 corresponding to the number of blocks between the center of a service area and a vertex.

Several practical advantages are gained by this constraint. If service areas were of various sizes and boundaries were cut block sides at various spots as shown in Figure 7, it would be difficult for a user to determine which service area included his point of destination. Incorrect decisions would cause increased walking cost and disturb the optimum capacity of terminals. Terminals may also be easier for the inexperienced traveler to find under constraints that yield some uniformity.

A size 1 service area provides service to half of each of four blocks, or a total of eight block sides. A size 2 service area encompasses a total of 32 block sides, and a size 3, a total of 72 block sides. Thus, the total walking distance increases exponentially with the size of service area, so actual values will not increase as rapidly. Figure 8 shows the total walking distance as related to service area size.

EFFECT OF TERMINAL DISPLACEMENT

As indicated previously, the center of the service area should be located at an intersection. The distance between the service area center and the vertexes of the diamond, therefore, must be an integer multiple of block sides. Figure 9 shows the major advantages of such requirements, which are listed in the following:

1. Terminal A provides minimum average walking distances for all users. The cross-hatched areas show that, for the service area with terminal B, some demand points can be reached only by walking longer distances outside the defined service area.
2. Terminal A provides more easily discernible service area boundaries, inasmuch as boundaries do not intersect block sides.
3. Terminal A provides better safety features and less walking time by reducing the number of street crossings.

Although locating the terminal at an intersection is desirable, congested traffic and land availability at urban intersections usually limit an intersection location for a terminal. In this respect, a slight displacement of a terminal from the intersection is often necessary to be practical. For the uniform demand case, the terminal may be a small distance from the center of the service area (the intersection) without changing the average and total walking distances. The service area geometry, however, must remain centered at the intersection. This fact is proved analytically and shown in Figure 10. The permissible displacement of individual terminals from the intersection center would provide great flexibility in determining a terminal location because it would be at any of four corners or along any of eight block sides near the intersection.

Figure 7. Nonfeasible service area size.

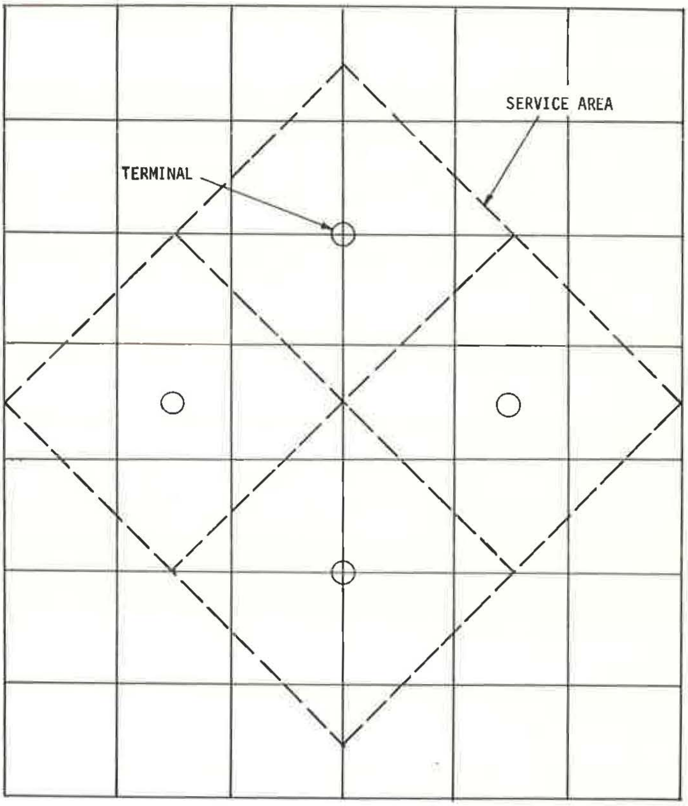


Figure 8. Total walking distance by service area.

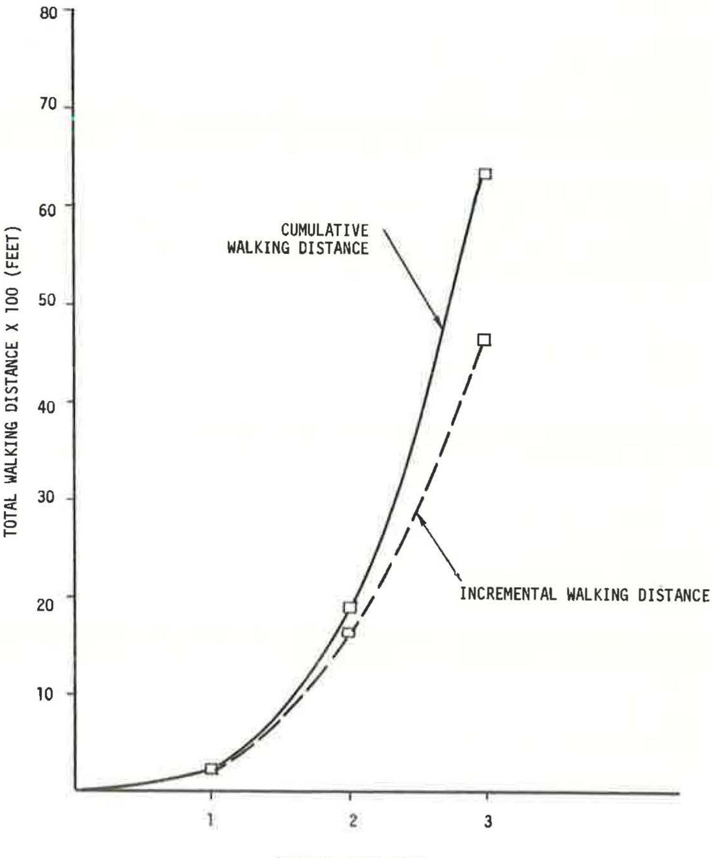
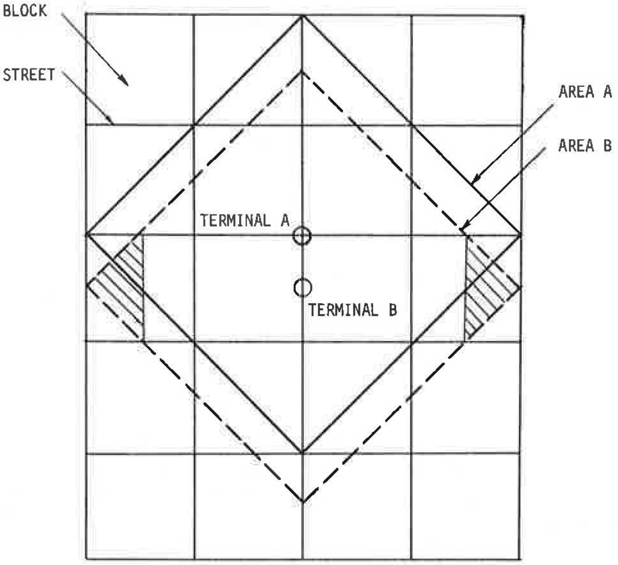
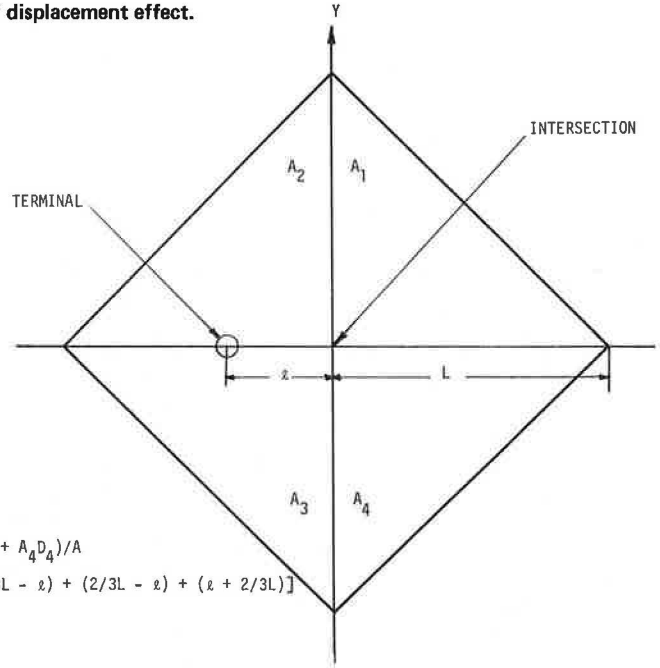


Figure 9. Effect of terminal displacement.



AREA A = AREA B

Figure 10. Analysis of displacement effect.



$$
\begin{aligned}
\bar{D} &= (A_1D_1 + A_2D_2 + A_3D_3 + A_4D_4)/A \\
&= \frac{1}{4}\left[(\ell + 2/3L) + (2/3L - \ell) + (2/3L - \ell) + (\ell + 2/3L)\right] \\
&= 0.67L \\
&= 0.47S
\end{aligned}
$$

The site where land is available at lowest cost and is most compatible with the traffic flow in the area should be selected. If a terminal is located near an intersection, the entrance should be as far away from the intersection as possible. This criterion minimizes the adverse effect of terminal traffic (vehicle and pedestrian) on intersection capacity.

A reduction in users' walking distances may be gained by locating the terminal closer to higher demand points under non-uniform demand cases. Major displacements of the terminal, however, may affect the service area boundaries (it was assumed that people will always use the nearest terminal in a network of terminals). This assumption led to a determination of the optimum terminal location under the non-uniform demand case.

If demand within the defined service area of a terminal is non-uniform, the optimum terminal location is not necessarily at the center of the service area (the intersection). To determine the optimum location for a terminal with the objective of minimizing the walking distance, we used the Golden Section Search procedure (20). Because a small displacement of a terminal from the intersection was shown to shorten the average walking distances and because the terminal is constrained to lie along the outer periphery of blocks, determination of the optimum terminal location can be accomplished by two undimensional Golden Section Searches. One search determined the best location parallel to the X axis along the street that corresponds to the diagonal parallel to the Y axis. The search was limited in all directions to within the arbitrarily selected 200 ft from the intersection; and the objective function, user walking distance, was minimized. The minimum walking distances for the location in two directions were compared, and the better of the two was selected. This location was at the center of the street, and the best side of the street was determined to be the side favored by the search along the other axis direction. A computer program was developed to control this optimization. Results were found to be consistent with the general hypothesis that the unique optimum location of the terminal must be found in accordance with the demand distribution within the service area. In this case, the quantity and direction of terminal displacement toward points of greater demand can be effectively governed to achieve the optimum characteristics.

SUMMARY AND CONCLUSIONS

To be successful, a transportation mode must go beyond providing satisfactory service from terminal to terminal. A total system approach is called for in which consideration is given to the cost of convenience associated with the actual location of the terminal. This study attempted to quantify some of these critical relationships in terminal location. Although a number of diverse theories, such as the classical central-place principle, have been employed to determine the optimum location pattern for service centers, this study represents a departure from previous work in two distinctive ways: Gridiron routes corresponding to urban street patterns are assumed to prevail inasmuch as this configuration is found in the majority of American cities; and the terminal location system is optimized from the viewpoint of minimizing user access distance, which, in turn, maximizes the urban mobility.

A terminal in a network of terminals should privide service to all points within a bounded area. In this study, terminal location was constrained to lie along the outer periphery of block sides, and users were assumed to patronize the terminal nearest their destination. The configuration of the optimum service area was shown to have several important characteristics: The service area must be diamond shaped with major axes paralleling the gridiron street pattern in urban areas; the service area must be centered at an intersection; the distance between the service area center and vertexes must be an integer number of block sides; and the border lines of the service area should be parallel to street block diagonals.

For the multiple service areas of a terminal network that provides some level of service to all points within an urban area, curtailment of the possible sets of service areas was shown to be possible. The best set of service areas of uniform size may be determined for a section of uniform demand characteristics. However, the economical consideration of the terminal location pattern must be weighted with the present land availability and the traffic flow conditions for practical applications.

The method developed by this study appears to show considerable promise in helping to solve the location problems of transportation terminals of existing cities as well as those of new towns. However, a complete set of actual data describing user characteristics, the specified service level of the transportation mode in question, and the physical layout of the concerned area should be collected to test the proposed method. If a city is served by a number of transportation modes, the integration of all terminal locations for all modes is extremely essential to optimize the system operations. Therefore, further study is necessary not only to test the applicability of the derived solution method by practical applications but also to extend the analysis to a more comprehensive scale in consideration of the terminal interfaces among multimodes in urban areas.

ACKNOWLEDGMENTS

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