Structuring a Systems Analysis of Parking

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Although it has been recognized for some time that parking constitutes an important element of the urban transportation system, analytical tools for evaluating alternative parking programs are relatively undeveloped. This paper suggests a framework for conducting a systems analysis of the parking or terminal system. The relationship between the analysis processes used to evaluate a parking system and highway and transit networks is first identified. It is suggested that a parking analysis should follow the application of the travel demand models but should precede assignments to the highway and transit networks. The framework for carrying out a systems analysis of the parking process is then presented. Two major phases of this strategy are the calibration and validation of the component models of the parking analysis package and the application of this package to evaluate the consequences of alternative parking programs.

The Parking System Simulation Model, which simulates the operation of a given parking system for a given time-dependent parking demand, is a key component of the proposed framework. The parking allocation model, which at every time period allocates arriving vehicles to the available parking facilities, is the central element of the Parking System Simulation Model. A parking systems analysis could be utilized to effectively and efficiently evaluate alternative parking programs. It would appear that the analytical framework proposed herein offers promise as a structure for carrying out an analysis of parking.

•DECISION-MAKERS have noted that transportation facilities represent long-term investments and that future traffic needs should be considered when developing a transportation program. The development of the high-speed digital computer in the middle and late 1950s permitted the transportation planner to develop and implement powerful analytical tools for evaluating alternative transportation plans. These tools include methods to estimate the spatial pattern of travel demand and modal preference and models to simulate the operation of highway and transit networks, assuming a prespecified set of travel demands.

Although terminal facilities, such as the parking system, constitute an important element of the urban transportation system, analytical tools for evaluating alternative designs of parking are relatively less developed than network analysis procedures. Current parking studies generally involve the tabulation of data collected in three types of studies: an inventory of the existing parking supply, a usage study of existing parking facilities, and an at-the-curb interview of parkers. The development of analytical tools for estimating future demands and simulating the operation of the parking system has been relatively limited.

The objective of this paper is to suggest a framework, involving a set of models and methods, for conducting a systems analysis of the parking or terminal system. It is anticipated that such an analysis could be exploited to efficiently and effectively evaluate alternative parking system designs and operating policies, for both the present and the

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future. This model system should be responsive to variations in parking system design (e.g., the location and capacity of facilities), to operating policies such as parking prices and restrictions, to the socioeconomic and travel characteristics of the users, and to the highway and transit system designs.

PARKING SYSTEMS ANALYSIS WITHIN THE OVERALL TRANSPORTATION SYSTEMS ANALYSIS PROCESS

Terminals represent only one element of the urban transportation system and, for this reason, the relationship between the analysis processes used to evaluate the parking system and those used to evaluate the highway and transit networks should be identified. A flow diagram of the network evaluation process is shown in Figure 1. It should be noted that the steps outlined in the diagram represent only a portion of the overall transportation systems analysis process.

Current travel demand models, which estimate the spatial distribution of demand by mode, contain implicit or explicit assumptions regarding the impedances associated with travel between a given origin and a given destination. This observation is shown in Figure 1 by introducing a step to assume travel impedances before travel demand is estimated. Once the characteristics of a given transportation facility are fixed, the impedances associated with travel on that link are functions of demand. For example, engineers and traffic flow theorists have observed that, over a certain range, the speed of travel on a facility is inversely proportional to traffic volume.

These observations suggest a basic paradox in the current transportation planning process. Estimates of impedances are required as inputs to the travel demand models, but these impedances are unknown until after the travel demand and network simulation models have been exercised. To overcome this problem, the transportation planning process should be iterative; impedance estimates derived from the outputs of the network simulation models should be compared with the assumed inputs to the travel demand models. If the assumed and estimated impedances are inconsistent, a new set of assumed impedances should be developed and a new cycle of the analysis process initiated. It is anticipated that this cycling process could be designed so that the assumed and estimated impedances converge.

In this context, it is possible to examine the position of the parking analysis process within the network evaluation process. The impedances associated with the terminal portions of a trip should be considered in conjunction with the impedances associated with the over-the-road portion to estimate the total impedance associated with travel between a given origin and a given destination. In congested areas, such as the central business district (CBD) of a city, these terminal impedances may constitute a substantial portion of the total travel impedances.

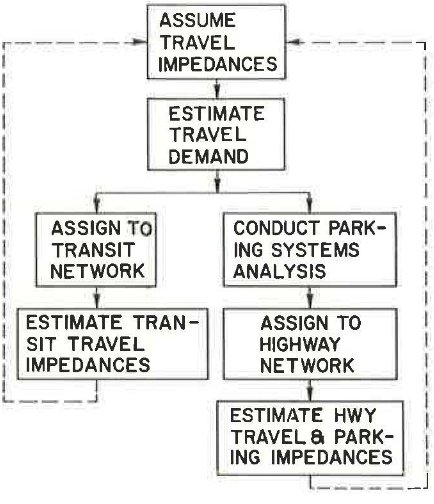

Figure 1. Network evaluation process.

Because an individual may park in a zone other than the trip destination and then walk to the destination, the distribution of automobile trips may be different from the distribution of person trips. For this reason, application of the parking simulation model, which could be used to develop vehicle trip tables different from the journey desires of the automobile drivers, should precede application of the highway network simulation model.

PARKING SYSTEMS ANALYSIS: STRATEGY

The objective of the analysis is to provide information that will assist in the formulation of a parking program. An overview of a proposed set of steps to carry out a systems analysis of the parking process is shown in Figure 2.

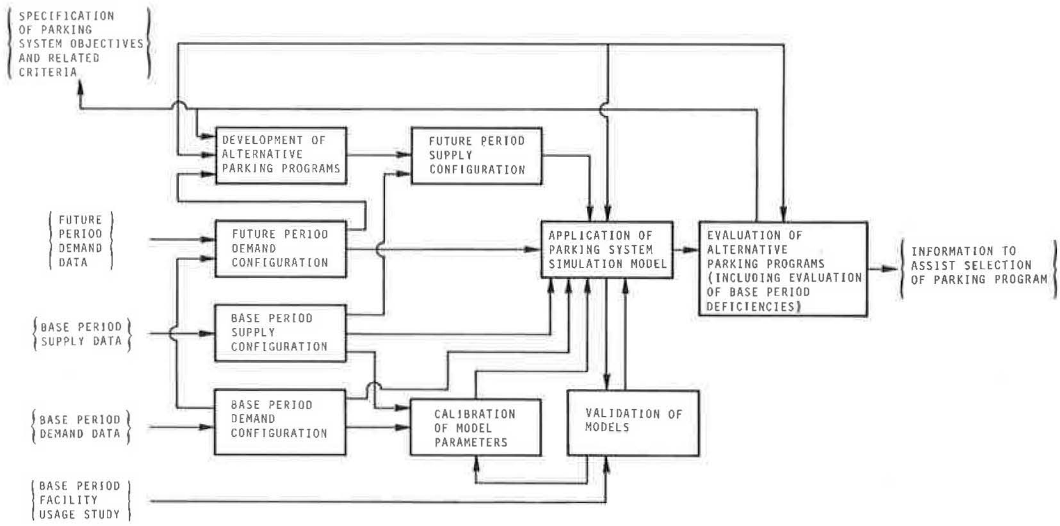

Figure 2. Flow chart of parking systems analysis.

Parking System Simulation Model

In the Parking System Simulation Model (PSSM), the operation of a given parking system is simulated for a given time-dependent parking demand. As shown in Figure 3, the simulation model has the following basic steps:

1. Initialization,
2. Determination of arrivals,
3. Allocation of arrivals to facilities,
4. Updating of parking supply for subsequent cycles,
5. Performance evaluation, and
6. Advancement of clock to the next cycle.

The allocation model is the central element of the simulation model. For a given population of parkers, defined by trip purpose and socioeconomic status and destined to a final destination zone, some level of disutility can be associated with each parking facility. The model, mathematically developed in a subsequent section, is based on the assumption that arriving parkers are allocated among alternative facilities such that the aggregate disutility for all parkers is minimal, subject to capacity constraints for each facility and subject to the satisfaction of the demands of all groups of parkers.

At each cycle of the simulation, demand is an exogenous input to the simulation model. However, parking supply is an exogenous input at the first cycle only, because in subsequent cycles the supply available at a given parking facility is a function of its maximum capacity, of the restrictions imposed (such as no on-street parking during rush hours), and of the parkers assigned to this facility during previous cycles.

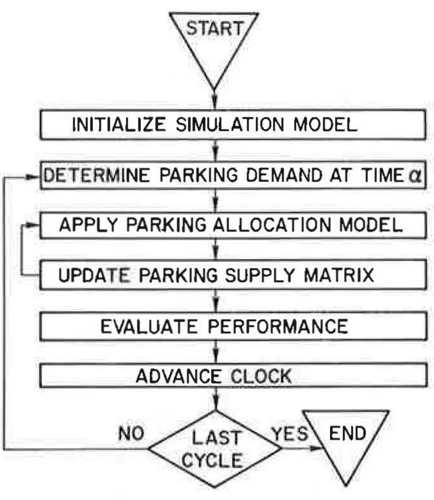

Figure 3. Parking system simulation model.

Demand Configuration

Parking demand is an input to the PSSM. This model requires disaggregation of the stock of demand, and to a certain extent its operation and the usefulness of its output depend on the type of demand inputs. Further, it is assumed that certain parameters influencing travel demand also influence parking choice.

Spatial, socioeconomic, and trip characteristics should be the principal dimensions in the stratification of the demand data. Parking demand must be measured in vehicle trips. If estimates of only person trips are available, automobile occupancy must be estimated. Ideally, occupancy should be a function of each of the stratification variables. For most purposes, it is sufficient to stratify vehicle occupancy by trip purpose, although the socioeconomic status of the traveler may also be important.

Spatial characteristics imply final destination and, eventually, origin. Socioeconomic characteristics include income and occupation, which determine the ability to pay for or the acceptance of a parking location (e.g., in terms of the willingness to walk a certain distance). Trip characteristics imply trip purpose, parking duration, demand distribution throughout the day, and occupancy (if demand is in terms of person trips). However coarse the stratification, it is necessary to have some information about these items, assuming that there may be some relationship between them (such as, perhaps, origin and income). This enumeration is only illustrative, and more specific definition will be given later in the paper. The design of the models and the accompanying computer programs are based on a flexible stratification structure, keeping in mind that a minimum of information is required about the demand input.

At least two sources for acquiring base-year demand data are possible: surveys conducted in conventional urban transportation studies and "at-the-curb" interview studies of parkers. The U.S. Bureau of Public Roads has developed a set of computer programs that facilitate the development of parking demand data from origin-destination data (1). The file of trip records acquired during the home interview survey is searched and trips into and out of a given area by a given vehicle are linked, thus allowing the derivation of information (including parking duration) and the creation of a single parking record. Alternatively, base-period parking records could be developed from an "at-the-curb" interview of parkers (2, 3).

In order to calibrate the parking models, it would be useful for the base-year parking record to contain information that allowed parking demand to be stratified by the variables previously identified and that indicated the actual impedance associated with parking at a given parking zone when traveling to a given final destination zone. To satisfy the latter requirement, the parking record should contain information on the impedances associated with parking at the given parking zone (e.g., total parking cost, vehicle occupancy, and waiting time for access and egress) and the impedances associated with traveling from the parking location to the final destination (e.g., zone of parking, zone of final destination, and access mode, which would allow the calculation from networks of access times, distances, and costs). These requirements may imply that additional information should be acquired during the home interview survey conducted by an urban transportation study or during the "at-the-curb" interviews of parkers or both.

When validated, the parking models can be used to evaluate the consequences of alternative parking programs. Future period demand data consist of origin-destination vehicle trip tables, stratified by trip purpose or socioeconomic status of tripmakers or both, that are developed in the urban transportation planning process. Through tabulations of the base period data, factors are developed to stratify future period or other trip tables by time of arrival at parking zone and parking duration.

Supply Configuration

In the parking analysis, information on the supply of parking is used in the PSSM and in the calibration of model parameters. Parking inventory data are organized in a form suitable for input to the analysis during the supply configuration phase. Two types of supply variables are required:

1. Interchange variables that describe the impedances associated with travel from a given parking facility k to a given final destination zone j (examples of interchange variables include distance or time or both associated with walking from k to j, feeder vehicle time, and feeder vehicle cost); and

2. Parking facility variables that characterize a given facility, including capacity, a restriction schedule (hours when parking is forbidden and maximum duration), a price schedule (because price is generally a function of the duration of parking), and the waiting time at the facility (which may be a function of the type of facility).

Validation of Models

Initially, the PSSM is exercised to determine if base-year conditions can be replicated. In the model validation phase, results of applying the simulation model for the base period are compared to the results of parking usage studies (3). If necessary, the parameters of the parking models are appropriately adjusted, and this cycle of refinement and testing continues until the simulation model adequately replicates existing conditions.

Development of Alternative Parking Programs

Results of the simulation model for the base condition can be used to identify deficiencies in the existing parking system. A variety of information inputs, including specification of parking system objectives and related criteria, future parking demand data, and the results of previous evaluations of alternative parking programs, can be used to develop alternative parking programs.

Evaluation of Alternative Parking Programs

Traditional parking studies generally provide information on the location of parking "deficiencies". This paper views a deficiency as a discrepancy between the actual performance of the system and a specified standard. Hence, the specification of parking system objectives and related criteria is a basic input to the parking systems analysis. An accounting scheme defining parking system performance so that the user can identify deficiencies according to his own criteria and standards is included in the simulation model.

A truly comprehensive evaluation of alternative parking programs implies that the performance and the consequences of the program be evaluated from at least four points of view: (a) operator (or operators) of the parking system; (b) system users; (c) non-users in the system environment; and (d) government. A complete discussion of the objectives and criteria that should be used when evaluating alternative parking programs is beyond the scope of this paper, and this section is restricted to a discussion of the types of evaluation information directly provided by the PSSM as implemented in the computer system developed by Peat, Marwick, Mitchell and Company.

All evaluation information could be presented at each time period for which the simulation was run and/or as a summary for a given group of such periods (e.g., a.m., p.m., or all day). In the computer system developed by Peat, Marwick, Mitchell and Company (4), the following operator evaluation data items could be obtained:

1. Number of parkers assigned,
2. Revenue,
3. Total capacity of facility, and
4. Available spaces in facility.

Items 1 and 2 could be obtained stratified by facility and by all of the stratifications contained in the demand data, whereas items 3 and 4 could only be stratified by facility.

From these outputs, the analyst could determine a variety of other information for evaluating a parking program from the operator's viewpoint, including the following:

1. Number of parkers in facility;
2. Number of space-hours of use;
3. Revenues;
4. Number of parkers who used the facility;
5. Turnover, defined as the ratio of the number of vehicles using the facility during the entire simulation to the capacity of the facility;

6. Occupancy, defined as the ratio of the total space-hours of use during the entire simulation to the total available space-hours; and

7. Peaking, in particular the maximum number of vehicles in the facility at any one time and the time period of the peaking occurrence.

To provide evaluation information with respect to the user's point of view, it is necessary to evaluate the parking impedances of each group of parkers. These parking impedances are the interchange variables and parking facility variables and include, for example, walking time or distance between the parking facility and the final destination and parking cost. In the computer system developed by Peat, Marwick, Mitchell and Company (4), the basic user evaluation data item is the product of the number of parkers that fall into a given category and the level of the given interchange variable or parking facility variable. Any of these user items could be obtained stratified by facility and by all of the stratifications contained in the demand data. By appropriately summing the products with respect to one or more of the stratification variables and dividing by the number of parkers, we can evaluate average system performance, for example, with respect to a given destination zone or group of parkers.

PARKING ALLOCATION MODEL

An allocation model, which at every time period allocates arriving parkers among the available parking facilities, is the central element of the PSSM. The model developed in this section lends itself to various levels of analysis, according to the amount of information provided or the objectives of the study or both.

Disutility Functions for Parkers

Several variables appear to be of particular importance in influencing parking behavior. These include the following:

1. The total "out-of-pocket" cost of parking;
2. The distance or time or both associated with walking from the parking facility to the final destination;
3. Travel time and travel cost associated with a special feeder system;
4. Waiting time at the parking facility;
5. Safety; and
6. The location of the parking facility with respect to travel route.

A disutility function can be defined that transforms several measures of parking disutility into a single estimate of disutility. This function expresses a trade-off between one measure of parking disutility and all others for a given level of disutility. It is initially suggested that the behavior of a given group of parkers be essentially a function of total "out-of-pocket" cost and total time of access to final destination. Various parking studies have noted that, for a given purpose, the price paid for central business district parking generally decreases when "walk time" increases. Although the following discussion is based on these factors, other measures of disutility could be contemplated; for example, walking distance could be used as a substitute for walking time. The disutility function could have a number of forms, for example (Fig. 4),

$$Y(j, k, q, d) = \alpha(q)t(j, k) + \beta(q)c(k)$$

$$Y(j, k, q, d) = \alpha(q)\,[t(j, k)]^{\beta(q)}\,[c(k)]^{\gamma(q)}$$

$$Y(j, k, q, d) = \alpha(q)t(j, k) + \beta(q)c(k) + \gamma(q)\,[c(k)]^2$$

$$Y(j, k, q, d) = \alpha(q)c(k) + \beta(q)t(j, k) + \gamma(q)\,[t(j, k)]^2$$

where

$Y(j, k, q, d)$ is the disutility of group q, a subscript used to denote a group of users, defined by their trip purpose, p, and/or their socioeconomic characteristic, g, for a given parking duration d;

$t(j, k)$ is the total time required to walk from parking facility k to destination j plus the waiting time at facility k;

$c(k)$ is the total out-of-pocket cost of parking at facility k; and

$\alpha(q), \beta(q), \gamma(q)$ are calibrated parameters characterizing a group q.

Lisco (5) recently completed a study of the relationship between parking costs and distance from the financial area in the Chicago CBD. In approximately ½ mile, parking costs decreased linearly from $3.00 to 75 cents per day, thus implying that those who drive downtown are willing to pay 30 cents per day to avoid walking an extra block.

Two further points should be noted. First, the disutility could be simply a function of walking distance, walking time, or cost. Second, the analyst could set acceptable, not to be exceeded, limits for walking distance, walking time, or parking cost and in this manner identify deficiencies in the parking system.

At a given time period of arrival a, let $X(j, k, q, d)$ denote the number of users from group q who are destined for zone j and park at facility k until time period of departure d. The total parking disutility of these users is

$$Y(j, k, q, d) \times X(j, k, q, d)$$

Then the aggregate disutility of parking at time period a is equal to the sum of the disutilities over all denstinations, parking facilities, groups, and departure periods from the parking facilities,

$$\sum_j \sum_k \sum_q \sum_d Y(j, k, q) \times X(j, k, q, d)$$

Representation of Supply

Parking supply may be conveniently represented using a matrix formulation. An H × K matrix is defined in which the columns represent time period (1, . . . , h, . . . , H)

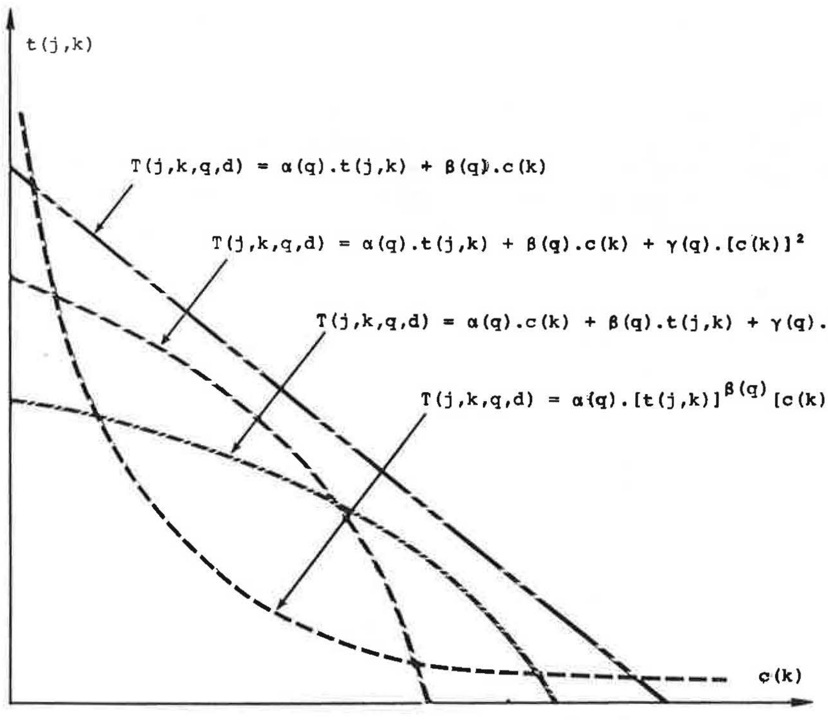

Figure 4. Alternative disutility functions.

and the rows represent facilities $(1, \ldots, k, \ldots, K)$. All entries in a given row k are set equal to $m(k)$, the maximum capacity of facility k. The maximum capacity matrix is

$$M = [m(h, k)]$$

where $m(h, k) = m(k)$.

An $H \times K$ matrix is defined in which the columns and rows represent time periods and facilities respectively, and the entries are set equal to the number of spaces restricted to parking at a given facility and a given time period. Let the restriction matrix be

$$R = [r(h, k)]$$

It is then possible to define a parking supply matrix that represents, at a given time period, the supply available for all following time periods. This matrix is updated at each cycle of the simulation model. If $S_a(h, k)$ is called the matrix, the entries of which represent the parking supply available at a facility k at a fixed time period a for subsequent time periods h, then at the first time period $(a = 1)$ the available supply is represented by the entries of the matrix

$$S_1(h, k) = M - R = [m(h, k) - r(h, k)]$$

The parkers arriving at time period of arrival 1 are then allocated and the supply matrix is updated by decreasing the corresponding entries. The entries of supply matrix at time 2 will be

$$s_2 \,(h, k) = s_1 \,(h, k) - \sum_j \sum_q \sum_{d>h} X(j, k, q, d)$$

In general, the entries of the supply matrix at time period of arrival a for all $h > a$ are

$$s_a \,(h, k) = s_{a-1} \,(h, k) - \sum_j \sum_q \sum_{d>h} X(j, k, q, d)$$

<u>Formulation of the Parking Allocation Model</u>

The allocation model is based on the assumption that parkers are allocated among alternative sites such that the aggregate disutility for all parkers is minimal, subject to capacity constraints for each facility and to the satisfaction of the parking demand of each group. For a given time period a, this may be stated mathematically as:

Minimize

$$\sum_j \sum_k \sum_q \sum_d Y(j, k, q, d) \times X(j, k, q, d)$$

subject to

$$\sum_j \sum_q \sum_{d=a} X(j, k, q, d) \leq s_a \,(a, k)$$

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$$\sum_j \sum_q \sum_{d=h} X(j, k, q, d) \leq s_a \,(h, k) \qquad \text{(for each k)}$$

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$$\sum_j \sum_q \sum_{d=H} X(j, k, q, d) \leq s_a \,(H, k)$$

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

$$X(j, k, q, d) \geq 0$$

where

$X(j, k, q, d)$ is the number of parkers estimated by the model;
$s_a(h, k)$ is the capacity of an entry of the supply matrix at analysis period a;
$Y(j, k, q, d)$ is the disutility of parkers;
$Y(j, q, d)$ is the number of parkers;
j is an index identifying a zone of final destination;
k is an index identifying a parking facility;
q is an index identifying a group of parkers;
d is an index identifying a time period of departure; and
h is an index identifying a time period $(a \leq h \leq H)$.

Both the objective function and the parking demand constraints have a straightforward structure, but the parking facility capacity constraints are more complex. At a given analysis period a, the total number of parkers assigned to a facility k (which is calculated by summing parkers over all destinations j, all groups q, and all departure periods d) cannot exceed the capacity $S_a(h, k)$ in that facility at that analysis period. This represents both a necessary and a sufficient capacity condition for each facility provided that no parking restrictions will be imposed at some time period of departure d, where $a \leq d \leq H$. If such restrictions do exist (e.g., a ban on curb parking during the 4 to 6 p.m. period), the capacity constraint may occur during a time period h following the given analysis period a. To develop a necessary and sufficient capacity constraint set for this case, we must check that the total number of parkers assigned to a facility k for each time period remaining in the analysis (i.e., a, . . . , h, . . . , H) is less than or equal to the capacity of the facility at the period. Hence, if restrictions exist, $H - a + 1$ capacity constraints have to be added to the capacity constraint for analysis period a.

SOME PROBLEMS AND PROSPECTS

This paper represents only an initial step toward a rather ambitious but important objective: the implementation of an analytical framework for conducting a systems analysis of a parking or terminal system. Although the models and methods proposed in this discussion are in a developmental stage, certain concluding observations regarding the structure of the model system are appropriate.

It was suggested in the introduction that the models developed to carry out a parking system analysis should be responsive to variations in the parking system design, operating policies, socioeconomic and travel characteristics of the users, and highway and transit system designs. The analytical framework proposed is responsive to one or more variables relating to each of these four sets of factors. Parking system design variables such as the location and capacity of facilities are introduced into the parking allocation model either in the parking facility to final destination zone interchange variables or the parking facility variables incorporated in the disutility function or in the constraints.

A significant feature of this parking systems analysis framework is its ability to estimate the effects of alternative operating policies, such as parking prices and restrictions, or even staffing policies for attended facilities. Through the use of queuing or simulation models, the waiting time associated with alternative staffing policies for a given facility can be evaluated. Both parking price and waiting time can be incorporated into the disutility function. Parking restrictions, such as the maximum allowable duration or time periods in which a facility is unavailable, are also considered by appropriately adjusting prices to reflect the penalty associated with remaining in a facility beyond the allowable duration. The available parking supply in a given analysis period is reduced to take account of periods in which parking in the facility is restricted.

An increasing amount of attention is being devoted to the relationship between operating policies and the characteristics and efficiency of the urban transportation system. Examination of recently developed modal preference models (6) suggests that parking prices may have an important influence on the consumer's choice between automobile and transit. As the use of operating policies is explored, it becomes increasingly important that urban transportation planning models exhibit appropriate sensitivities to these policy variables.

Socioeconomic and travel characteristics of the users, such as income status, trip purpose, time of arrival, and duration, are considered either in the stratifications used to estimate parking demand or in the stratifications used in developing the disutility functions. Considerations relating to the highway and transit system designs are generally introduced into the analysis through the parking demand estimates derived from the outputs of the standard urban transportation planning models. However, special situations, such as the parking facility to final destination service provided by a CBD passenger distribution system or peripheral parking with public transit feeder, can be directly considered in the parking systems analysis by introducing the appropriate variables into the disutility function.

Thus, it would appear that the analytical framework proposed in this paper offers promise as a means for carrying out a systems analysis of parking. This prognosis would be confirmed by using the models in a wide spectrum of operational planning applications.

ACKNOWLEDGMENTS

This material was developed as the conceptual basis for a parking analysis computer system developed by Peat, Marwick, Mitchell and Company for the U.S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads. The authors would like to express their appreciation to Robert W. Whitaker of Peat, Marwick, Mitchell and Company for his important comments, which greatly contributed to the development of these concepts. Also, the authors gratefully acknowledge the assistance of Steiner M. Silence and Robert W. Stout of the Bureau of Public Roads and Lawrence L. Schulman, formerly of the Bureau.

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Discussion

V. SETTY PENDAKUR, University of British Columbia—The paper by Ellis and Rassam is an excellent beginning in further sophisticating the analytical tools for evaluating alternative parking programs. They have shown how systems analysis can be structured for evaluating parking programs.

As a procedural tool, application of systems analysis would appear to be a sophisticated step forward. The transportation planner, however, must be aware of several contingent liabilities of systems analysis applied to parking. It is imperative that systems analysis must be on a continuous basis because parking is a dynamic response to the constantly changing patterns of employment and shopping intensities. The simulation model should contain the key public and private components of parking supply. In this regard, the private component of parking responds to the private enterprise market structure where price-demand theories are applicable subject to limitations of public policy. On the other hand, the public component of parking supply, whether it is on-street or off-street, may not respond similarly in terms of price-demand-supply in the simulation model.

In developing allocation and distribution models, it is necessary to give further consideration to the rapidly changing user characteristics. It has been recognized by transportation planners for some time that walking distances, mode preference, and indifferences vary from community to community and are dependent on climate, alternative transport systems, user charges, and the socioeconomic status of the users, as well as the community values. It would appear that the analytical procedures proposed in the paper would take this into consideration, but it is not clear how the dynamic character of the model could be preserved.

Furthermore, base period and future period demand configurations are altered radically with changing sectoral allocation of public funds depicting community values. In the development of alternative parking programs and the stages of development, systems analysis must take into consideration the changing emphasis in public enterprise economics. In satisfying a given demand with a given capital budget, mode preference, impedences, and cost-demand externalities all play a major role and should be included in the systems model. It is not clear how the analysis could be applied when the major portion of available parking is public and on the street and where it could not be aggregated to provide a meaningful input to check out the simulation and allocation models. It is imperative that the techniques of analysis and the simulation models be responsive to public policy variables and capable of discerning consumer choice and impedences.

The most important element in the proposed systems analysis is the "specification of parking systems objectives and related criteria". This should be considered as a dynamic function and should be subjected to validity verification tests periodically. Although the tools of analysis applicable to adequacy and demand analysis are quite sophisticated, there are still basic weaknesses in defining systems objectives within the framework of public policy formulation and in the area of implementation of proposed programs to satisfy the projected demand. It must be pointed out that analytical sophistication without a dynamic element of public policy response in the simulation model will not be of much use.

It is assumed in the proposed model that socioeconomic data will be available in a stratified form in terms of user groups and traffic zones. It should be pointed out that these types of data are hard to obtain on a continuous basis and it is much more difficult to obtain for small urban areas. If systems analysts use the existing and comparable data sources, such as the census, care must be taken to ensure that the resultant community values are transferable in the spectrum of type and size of the community and the degree of urbanization. In the absence of such a safeguard, it is likely that the simulation model will perpetuate currently existing standards, values, and preferences.

The authors have demonstrated that systems analysis is a basic kit of tools that could be applied to the solution of parking problems. The paper presented is an excellent beginning in an important area of public concern.

LAWRENCE L. SCHULMAN, Information Systems Company—In discussing this paper, I feel it is necessary to do so in light of a recent challenge that has been presented to researchers and analysts involved in urban transportation planning. In essence, this challenge involves the existing and possibly widening gap between the research point of view and the program point of view. Research is fine; it can and does provide many powerful tools. However, urban transportation problems exist now, and programs must be developed to solve them now. The decision-makers cannot wait! They must act and we must provide the proper tools. If we do not, the decisions will be made without the benefit of complete analysis, and it is highly probable that they will not be as effective as they might be. It is in this light, therefore, that I discuss this paper, for I believe the authors have developed a system that answers the challenge.

The paper outlines a unique tool that, to the best of my knowledge, is the first tool that approaches analytical equality with the corresponding components of the transportation system. The system utilizes a mathematical representation of the parking phenomenon and minimizes this expression based on the constraints of supply and demand. The key to the operation of the model is the minimization of total "user dissatisfaction", where dissatisfaction is measured by factors such as walking distance between facility and destination, facility costs, queuing times at the facility, and operation characteristics of the facility.

As importatnt as this model is, however, probably more important is what it makes available to the analyst. For the first time a system is available that provides for a meaningful analysis of the three components of transportation—the roadway, the parking facility, and the transit facility. It provides a means of obtaining quantitative answers to the effect that major changes in one urban program have on the others. It provides quantitative answers to actions such as the following:

1. To reduce existing congestion on major downtown streets a decision has been made to remove curb parking. What effect does this have on the level of parking service provided to the community? How much and what type of parking must be provided to replace that lost and to replace the level of service that existed before?
2. What effect does an improved transit system have on reducing traffic congestion and improving level of parking service?
3. What level of transit service would have to be provided to allievate or significantly improve traffic congestion or the level of parking service or both?
4. What effect do parking restrictions on the major radial arterials or major downtown streets have on traffic congestion relief and parking level of service?
5. What effect would a program of fringe facilities located along a major corridor have on the total system or, probably more important, what type of usage can be expected at these outlying facilities? This could be tested for various fringe operating conditions.

Although the previous applications are probably more significant in that they involve quantitative analysis of the entire transportation system, one cannot overlook the importance of this tool in providing quantitative measures of the evaluation of alternate parking programs. Such alternate programs would include comparisons of the following:

1. A system of private facilities only, municipal facilities only, or a combined program of private and municipal facilities;
2. Attendent versus nonattendent parking systems;
3. Programs designed to cater to short-duration parking and penalize the long-duration parker;
4. Programs to discourage parking downtown through prohibitive parking costs; and
5. Alternate facility locations and alternate facility configurations.

In quantifying these possible programs, the analyst will provide measures of the level of service, parking fees, walking distances, revenues, and the like.

In connection with the last item, through use of this system the analyst will have a tool for measuring the effect that parking facility location and characteristics will have on downtown circulation, because the last few moments of the vehicle trip are a function of parking destination as well as purpose destination.

Returning to my opening remarks, in light of the analytical opportunities provided by this system, I believe this paper does answer the challenge. However, the system must be made available for widespread use as quickly as possible, and in such a manner that it will be useful to the largest number of analysts.

RAYMOND H. ELLIS and PAUL R. RASSAM, Closure—We would like to thank Pendakur and Schulman for their discussions and say that we generally agree with their comments. Our aim was to underline the importance of the parking system in the urban transportation process and to provide a framework in which to analyze such a system. While striving to provide a workable tool, we remain aware of the prototype level of the approach offered in this paper and realize that further work is required to reach a fully operational level. We intended to provide the analyst with a flexible analytical tool that encompasses the general nature of the problem but also lends itself to the specific requirements of a given application. The full use of the proposed models and their accompanying computer programs depends largely on the resources available to the analyst.

In response to Pendakur's comments concerning "specification of parking systems objectives and related criteria", we would like to point out that no attempt was made in this paper to specifically develop such objectives. We agree that they constitute a very important aspect of a parking study but believe that they should be developed individually for each study, the purpose of the present work being to provide analytical support for measuring their attainment. As to on-street public parking, the model can provide meaningful answers; e.g., it can point out whether there is enough capacity, whether the demand is satisfied within acceptable walking distances, and the like. Finally, we are aware that present data and future behavior are the Charybdis and Scylla of transportation studies.

We would like to conclude by saying how much we agree with Schulman's concern about reconciling research with the pressing needs of decision-makers. We are grateful to him for his stimulating comments on our work while he was associated with the U.S. Bureau of Public Roads.