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Foreword

The papers in this RECORD demonstrate the continuing interest in the significant problem of parking. The authors suggest ways to study or analyze various parking characteristics, and the information presented should be helpful to those involved in evaluating alternate parking systems.

Concerned that analytical tools for evaluating alternative parking programs are relatively undeveloped in contrast to network analysis procedures, Ellis and Rassam suggest a framework for conducting a systems analysis of the parking or terminal system. They report their development of a parking system simulation model containing six basic steps and including a parking allocation model. They conclude that the system of models and methods described could be used to systematically evaluate alternative parking programs.

In the next paper, Schulman and Stout suggest the utilization of origin-destination data in estimating downtown parking characteristics in order to reduce the cost of traditional parking studies. As in the first paper, a model is used to simulate the distribution of parkers (demand) to available parking facilities (supply), and its use permits evaluation of alternate parking systems.

In the third paper, Yu analyzes fleet parking terminal capacity so that parking operations under this small-vehicle concept can be compared with standard parking operations. He concludes that there is favorable promise of relief in the concept but notes also the revisions in urban vehicle design, operator-vehicle relationships, and terminal facilities that are required to implement such a system.

In the final paper, the author reports on his investigation of trends in central business district parking from 1956 to 1968. After assembling reports and extracting data from 99 parking studies made between 1960 and 1968, Stout analyzed the study results and summarized them according to five population groups. He then made comparisons with several 1956 parameters.

Contents

Structuring a Systems Analysis of Parking

RAYMOND H. ELLIS and PAUL R. RASSAM, Peat, Marwick, Mitchell and Company

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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Paper sponsored by Committee on Parking and presented at the 49th Annual Meeting.

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.

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.

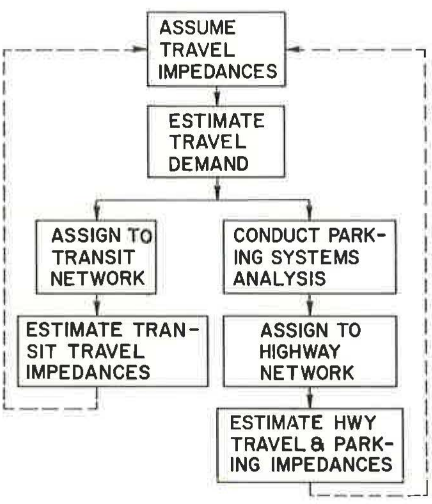

Figure 1. Network evaluation process.

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.

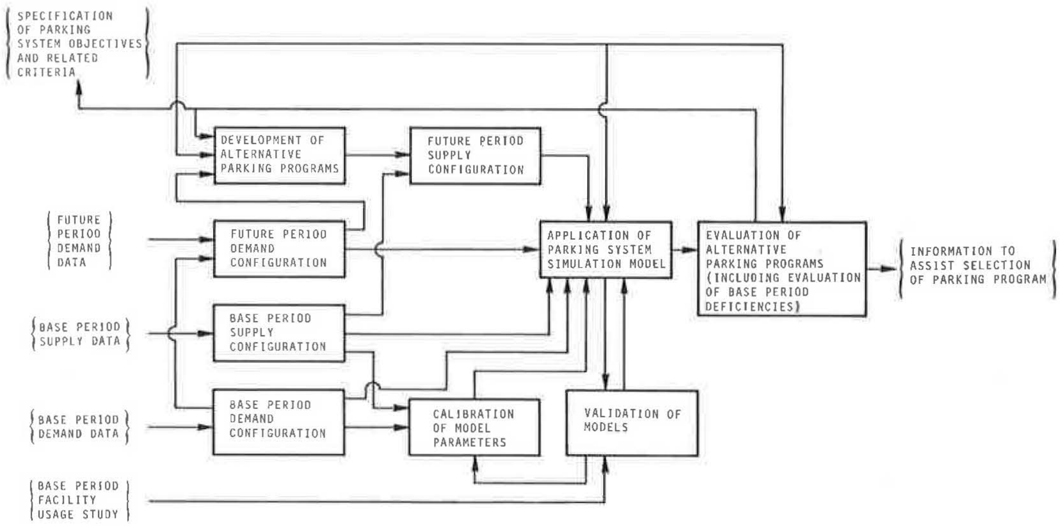

Figure 2. Flow chart of parking systems analysis.

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.

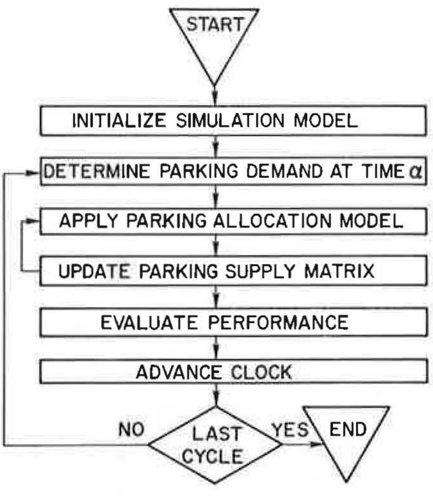

Figure 3. Parking system simulation model.

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) nonusers 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)

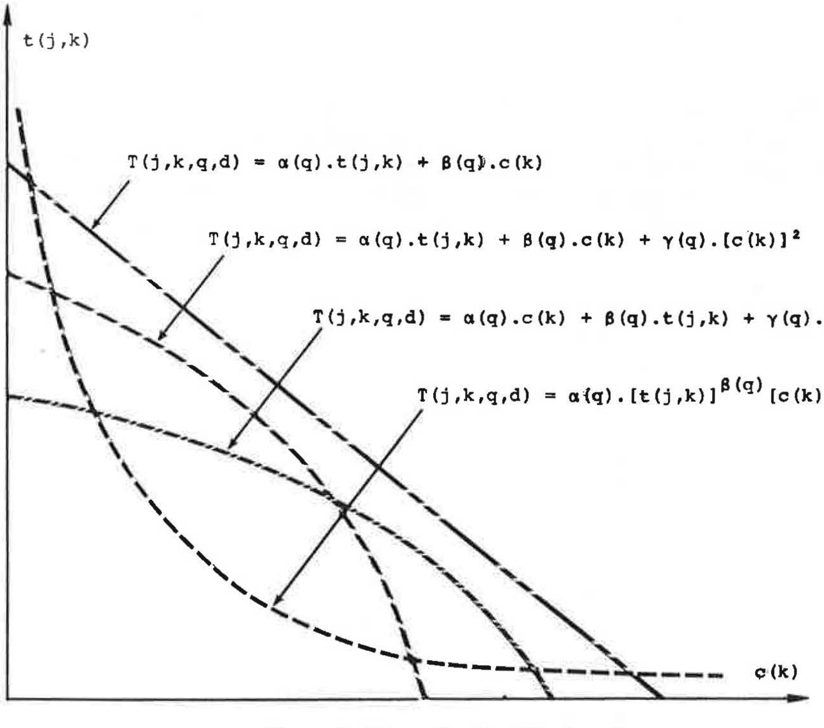

Figure 4. Alternative disutility functions.

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

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

Formulation of the Parking Allocation Model

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

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

****

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

****

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

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

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

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.

A Parking Study Through the Use of Origin-Destination Data

LAWRENCE L. SCHULMAN, Leo Kramer, Inc.*; and
ROBERT W. STOUT, U.S. Department of Transportation,
Federal Highway Administration, Bureau of Public Roads

The traditional parking study has become so costly as to be prohibitive. A new procedure has been developed using origin-destination data to estimate downtown parking characteristics. Together with an inventory of supply, demand data can be used to calibrate a model that simulates the distribution of parkers to available parking facilities. This model can be used to analyze and evaluate alternate parking systems for both the existing parking demand and the forecast parking demand. The alternate parking systems can be expressed in terms of number of spaces, location of facilities with respect to trip generators, rate structure, time restrictions, or additional delays such as queuing time or feeder bus time if fringe facilities are being considered. This model can be used independently to test alternate parking programs or as a tool within the urban transportation planning process to analyze and evaluate alternate transit, parking, and highway systems. In the first application, parking demand is considered as a constant, regardless of the level of parking service provided; in the second application, parking demands will fluctuate as transit and highway use changes with different levels of parking service.

•THE IMPACT of parking on the downtown transportation system has been known for many years. Improper facility location and inadequate parking supply reduce traffic-carrying capability of downtown streets, increase accident potential, and confuse vehicular and pedestrian movements. However, techniques for analyzing these relationships have never been clearly defined.

The procedures discussed in this paper are the result of a project initiated 3 years ago. The objectives of the research were to evaluate existing parking study technology and develop new procedures that would be more efficient, that would be fully compatible with existing urban transportation technology, and that would result in more meaningful reports for the decision-makers.

To define and study the parking activity, three types of data are required: (a) a measure of parking supply and its characteristics—location, costs, turnover, and restrictions; (b) a measure of parking demand and its characteristics—location, arrival time, duration, and purpose; and (c) a measure of usage characteristics—walking distance, parking cost, and duration. To gather these data, conventional study techniques include a field inventory to determine supply characteristics and a special parker interview to determine demand and use characteristics. However, the latter is time-consuming, expensive, and provides data that could be developed from existing surveys.

The origin-destination (O-D) survey produces a data set that provides information very similar to that collected in the parking survey and, during the preliminary stages of this project, it was determined that these data would provide a meaningful estimate

*Mr. Schulman was with Data Processing Financial and General Corp. when this research was performed.

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of downtown parking demand. Use of this data set, which is conventionally used in forecast and analysis of travel demands, has many advantages, including the following:

1. It provides an immediate, inexpensive estimate of parking demand and use;
2. It provides a unique estimate of vehicle travel downtown and the parking demand that these vehicles will generate;
3. It allows additional use of an extensive data set already collected; and
4. It provides a unique estimate of forecast trips and forecast parking demand.

The idea of using O-D data is not new. In recent years, many studies have used O-D data as a basis of estimating parking demand; however, the procedures have never been refined, and consequently only limited parking data could be obtained. This new procedure involves a technique that can produce a full parking data set by combining successive trips made by an individual to and from the downtown area. Figure 1 shows a schematic of an individual's trip to and from the CBD. The left portion represents the individual's trip to the CBD, the right portion the trip from the CBD. The lower portion represents the combined resultant parking record.

As previously indicated, several data items are desired to fully describe parking demand and use characteristics. These include trip purpose, parking destination, facility used, parking costs, walking distance, arrival time, and duration. All of this information can be obtained from the combination of these two trip records. From the first, it can be determined that the individual traveled from home to a certain CBD zone and arrived at 10:00 a.m. Also, it can be determined that he went shopping, parked at a lot a block from his destination, and paid a fee of 65 cents. From the second, it can be determined that he left the CBD at 10:30 a.m. and returned home. The duration is then calculated as the difference between the time of parking (10:00 a.m.) and the time of unparking (10:30 a.m.).

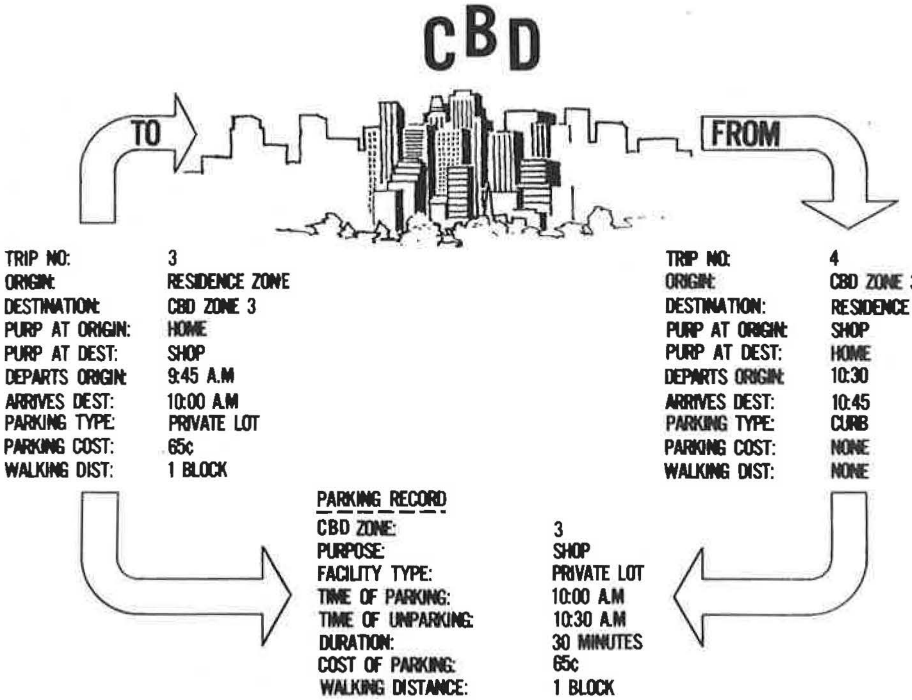


Figure 1. Use of origin-destination data to create a parking record.

TABLE 1

PERCENTAGE OF PARKING BY FACILITY AND COST

Facility	1960			1963			Difference		
	Free	Pay	Total	Free	Pay	Total	Free	Pay	Total
Curb	12	53	65	23	32	55	11	-21	-10
Lot	21	13	34	32	10	42	11	-3	8
Garage	—	1	1	2	1	3	2	—	2
Total	33	67		57	43		24	-24	

VALIDITY OF USING ORIGIN-DESTINATION DATA

Despite the advantages that have been cited, there were several immediate questions concerning the validity of using O-D data for CBD parking analysis. In essence, these questions concern the possible underreporting of CBD trips in the O-D survey. To evaluate how crucial this underreporting might be, a preliminary comparison was made between 1960 parking study data for Sioux Falls, South Dakota, and similar data extracted from the 1963 transportation study. A comparison of the data sets for trip purpose and facility use for the total CBD is given in Table 1 and shown in Figure 2. In each of these comparisons, an appropriate factor was applied to the 1963 transportation study data to account for the 3-year time difference. In Figure 2 it is shown that a total of 16,169 parking activities are reported in the 1960 parking study and 17,124 parking activities are reported in the 1963 O-D data. This indicates a difference of 955 activities or 6 percent (parking study as a base figure). It also indicates that the difference in percent distribution of parking activity by purpose is 5 percent for shopping, 2 percent for work, 2 percent for personal business, and 5 percent for other. Table 1 gives a similar comparison between the two data sets for facility use. It is observed that both data sets show similar facility use but show a difference in cost. Curb usage in the 1963 data is 10 percent less than in 1960, and lot usage is 8 percent higher. These minor discrepancies are not alarming and could be caused by elimination of curb facilities in the 3-year period with an accompanying increase in lot facilities. However, the 24 percent difference in cost is not easily explained. It is interesting to note that, although not reported in this paper, a similar comparison was made between the 1960 parking study and parking data extracted from a 1956 O-D data set with an identical result—close comparison in facility and significant difference in cost.

Figure 3 shows accumulation curves drawn for the 1960 and 1963 data. The similarity of the two curves further reinforces the conculsion that the data sets are similar. In addition, this comparison indicates that the times of arrival and departure reported in both sets are similar.

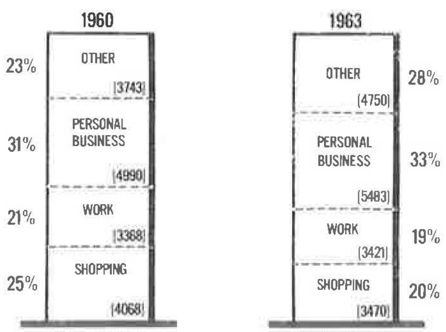


Figure 2. Comparison of parkers distributed by purpose.

PROCEDURES FOR USING ORIGIN-DESTINATION DATA

In developing procedures for using the origin-destination data, the two basic phases of the parking analysis must be considered. The first phase concerns the analysis of the existing or base year conditions and locates the existing parking deficiencies; it is the basis of an immediate action program. The second phase involves the analysis of forecast parking demands and locates the facilities needed to satisfy the future demand; it is the basis for a long-range program. This long-range program provides the framework for the total comprehensive parking program and reflects the ultimate level of service desired by the forecast year. Therefore, the immediate action program must be designed so as to be compatible with the long-range plan. The coordination of these programs is the initial step toward design of the comprehensive parking program for the downtown area.

As with conventional parking studies, the new analysis involves utilization of the two basic data sets—the base year data and the forecast data. Figure 4 shows the steps in processing the data. The analysis begins with the three base year data files—the external trip file, the internal trip file (home interview survey), and the parking supply file. The internal trip file is the data set that contains most of the parking data; therefore, it is processed first. The trip cards are sorted and processed through a linking routine, thereby creating the internal parking demand file. This file is summarized, creating tables that define the internal parking demand and parking characteristics. These characteristics are then used to transform the external trip file into an external parking demand file. The merging of these two files results in the base year parking demand data set.

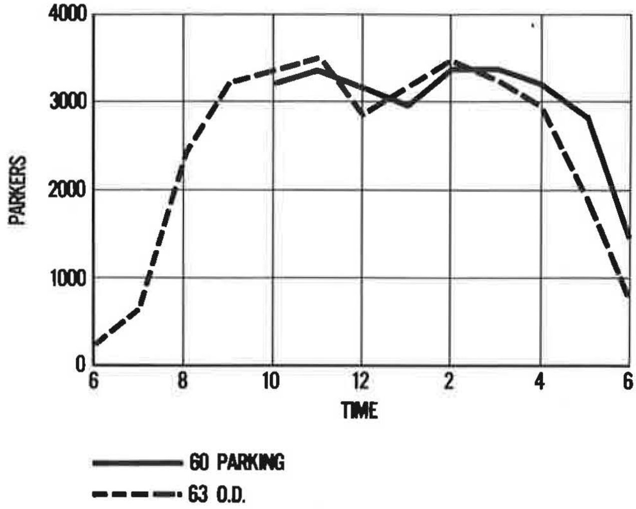


Figure 3. Total parking accumulation in Sioux Falls for 1960 and 1963.

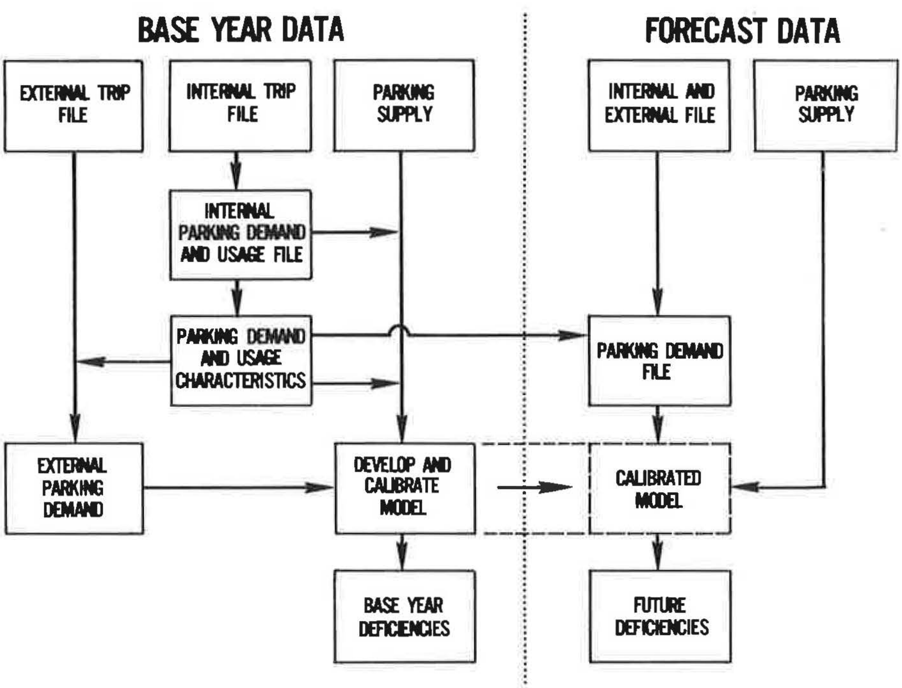


Figure 4. Procedures for use of origin-destination data.

Having defined the parking demand file, we proceed to the next step, the distribution of this demand to the available supply. This involves use of a special distribution model that has been developed for this purpose. As with other transportation models, however, this distribution model first must be defined and calibrated. Once the model has been calibrated, the base year data can be analyzed and existing deficiencies noted.

One of the major objectives in the development of this new procedure was to provide reports that would be more useful to those individuals who make the decisions concerning development of parking programs. Therefore, the reporting function of the distribution model is such that it will indicate the general location of the deficiency, the magnitude of the deficiency, whether the deficiency results from the need for additional long- or short-duration parking, and the time that the deficiency occurs. With this detailed information, a short-range or immediate-action parking program can be developed.

Next, the forecast data are analyzed. These data consist of the forecast trip ends and parking supply. This may be the existing supply or an estimate of the future parking supply. The forecast trip ends are transformed into a future parking demand file through use of the characteristics developed for the base year. The parking demand and supply are then analyzed using the calibrated distribution model. A report similar to that of the base year is created, and the long-range parking program is developed.

ELEMENTS OF THE PROGRAM SYSTEM

To analyze the O-D data as described, it was necessary to develop a system of seven special programs. These programs are as follows:

1. LINK—edits and links successive person trips to and from a given area;
2. UPDATE—allows corrections of errors in the basic trip files;
3. TABULATE—summarizes and tabulates data in a matrix form (samples of output of TABULATE appear later in the text);
4. EXTRACT—extracts matrices created through TABULATE;
5. EXPAND—formats data for regression analysis or tabulation;
6. MODPARK—merges and factors data sets; and
7. ALOCAT—distributes parking demand to supply based on input parameters.

In general the program system operates as shown in Figure 5.

In step 1, the sorted internal trip file is processed through the LINK program, creating the preliminary parking record file and a list of data errors. Inputs to this program include definition of the input data, definition of the variables that identify the trips and the trip-maker, and definition of the CBD zones. The error listing indicates data collection, coding, or punching errors observed in the input file that prohibit the linking of certain records.

Errors in the input data are resolved through use of program UPDATE in steps 2 and 3. The corrections are appropriately coded on operation cards and processed with the original tape through the program. An updated internal trip file is produced that is then processed through the LINK program, producing the final internal parking record file.

In step 4, the parking demand file is processed through the TABULATE program, which summarizes the internal parking data in the form required to process the external trip file. In step 5, these summarized internal data are processed through the EXTRACT program, which produces the data deck needed for further processing.

In step 6, the external trip file is processed through TABULATE, which summarizes the external trip file in the form needed for adding the external trips to the internal parking demand file. These summarized external trip data are processed through EXTRACT (step 7), which produces the data deck required for further processing.

In step 8, the internal parking demand deck produced in step 5 and the external trip deck produced in step 7 are processed through the MODPARK program, which merges the decks and produces a total parking demand data deck needed for further processing. Simultaneously, the internal parking demand file tape can also be processed and an updated total parking demand file tape produced.

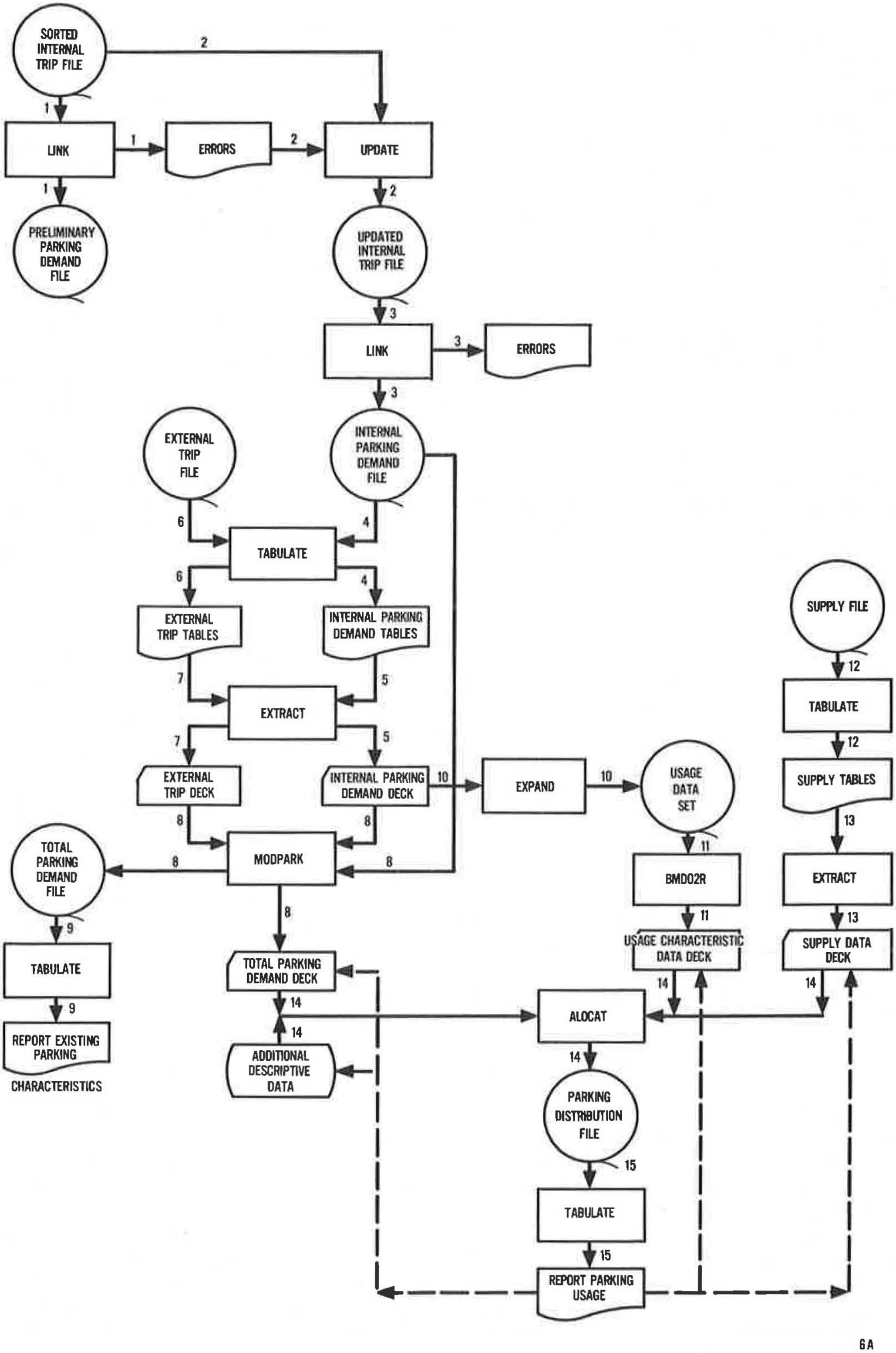


Figure 5. Parking study procedure.

In step 9, the parking demand file produced in step 8 can be processed through TABULATE to produce all desired summaries of parking characteristics.

One of the data sets produced by steps 4 and 5 contains information on those variables reflecting the trade-off between walking distance or time and parking cost. This data set is processed through the EXPAND program (step 10), which produces a data file needed to further process the trade-off relationships. This data file is processed through the Bio-Medical Computer program (step 11), which develops the statistical relationships between time and cost utilized in the distribution model (1).

In step 12, the base year supply data are processed through TABULATE, which summarizes the data as needed for the further processing. This summarized supply data file is processed through EXTRACT, which produces the required data deck, in step 13.

In step 14, the demand data (step 8), the time-cost relationship (step 11), the supply data (step 13), and other necessary input data are processed through the ALOCAT program, which distributes the demand to the supply. The additional input data include parking costs, parking time restriction, time separation between generators and parking facilities, and other facility characteristics such as queuing time and attendant parking.

In step 15, the output tape from step 14 is processed through TABULATE, producing the desired tabular summaries. The initial tables produced would be those for comparison of the synthesized data and the base year data. Based on these comparisons, appropriate revisions are made in the input parameters to step 14 and ALOCAT is rerun. This iterative procedure continues until staisfactory calibration is achieved. At this point TABULATE produces the final reports.

THE ALOCAT MODEL

Program ALOCAT provides one of the major innovations in the parking technology. In previous parking studies, supply and demand were analyzed by block through comparison of total parking activity for the study period (usually 8 or 10 hours) and total supply available in that period, or through comparison of total parking activity for the peak hour and total supply available in that hour. This analysis results in a block-by-block determination of parking surplus or deficiencies. To account for the known fact that parkers do not necessarily park in the block of trip destination, the individual deficiencies are arbitrarily assigned by hand to surplus in adjacent blocks. The resulting report contains information on the total number of spaces required to satisfy the deficiency in the block.

ALOCAT provides a dynamic, iterative distribution procedure that distributes an increment of parking demand to the available supply based on the characteristics of the parking demand, the user, and available parking facilities. Possible user and demand characteristics include origin of the trip, destination of the trip, arrival time, purpose, duration, and socioeconomic level of the trip-maker. Possible supply characteristics include location with respect to demand generators, number of spaces, time restrictions, and fee structure.

The distribution is performed for defined time intervals such that all individuals desiring to park in that time period do so with a minimum of dissatisfaction, where user dissatisfaction may be measured in terms of total cost and the distance between the parking facility and the ultimate trip destination or the time elapsed in traveling this distance. This time element also can be expanded to include queuing time involved in entering a particular facility or the time involved in using a feeder bus if a change-of-mode facility is being used.

The degree to which the numerous options in the ALOCAT program can be used is directly related to the type of information available in the demand data file and the degree to which this data set can be stratified. If detailed information is not available, the corresponding stratification is dropped, and the data are analyzed at the next level. A minimum stratification of CBD destination zone, time of arrival, and time of departure must be possible.

The discussions to this point have involved the utilization of O-D based parking demand; however, at this time, it has not been conclusively proved that these types of data can undergo all stratification necessary to fully utilize the options available. Therefore, to allow very detailed special purpose analysis using the ALOCAT model to the fullest extent possible, the system has been designed to accept data available through any survey technique and is not limited to O-D based data.

The reporting function of ALOCAT is such that it can provide many types of summaries. These reports can be classified as those defining the operation of the facility and those defining the use of the facility. To define facility operation, for each time interval (iteration) used for distribution, it can report the number of vehicles entering the facility, the total number currently in the facility, revenue for this interval, total space-hour use through the interval, total revenue through the interval, maximum number of parkers at any time, time this maximum occurred, and the total number of parkers who used the facility. To define usage, it will report total number of parkers in a cell where the cell can be defined by origin zone, destination zone, parking facility, purpose, socioeconomic level of trip-maker, time of arrival, time of departure, duration, walking time or distance between facility and destination, or parking costs.

SIGNIFICANCE OF THE NEW PROGRAM SYSTEM

The design of a program system that facilitates a systematic parking study using O-D data is a significant achievement in itself. However, this system also provides a major new tool for evaluating alternate parking programs by themselves and, possibly more important, a tool for evaluating alternate total transportation programs—programs that include alternate highway, transit, and parking systems. Again, the extent of analysis possible is a function of the amount of data available.

As a tool to evaluate operation of parking facilities under different environments, the following possibilities exist. In each of these applications the underlying assumption is that parking demand remains constant regardless of the supply configuration. Because the parameters describing the parking facility include location with respect to demand generators, fee structure, and parking restrictions, any or all of these parameters can be changed and the effect of these changes on use and operation can be determined. Therefore:

1. If the difference between municipal and private parking facilities can be expressed by rate structure, a system of private only, municipal only, or combined private and municipal could be studied through manipulation of the parking cost parameters.
2. If the difference between attendant or self-park facilities can be expressed in queuing time, the effects of either operation could be determined through manipulation of the distance (time) parameters.
3. If it were desired to evaluate the effect of a program of facilities designed to cater to the short-duration parker (increased hourly rate as duration increases), these facilities could be identified through an appropriate rate structure and the operator and user reports evaluated.
4. If it were desired to evaluate the effect of discouraging parking in a central core area through establishment of prohibitive fee structures, an appropriate rate structure could be programmed and the system evaluated.
5. If serious parking deficiencies had been shown to exist in several areas, a proposed system of planned facilities could be added to the supply and the adequacy of this system evaluated. The effects of alternate location could be studied at this time.
6. If it were desired to evaluate a proposed system of fringe parking facilities, these facilities could be included in the supply and the time parameter extended to include feeder bus time (including waiting for the bus). Once the fringe parking system had been included, the model could then be used iteratively to evaluate the effect of CBD parking rate structures on fringe facility use or the effect that feeder bus time has on fringe facility use.

As previously indicated, the system also provides a tool for evaluation of total balanced transportation systems. The relationship of parking as an element of the transportation system has always been discussed, but this is the first practical tool that provides a means for evaluation. Specifically, this is a tool that can be used within the urban transportation planning process to evaluate alternate transportation systems.

One of the critical decisions in this evaluation is the determination of the point within the planning process at which the parking analysis would be most meaningful. Such determination requires a detailed analysis of the input and output of each major phase. In a greatly oversimplified view, the land use phase produces activities that are translated into person trip ends through generation and into vehicular trip ends—automobile and transit—through modal split. These vehicular trip ends are then translated into zone-to-zone interchanges through distribution and into link volumes through assignment. These resultant volumes are then analyzed to determine network revisions.

Within this framework, it was determined that the most appropriate placement of this analytical tool was after the determination of zonal automobile-driver trip ends. At this point, when the number of vehicles destined to park in the downtown and its environs has been identified, a determination can be made as to whether the existing supply is adequate to accommodate the arriving vehicles. If such demand were adequately accommodated by the existing supply, then the analysis could continue in the conventional manner. If parking supply were inadequate, however, certain decisions could be made to more equitably balance the transit-parking-automobile relationship. These decisions could involve the designation of additional land to parking, construction of additional parking supply, re-evaluation of generation procedures, or re-evaluation of the modal split procédures. Because many of these decisions would change the vehicular trip ends, this analysis is appropriately placed before trip distribution, assignment, and system evaluation.

As in the previous discussion, there are many ways in which the model can be used as a tool within the planning process. Two hypothetical situations follow:

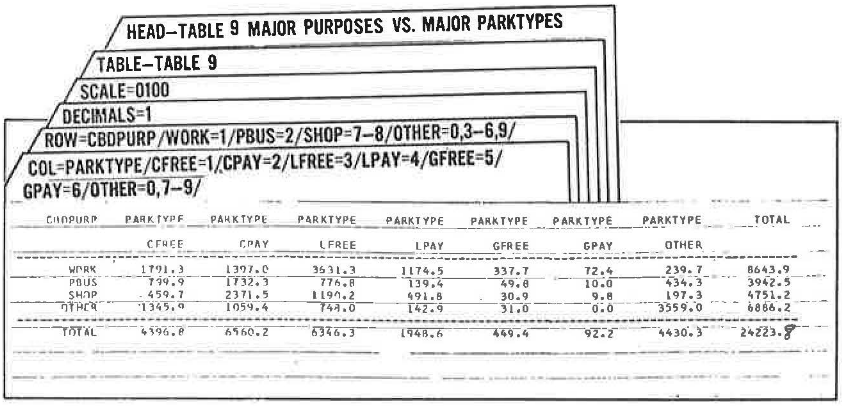
1. Assume the study has progressed through the system evaluation phase. At the appropriate point (after determination of the automobile-driver zonal trip ends), parking supply and demand were analyzed, and no major deficiencies were observed. However, now the loaded network indicates significant overloading of the downtown network and the major radial corridors. Furthermore, it is observed that these overloads could be substantically reduced through capacity increases brought about by removal of the curb parking. However, what effect does the removal of these spaces have on the adequacy of downtown parking? And second, what number and types of spaces should be provided to replace the lost facilities? Prior to the development of this system such questions could not be adequately answered.

2. Assume that there are serious parking deficiencies and traffic congestion in the downtown area. Assume that the study personnel want to show the effect that an adequate transit system could have in alleviating these problems. What level of transit service should be provided? How would a given level of transit service reduce the parking and traffic problem? What would happen if several fringe facilities were provided along the major transit corridor? How could parking rates be fluctuated to ensure use of the transit system? Prior to the development of this model, the effect of alternative transit, highway, and parking systems could not be evaluated.

AN EXAMPLE OF POSSIBLE REPORTS USING THE PROGRAM SYSTEM

The remainder of the paper is devoted to a typical example of the use of the O-D data for a parking analysis. It is intended to show the types of reports that can be produced using the system in its simplest form. The example includes the processing of the original data set, the creation of the parking data, the identification of areal parking deficiencies, and the determination of basic parking characterisitcs.

The data set used for this example contained approximately 29,900 trip records, of which 4,800 were CBD automobile-driver-oriented. In the initial linking of these records, 2,268 parking records were created, and 473 data errors (observations, miscoding, and mispunching) wère observed. Through updating of the original data file the



HEAD-TABLE 9 MAJOR PURPOSES VS. MAJOR PARKTYPES
TABLE-TABLE 9
SCALE=0100
DECIMALS=1
ROW=CBDPURP/WORK=1/PBUS=2/SHOP=7-8/OTHER=0,3-6,9/
COL=PARKTYPE/CFREE=1/CPAY=2/LFREE=3/LPAY=4/GFREE=5/
GPAY=6/OTHER=0,7-9/

CBDPURP	PARKTYPE CFREE	PARKTYPE CPAY	PARKTYPE LFREE	PARKTYPE LPAY	PARKTYPE GFREE	PARKTYPE GPAY	PARKTYPE OTHER	TOTAL
WORK	1791.3	1397.0	3631.3	1174.5	337.7	72.4	239.7	8643.9
PBUS	799.9	1732.3	776.8	139.4	49.8	10.0	434.3	3942.5
SHOP	459.7	2371.5	1190.2	491.8	30.9	9.8	197.3	4751.2
OTHER	1345.9	1059.4	748.0	142.9	31.0	0.0	3559.0	6886.2
TOTAL	4396.8	6560.2	6346.3	1948.6	449.4	92.2	4430.3	24223.8

Figure 6. Major purposes versus major parktypes.

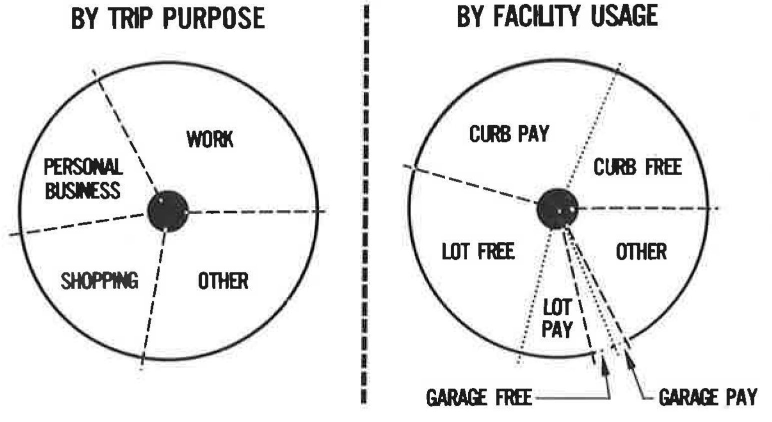
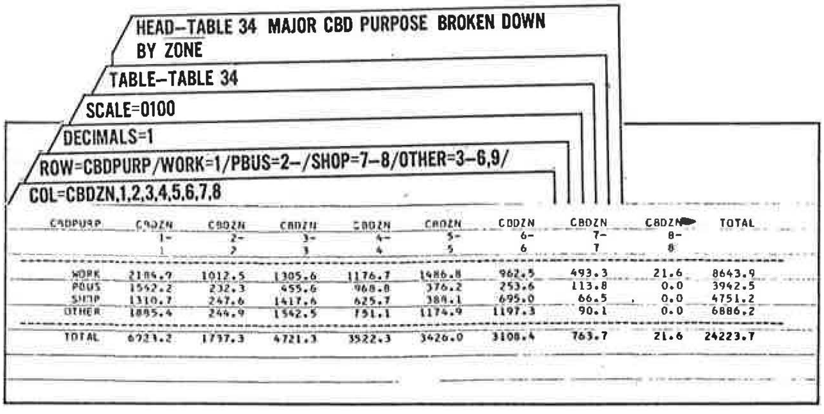


Figure 7. Distribution of parkers.



HEAD-TABLE 34 MAJOR CBD PURPOSE BROKEN DOWN BY ZONE
TABLE-TABLE 34
SCALE=0100
DECIMALS=1
ROW=CBDPURP/WORK=1/PBUS=2-/SHOP=7-8/OTHER=3-6,9/
COL=CBDZN,1,2,3,4,5,6,7,8

CBDPURP	CBDZN 1-1	CBDZN 2-2	CBDZN 3-3	CBDZN 4-4	CBDZN 5-5	CBDZN 6-6	CBDZN 7-7	CBDZN 8-8	TOTAL
WORK	2184.9	1012.5	1305.6	1176.7	1486.8	962.5	493.3	21.6	8643.9
PBUS	1542.2	232.3	455.6	968.0	376.2	253.6	113.8	0.0	3942.5
SHOP	1310.7	247.6	1417.6	625.7	384.1	695.0	66.5	0.0	4751.2
OTHER	1885.4	244.9	1542.5	751.1	1174.9	1197.3	90.1	0.0	6886.2
TOTAL	6923.2	1737.3	4721.3	3522.3	3426.0	3108.4	763.7	21.6	24223.7

Figure 8. Major CBD purpose by zone.

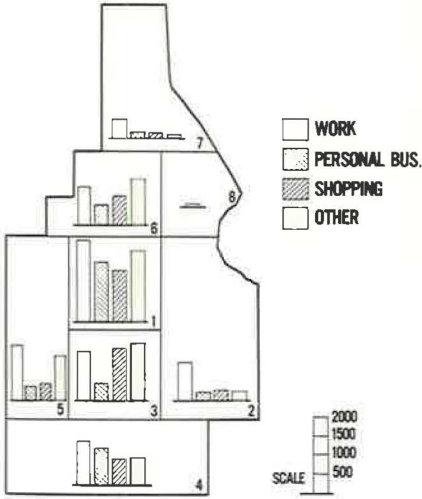
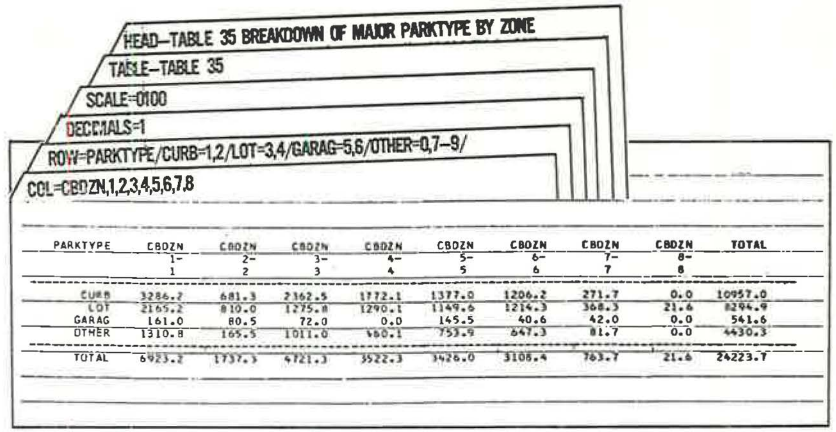


Figure 9. Distribution of parkers by zone and purpose.



HEAD-TABLE 35 BREAKDOWN OF MAJOR PARKTYPE BY ZONE

TABLE-TABLE 35

SCALE=0100

DECIMALS=1

ROW=PARKTYPE/CURB=1,2/LOT=3,4/GARAG=5,6/OTHER=0,7-9/

COL=CBDZN,1,2,3,4,5,6,7,8

PARKTYPE	CBDZN 1- 1	CBDZN 2- 2	CBDZN 3- 3	CBDZN 4- 4	CBDZN 5- 5	CBDZN 6- 6	CBDZN 7- 7	CBDZN 8- 8	TOTAL
CURB	3286.2	681.3	2362.5	1772.1	1377.0	1206.2	271.7	0.0	10957.0
LOT	2165.2	810.0	1275.8	1290.1	1149.6	1214.3	368.3	21.6	8294.9
GARAG	161.0	80.5	72.0	0.0	145.5	40.6	42.0	0.0	541.6
OTHER	1310.8	165.5	1011.0	460.1	753.9	647.3	81.7	0.0	4430.3
TOTAL	6923.2	1737.3	4721.3	3522.3	3426.0	3108.4	763.7	21.6	24223.7

Figure 10. Breakdown of major parktype by zone.

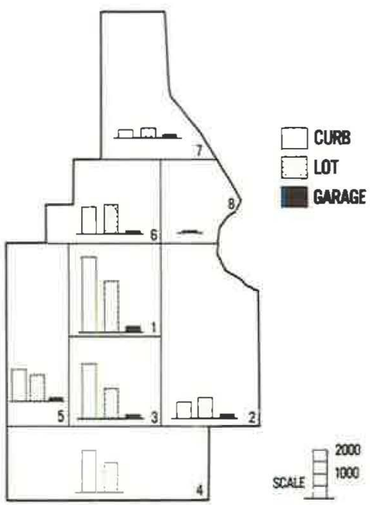
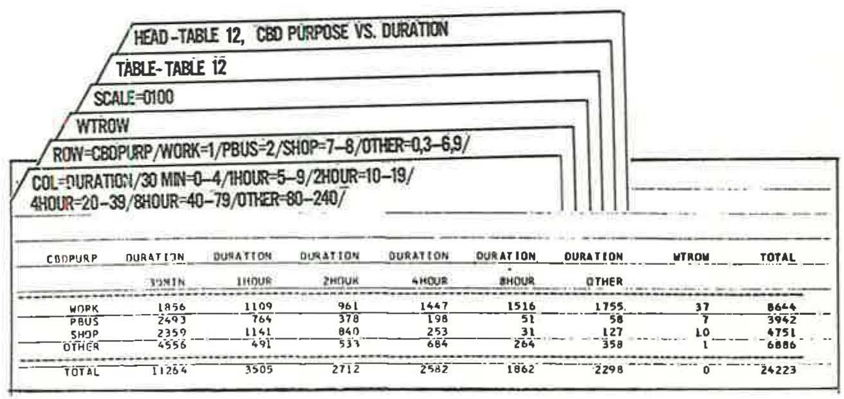


Figure 11. Distribution of facility use by type and zone.



HEAD-TABLE 12, CBD PURPOSE VS. DURATION

TABLE-TABLE 12

SCALE=0100

WTROW

ROW=CBDPURP/WORK=1/PBUS=2/SHOP=7-8/OTHER=0,3-6,9/

COL=DURATION/30 MIN=0-4/1HOUR=5-9/2HOUR=10-19/
4HOUR=20-39/8HOUR=40-79/OTHER=80-240/

CBDPURP	DURATION 30MIN	DURATION 1HOUR	DURATION 2HOUR	DURATION 4HOUR	DURATION 8HOUR	DURATION OTHER	WTROW	TOTAL
WORK	1856	1109	961	1447	1516	1755	37	8644
PBUS	2493	764	378	198	51	58	7	3942
SHOP	2359	1141	840	253	31	127	10	4751
OTHER	4556	491	533	684	264	358	1	6886
TOTAL	11264	3505	2712	2582	1862	2298	0	24223

Figure 12. CBD purpose versus parking duration.

```
HEAD-TABLE 20 FLOW INTO THE CBD BY HOUR AND QUADRANT
TABLE-TABLE 20
SCALE=0100
DECIMALS=1
ROW=STPARK,0-240-10
COL=ORGZN/INTRA=1-8/SEAST=11-12,35-45,80-81,94-96,103-110/
NWEST=16-20/ 22-34/SWEST=13-15,21,46-79/NEAST=9-10,82-93,97-
102,111-117/
```

STPARK	ORGZN INTRA	ORGZN SEAST	ORGZN NWEST	ORGZN SWEST	ORGZN NEAST	TOTAL
0- 9	0.0	0.0	9.7	10.4	0.0	20.1
10- 19	0.0	10.9	0.0	0.0	0.0	10.9
20- 29	0.0	9.8	0.0	0.0	0.0	9.8
30- 39	0.0	0.0	0.0	0.0	10.7	10.7
40- 49	0.0	29.9	0.0	20.0	0.0	49.9
50- 59	0.0	19.6	20.0	19.9	43.0	102.5
60- 69	4.8	101.4	50.3	241.8	51.3	449.6
70- 79	96.1	549.8	164.8	937.6	255.7	2004.0
80- 89	145.9	559.1	249.6	914.0	209.4	2077.0
90- 99	300.5	213.5	152.9	547.3	174.9	1389.1
100- 109	467.2	223.0	184.0	534.4	240.0	1648.6
110- 119	339.4	225.6	202.5	535.4	202.9	1505.8
120- 129	237.0	293.2	260.6	607.6	253.5	1651.9
130- 139	361.4	352.6	152.4	756.4	291.9	1914.7
140- 149	430.3	274.4	153.6	399.2	252.1	1509.6
150- 159	290.6	195.9	208.8	409.3	302.9	1407.5
160- 169	270.4	272.3	192.1	639.5	271.4	1645.7
170- 179	297.3	259.4	191.2	515.1	246.9	1509.9
180- 189	83.9	174.9	116.1	386.3	124.2	885.3
190- 199	159.6	438.6	212.3	517.0	126.3	1453.8
200- 209	67.8	221.0	100.0	381.5	81.2	851.5
210- 219	57.2	82.9	51.2	308.1	87.5	586.9
220- 229	47.1	52.2	73.4	93.0	74.2	339.9
230- 239	20.7	0.0	30.8	31.8	20.2	103.5
240- 240	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	3677.2	4558.9	2776.3	8805.6	3320.2	23138.0

Figure 13. Flow into the CBD by hour and quadrant.

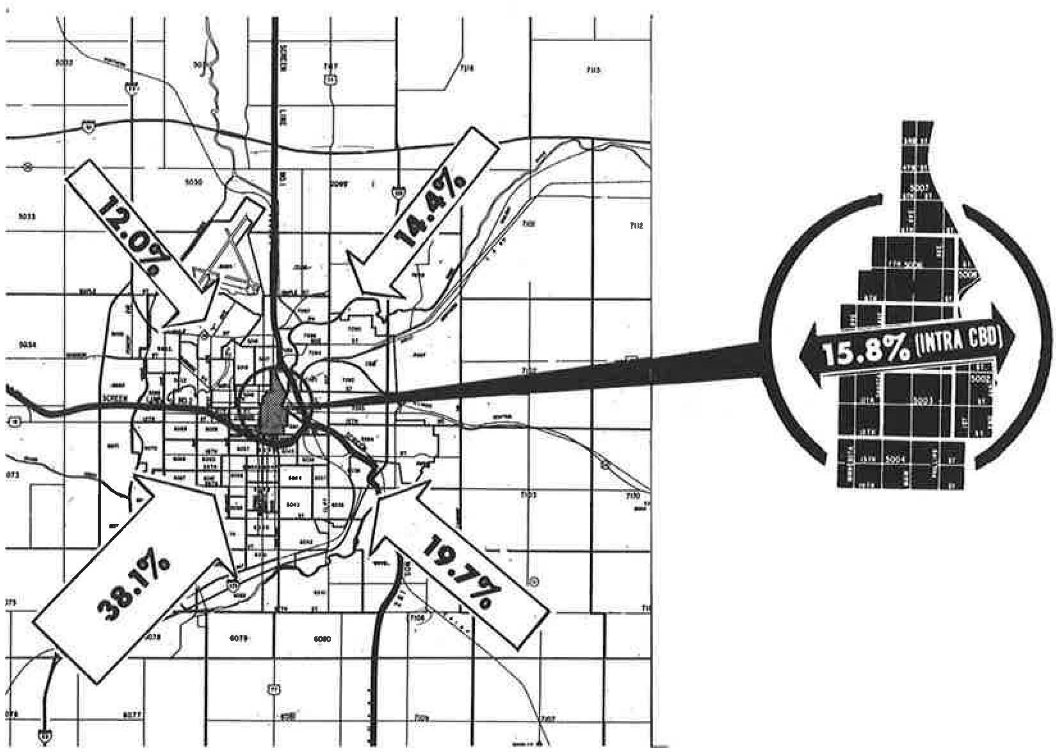


Figure 14. Distribution of CBD arrivals.

HEAD -TABLE 1 ACCUMULATION OF PURPOSE BY HOUR
TABLE-TABLE 1
SCALE=0100
ACCPARK
ROW=STPARK,0-240-10
COL=CBDPURP/WORK=1/PBUS=2/SHOP=7-8/OTHER=0,3-6,9/

STPARK		CBDPURP			CBDPURP			CBDPURP			CBDPURP			TOTAL		
				WORK			PBUS			SHOP			OTHER			
		IN	OUT	ACC	IN	OUT	ACC	IN	OUT	ACC	IN	OUT	ACC	IN	OUT	ACC
0-	9	0	0	0	0	0	0	0	0	0	20	0	20	20	0	20
10-	19	11	0	11	0	0	0	0	0	0	0	10	10	11	10	21
20-	29	10	0	21	0	0	3	0	0	0	0	0	10	10	0	31
30-	39	0	10	11	0	0	3	11	0	11	0	0	10	11	10	32
40-	49	213	89	135	47	40	5	30	0	41	271	274	7	561	403	189
50-	59	61	0	196	0	0	6	0	0	41	42	52	-2	103	52	241
60-	69	392	29	569	10	0	15	0	0	41	57	69	-13	459	89	613
70-	79	1431	135	1865	70	30	55	46	15	71	550	494	43	2097	674	2035
80-	89	1548	239	3175	142	162	35	115	20	165	309	320	33	2114	741	3409
90-	99	464	478	3161	370	240	166	371	176	360	226	181	78	1431	1075	3765
100-	109	429	561	3029	313	353	126	628	454	534	324	297	105	1694	1665	3794
110-	119	613	878	2764	309	238	195	354	503	386	249	249	105	1525	1868	3451
120-	129	497	662	2599	446	361	281	263	399	250	501	498	108	1707	1920	3238
130-	139	738	451	2886	468	483	265	445	333	361	289	305	92	1940	1572	3605
140-	149	487	529	2844	305	402	169	437	360	438	312	286	110	1541	1577	3569
150-	159	476	683	2637	309	319	160	352	418	372	291	321	88	1428	1741	3257
160-	169	416	789	2264	283	351	92	459	461	370	573	524	137	1731	2125	2863
170-	179	303	1906	662	222	211	103	296	496	170	754	810	81	1575	3423	1016
180-	189	134	326	471	142	143	102	227	137	260	387	312	156	890	918	989
190-	199	225	113	583	160	138	124	371	272	359	713	516	353	1469	1039	1419
200-	209	91	163	511	112	157	79	250	385	225	413	302	464	866	1007	1278
210-	219	30	334	207	131	184	25	73	234	63	352	364	453	586	1116	749
220-	229	63	177	93	82	76	31	25	46	43	179	426	206	349	725	373
230-	239	11	102	2	20	52	0	0	42	1	72	275	3	103	471	6
240-	240	0	0	2	0	0	3	0	0	1	0	0	3	0	0	6
TOTALS		8643	8645		3941	3940		4753	4751		6884	6885		24221	24221	

Figure 15. Accumulation of purpose by hour.

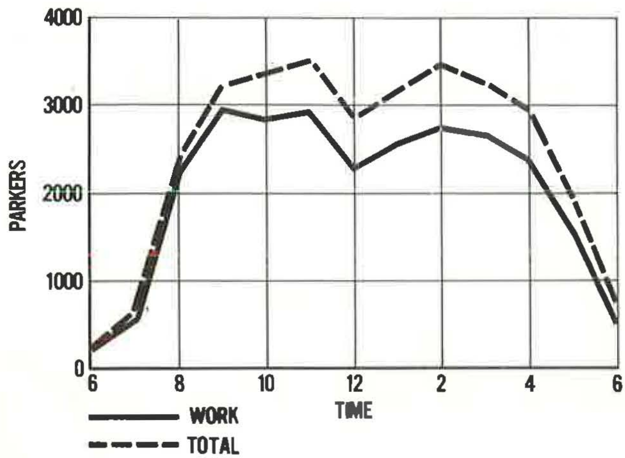


Figure 16. Total parking accumulation and work accumulation.

HEAD-TABLE 52 THIS IS A SUPPLY TABLE OF PARKTYPE BY ZONE
TABLE-TABLE 52
ROW=ZONE,1-8-1
COL=TYPE/CURB=1/LOT=2/GARAG=9/

ZONE		TYPE CURB	TYPE LOT	TYPE GARAGE	TOTAL
1-	1	288	530	125	943
2-	2	166	484	0	650
3-	3	255	227	50	532
4-	4	244	586	0	830
5-	5	189	287	22	498
6-	6	270	708	0	978
7-	7	136	54	0	190
8-	8	39	177	0	216
TOTAL		1587	3053	197	4837

TABLE 8

Figure 17. Parktype by zone.

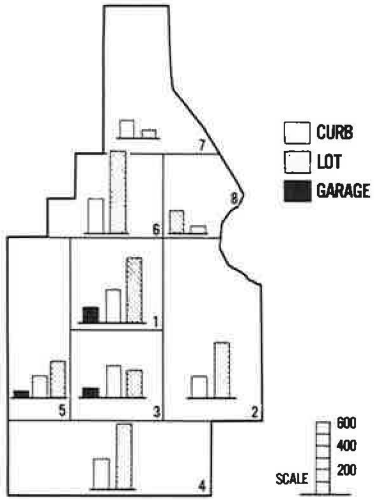
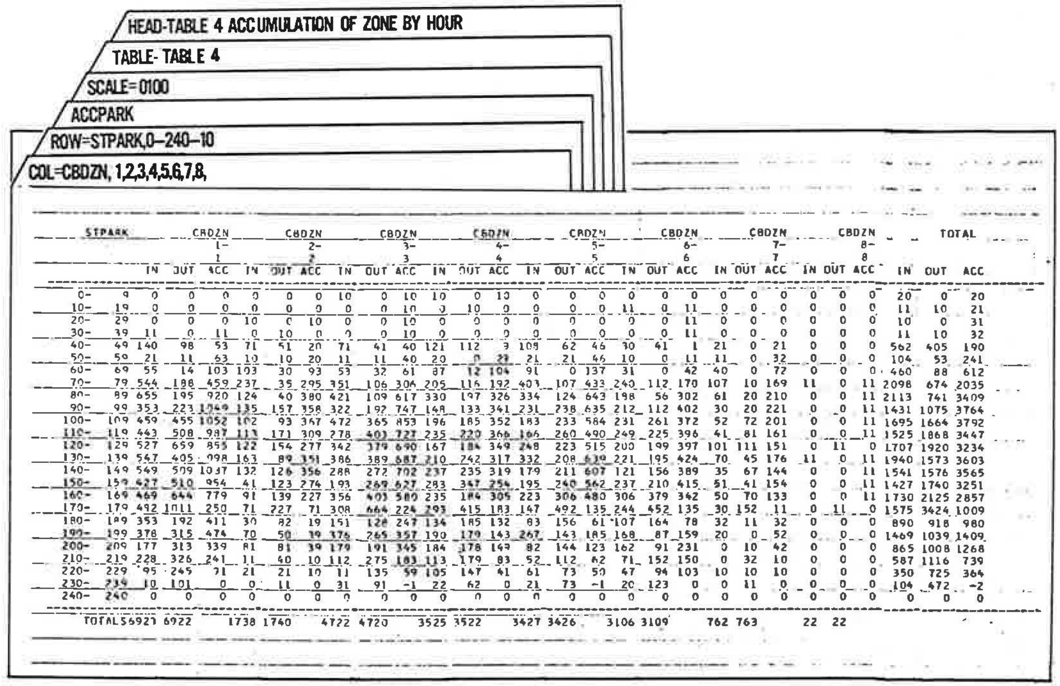


Figure 18. Distribution of existing supply by type and zone.



STPARK	CBDZN 1- 1 IN	OUT	ACC	CBDZN 2- 2 IN	OUT	ACC	CBDZN 3- 3 IN	OUT	ACC	CBDZN 4- 4 IN	OUT	ACC	CBDZN 5- 5 IN	OUT	ACC	CBDZN 6- 6 IN	OUT	ACC	CBDZN 7- 7 IN	OUT	ACC	CBDZN 8- 8 IN	OUT	ACC	TOTAL IN	OUT	ACC
0- 9	0	0	0	0	0	0	10	0	10	10	0	10	0	0	0	0	0	0	0	0	0	0	0	0	20	0	20
10- 19	0	0	0	0	0	0	0	0	10	0	10	0	0	0	0	11	0	11	0	0	0	0	0	0	11	10	21
20- 29	0	0	0	10	0	10	0	0	10	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	10	0	31
30- 39	11	0	11	0	10	0	0	0	10	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	11	10	32
40- 49	140	98	53	71	51	20	71	41	40	121	112	9	109	62	46	30	41	1	21	0	21	0	0	0	562	405	190
50- 59	21	11	63	10	10	20	11	11	40	20	0	29	21	21	46	10	0	11	11	0	32	0	0	0	104	53	241
60- 69	55	14	103	103	30	93	53	32	61	87	12	104	91	0	137	31	0	42	40	0	72	0	0	0	460	88	612
70- 79	544	188	459	237	35	295	351	106	306	205	116	192	403	107	433	240	112	170	107	10	169	11	0	11	2098	674	2035
80- 89	655	195	920	124	40	380	421	109	617	330	197	326	334	124	643	198	56	302	61	20	210	0	0	11	2113	741	3409
90- 99	353	223	1049	135	157	358	322	192	747	148	133	341	231	238	635	212	112	402	30	20	221	0	0	11	1431	1075	3764
100- 109	459	455	1052	102	93	367	472	365	853	196	185	352	183	233	584	231	261	372	52	72	201	0	0	11	1695	1664	3792
110- 119	443	508	987	113	171	309	278	403	727	235	220	366	166	260	490	249	225	396	41	81	161	0	0	11	1525	1868	3447
120- 129	527	659	855	122	154	277	342	379	690	167	184	349	248	223	515	200	199	397	101	111	151	0	11	0	1707	1920	3234
130- 139	547	405	998	163	89	351	386	389	687	210	242	317	332	208	619	221	195	424	70	45	176	11	0	11	1940	1573	3603
140- 149	549	509	1037	132	126	356	288	272	702	237	235	319	179	211	607	121	156	389	35	67	144	0	0	11	1541	1576	3565
150- 159	427	510	954	41	123	274	193	269	627	283	347	254	195	240	562	237	210	415	51	41	154	0	0	11	1427	1740	3251
160- 169	469	644	779	91	139	227	356	403	580	235	184	305	223	306	480	306	379	342	50	70	133	0	0	11	1730	2125	2857
170- 179	492	1011	250	71	227	71	308	664	224	293	415	183	147	492	135	244	452	135	30	152	11	0	11	0	1575	3424	1009
180- 189	353	192	411	30	82	19	151	128	247	134	185	132	83	156	61	107	164	78	32	11	32	0	0	0	890	918	980
190- 199	378	315	474	70	50	19	376	265	357	190	179	143	267	143	185	168	87	159	20	0	52	0	0	0	1469	1039	1409
200- 209	177	313	339	81	81	39	179	191	345	184	178	149	82	144	123	162	91	231	0	10	42	0	0	0	865	1008	1268
210- 219	228	326	241	11	40	10	112	275	183	113	179	83	52	112	62	71	152	150	0	32	10	0	0	0	587	1116	739
220- 229	95	245	71	21	21	10	11	135	59	105	147	41	61	73	50	47	94	103	10	10	10	0	0	0	350	725	364
230- 239	10	101	0	0	11	0	31	91	-1	22	62	0	21	73	-1	20	123	0	0	11	0	0	0	0	104	472	-2
240- 240	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL56927		6922		1738	1740		4722	4720		3525	3522		3427	3426		3106	3109		762	763		22	22				

Figure 19. Parking accumulation by zone and hour.

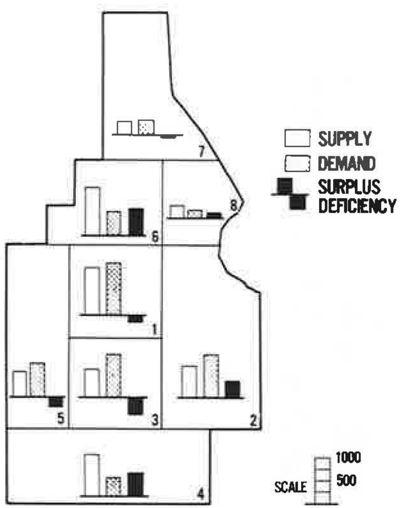


Figure 20. Surplus and deficiencies by zone.

errors were reduced and a file of 2,404 records was produced representing 24,225 parking activities.

Figures show examples of the types of conventional summaries that can be produced through use of the TABULATE program. Through specification of the desired row and column variables for each summary, a series of tables can be produced simultaneously. In these examples, the eight tabulations dealing with demand and use were generated simultaneously. Figure 6 shows a simple report of the distribution of parkers by trip purpose and facility use for the entire CBD. Information from the tabulation shown could be used to display purpose and facility use as shown in Figure 7.

Figure 8 shows the distribution of parkers by trip purpose for each zone of the CBD. Information from these data can be displayed as shown in Figure 9 by superimposing the purpose bar charts on the zonal map of the city.

Figure 10 shows facility use by each zone. Information is again shown on a zonal map in Figure 11.

Figure 12 shows parking duration by trip purpose. In this figure, the weighted average option had been specified, and the average parking duration for each purpose is shown. It indicates that the average parking duration for work trips is 3 hours 40 minutes, for shopping trips 1 hour, and for personal business trips 40 minutes.

Figure 13 shows the origin zone of parkers by major geographic area. This type of figure clearly indicates the substantial volume of arrivals from the Southwest. Figure 14 shows a representation expressed in percent of total arrivals.

In Figure 15 a parking accumulation of trips by purpose is shown in which a peak parking accumulation of 3,794 occurs at 11:00 a.m. The figure also shows that a peak accumulation of 3,175 parkers for work purposes occurs at 9:00 a.m., a peak accumulation of 534 parkers for shopping occurs at 11:00 a.m., and a peak accumulation of 281 for personal business occurs at 1:00 p.m. Figure 16 shows a plot of total accumulation and work accumulation. It clearly indicates the double peaking characteristic of the parking accumulation and the significant effect that work accumulation has on total accumulation.

Figure 17 shows the distribution of existing parking supply by zone. These data are shown in Figure 18 on a zonal map.

An accumulation of total parkers by CBD zone is shown in Figure 19. From this tabulation, the maximum number of parkers for each zone and the time the peak occurs can be determined. These peak demands can be compared with the available supply shown in Figure 17 (adjusted to account for efficiency) to immediately locate those zones of the CBD that have a parking supply deficiency. Figure 20 shows the comparison of supply and demand. It clearly shows that zones 1, 3, 5, and 7 have deficiencies. These zones would then be selected for a more detailed subzone analysis.

```
HEAD-TABLE 36 CBD PURPOSE VS. LAND USE
TABLE-TABLE 36
SCALE=0100
DECIMALS=1
ROW=CBDPURP/WORK=1/PBUS=2/SHOP=7-8/OTHER=0,3-6,9/
COL=LUCBD/AGRIC=0-9/RESDL=10-19/MFGDL=20-29/MFGND=30-39/
TRANS=40-49/RETAL=50-59/SRVCE=60-69/WHLSL=70-79/PBBLG=80-89/
PBOPN=90-99/
```

CBDPURP	LUCBD AGRIC	LUCBD RESDL	LUCBD MFGDL	LUCBD MFGND	LUCBD TRANS	LUCBD RETAL	LUCBD SRVCE	LUCBD WHLSL	LUCBD PBBLG	LUCBD PBOPN	TOTAL
WORK	40.7	84.9	115.1	492.8	1100.0	2355.1	2464.7	634.1	1346.6	9.7	8643.9
PBUS	0.0	73.3	20.7	34.5	132.7	914.5	1470.5	72.5	1201.0	22.8	3942.5
SHOP	0.0	0.0	11.9	14.9	31.2	4022.9	502.8	81.7	25.6	60.2	4751.2
OTHER	23.6	943.6	10.4	83.3	435.0	2004.7	1536.8	79.8	1587.2	181.8	6886.2
TOTAL	64.3	1101.8	159.1	625.5	1698.9	9297.4	5974.8	868.1	4160.4	274.5	24223.7

Figure 21. CBD parking purpose versus land use.

Figure 21 shows parking by purpose and land use for the entire CBD; however, similar printouts could be developed by zones. This information, together with land use data, could be the basis for a parking rate analysis.

These are just a few of the many possible reports that can be simply produced through use of the basic components of the program system. They do not include the sophisticated detail of the program ALOCAT, but merely indicate the summaries available through processing of the converted O-D data through the TABULATE program.

Details of program operation and model calibration are beyond the scope of the paper. However, detailed documentation and procedural guides will be forthcoming.

REFERENCES

1. Dixon, W.J. Bio-Medical Computer Programs. Univ. of California, 1967.
2. Schulman, Lawrence L. Parking as an Element Within the Comprehensive Transportation Planning Process. U.S. Bureau of Public Roads, Journal of Highway Research, Vol. 35, No. 1, April 1968.

A Parametric Analysis of Fleet Parking Terminal Capacity

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The parking demand is a critical dilemma, particularly in the central sections of urban areas. Effective solutions are urgently needed to resolve this urban crisis. The concept of a fleet vehicle system is receiving much attention as a possible solution to the urban parking problem. This system tends to change urban vehicle design and the operator-vehicle relationship, which leads, in turn, to facility alterations to make optimum use of parking terminal space. The intent of this study was to evaluate the potential of fleet-operated vehicle parking as a method of maximizing terminal space utilization. A parametric analysis of terminal capacity was used for easy interpretation of results. An individual fleet terminal having minimal capacity characteristics was compared to a present type facility having optimum capacity design. The geometrical patterns were selected such that the results, presented in percent capacity increase, represent a minimum expected improvement when the fleet concept is employed. The results of the study provide an indication of the effect of the fleet vehicle system on the urban parking situation. Also, this study establishes a technique that may be expanded to provide parking planners with an efficient method of analyzing parking terminal capacity. A new approach to deal with the growing parking problem in urban America is presented.

•THE CONTINUED POPULARITY of the motor vehicle, along with the expansion of the highway system, has greatly increased the need for parking spaces. The problem is especially critical in the large urban centers with highly congested areas. The parking demands on downtown sections have risen more rapidly than the associated daytime population of such areas. As a result, parking has become a major urban land use, and the availability of parking space has become a growing concern in urban America.

It is significant to note the repercussions of the parking problem. In the larger cities, the lack of proper parking facilities is resulting in decentralization of the business district. Yet, parking facilities in high-density areas are extremely costly because of high land value. The cost per parking space for an off-street parking facility has gone up to $50,00 for conventional ramp structures in high-density urban centers (5). On the other hand, the majority of the cars driven into and parked in urban areas occupy from 300 to 350 sq ft of space each. An office worker, for example, requires more space to store his car than he occupies himself in the office (2). If buildings continue reaching greater heights and drawing more commuters, the problem will continue to grow.

Knowing the increased demand and cost for parking, the real threat is that the majority of the standard facilities involve noneconomical land use. Three reasons can be cited for this: First, the competition for space is greatly increased by the office worker or long-term parker; second, the standard stall size is often wasteful of parking space when considering the great variation in car sizes; and third, the geometrical design for the existing type of parking operation does not optimize space utilization.

Accompanying this diversity of interests is a wide variety of views on how best to solve the parking problem. Land availability and cost limitations are now forcing the

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development of new concepts to remove the great strain on parking in urban areas. Numerous concepts have been formulated, among them a technological proposal examining the feasibility and desirability of introducing a minicar (small fleet vehicle) system into the central parts of large metropolitan complexes (1). The advent of such a system would present the opportunity to resolve the urban parking crisis. The parking system would be planned with the purpose of minimizing area per parker and changing the vehicle-operator relationship. This, in turn, would maximize the use of available land for parking while providing convenience in operation.

STUDY OBJECTIVES AND SCOPE

The objective of this study was to determine the effect of the urban fleet vehicle system on parking space requirements in urban areas. This was achieved by comparing the parking capacity of a typical existing facility to that of a fleet vehicle terminal having caparable facility dimensions.

The study specifically investigated the following:

1. A parametrical method of analysis for the capacity of off-street parking facilities for both standard and fleet parking operations,
2. The effect of facility variations and restrictions on standard facility and fleet facility capacities,
3. The effect of vehicle size variation on standard facility capacity, and
4. The approximate capacity improvement in percent for fleet parking facilities over standard parking facilities.

The study presents only an illustrative comparison using typical facilities with some controlled variables. The analysis concepts employed for this study could be expanded to include greater variation in facility characteristics, if this method of analysis should prove valuable. For facilities having design features comparable to those analyzed, the analysis data included may be used for design considerations. But this is only secondary in the scope of the study.

THE URBAN FLEET VEHICLE CONCEPT

Before proceeding to the capacity analysis of fleet parking terminals, a brief description of the urban fleet vehicle system is necessary to fully understand the concept and its implications. As stated earlier, this vehicle system would be introduced into the central parts of large urban areas. The hybrid-powered small vehicle would collect and distribute people on a rental fleet-operated basis, while operated between specially designed terminal locations. The users would rent vehicles at certain terminals, drive them to their destinations, and leave them at any other terminals in accordance with daily trip patterns. It is expected that such an urban transportation system would alleviate some of the growing problems associated with conventional automobiles, such as traffic congestion, air pollution, and costs of personal ownership.

The design vehicle would weigh about 2,000 lb and be 9 ft long, 6 ft wide, and 5 ft tall (1). The vehicle would have a tilt-forward front and swinging doors on each side so that the doors could be fully opened within the design width. Thus, it would require no additional side clearance. The vehicle would be designed for easy maneuverability, efficiency, and low-cost operation.

An important aspect of this system is its novel parking operation. If the vehicle fleet is operated on a rental basis, the operator-vehicle relationship is drastically changed. Because the operator no longer owns the vehicle he drives, he is indifferent in his choice of vehicles. This arbitrary vehicle selection permits immediate access to each individual parked vehicle in the terminal. Solid-packed parking becomes a practical method of increasing terminal capacity. For this reason, there is no need to have access aisles in the central section of the terminal except for the area required for easy ingress to and egress from a terminal. The area required for vehicle circulation, therefore, can be much less than the area for conventional parking operations. Another feature is that the size of fleet vehicles is reduced to almost half the size of the standard vehicle, and thus the dimensions of parking stalls are decreased. These significant changes would lead to parking alterations that would optimize use of terminal space.

METHOD OF ANALYSIS

To study the effect of the urban fleet vehicle on parking facility capacity, methods were formulated for comparing ultimate design capacities in the following types of facilities:

1. Type A—the standard vehicle off-street parking facility with self-service parking;
2. Type B—the urban fleet vehicle facility having characteristics similar to the standard facility managed with self-service or fleet attendant parking; and
3. Type C—the strict fleet system facility in which only fleet rental vehicles are parked.

Type A was compared to Types B and C. The respective results were used to determine the impact of both a vehicle size reduction and the complete fleet system on terminal capacity.

Because 90-deg angle parking yields greater space utilization in most cases (3), it was designated as the typical parking configuration. However, parametric equations could be modified to include capacity variations due to angled stalls. Furthermore, the rectangular parking facility, which represents a majority of parking facilities, was used in the comparative analysis. Such factors as entrance and exit gates, ramp allowances for multilevel facilities, and construction allowances are all included in the parametrical equations. The aisle width for two-way traffic was expressed as three times the stall width, which in most cases would provide the necessary space for efficient vehicle movement to and from the stall (3). The geometrical configuration was selected such that this method of analysis permits comparison of the expected minimum capacity for fleet vehicle facilities with the ultimate design capacity of standard vehicle facilities.

CAPACITY ANALYSIS FOR STANDARD PARKING FACILITIES

An "ideal" parking configuration for standard private vehicles is shown in Figure 1. The parking capacity of a single or multilevel facility can be given by the following parametric forms:

$$C_W = \frac{2[W - 2(\ell_s - c)] - \Sigma n_w C_g - \Sigma K_w C_r}{w_s}$$

$$C_L = \frac{2[L - 2(\ell_s - c)] - \Sigma n_\ell C_g - \Sigma K_\ell C_r}{w_s}$$

$$N = \frac{W - 2(\ell_s + c) + 3W_s}{2\ell_s + c + 3W_s}$$

$$C_M = \frac{2[L - 2(\ell_s + c) - 3n_a w_s]}{w_s}$$

$$SC_i = C_W + C_L + N \times C_M \qquad (1)$$

where

SC_i = total parking capacity of a standard facility level i;
C_W = perimeter width capacity;
C_L = perimeter length capacity;
C_M = barrier capacity per barrier unit;
N = number of permissible barrier units;
W = overall facility dimension perpendicular to the parking barrier alignment;

L = overall facility dimension parallel to the parking barrier alignment;
w_s = stall width;
ℓ_s = stall length;
c = construction factor—a capacity reduction factor caused by structural characteristics of the facilities, such as columns and walls;
$\Sigma n_w C_g$ = width gate factor (in W direction)—a capacity reduction factor that reflects the influence on capacity of entrances to and exits from the parking facility;
$\Sigma n_\ell C_g$ = length gate factor (in L direction);
$\Sigma k_w C_r$ = width ramp factor (in W direction)—a capacity reduction term accounting for the area unavailable because of ramping and other interlevel vehicle transporting methods in multilevel facilities;
$\Sigma k_\ell C_r$ = length ramp factor (in L direction); and
n_a = aisle multiplier—the number of aisles directed perpendicular to parking barrier alignment.

To use the above parameters in the determination of facility capacity, it is desirable to clarify their meaning further and to impose some limitations on their values, including the following:

1. The parameters C_W, C_L, and C_M used in capacity estimations must be integer quantities because the fraction of a stall space provides insufficient room to accomodate a possible single vehicle. For example, if the calculated value of C_W was 62.75, the nominal value used in the capacity determination would be 62.
2. The number of barrier units, N, should also be restricted to a nominal value, with the exception $(N_{calculated} - N_{nominal}) \geq (\ell_s + c + 3w_s)/(2\ell_s + c + 3w_s)$, in which case the nominal value of N can be increased by 0.5, and thus appears as 3.5, 4.5, and so forth.
3. The capacity reduction factors, c, $\Sigma n_W C_g$, $\Sigma n_\ell C_g$, $\Sigma k_W C_r$, and $\Sigma k_\ell C_r$, are all design-dependent, being determined by the particular characteristics of a facility under

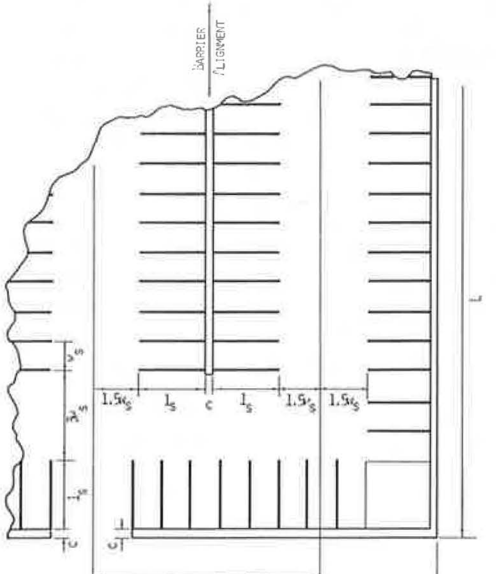

Figure 1. Typical configuration for standard parking.

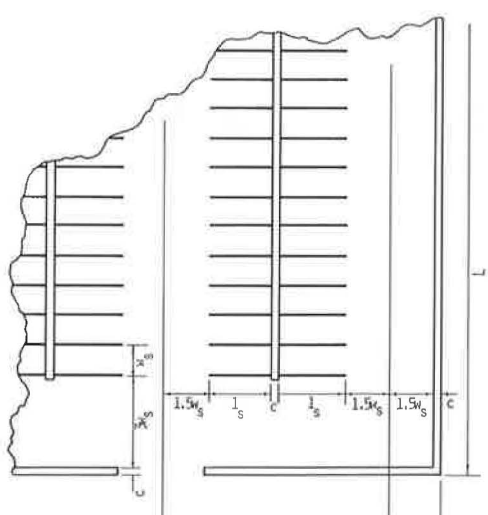

Figure 2. Typical configuration for standard parking (where $C_W = C_L = 0$).

consideration. For example, n_w and n_ℓ are the number of gates (entrances and exits) having the same characteristics. The value for C_g is dependent on the particular gate characteristics chosen for the terminal. Suggested values for C_g are given in Table 1.

If a facility has no parking stalls adjoining its perimeter, as shown in Figure 2, C_W and C_L should be eliminated from Eq. 1, and thus Eq. 1 becomes

TABLE 1

GATE FACTOR VALUES FOR STANDARD PARKING FACILITIES

Gate Characteristics	$\frac{C_g}{w_s}$	Stall Width (w_s), ft					
		6.0	6.5	7.0	7.5	8.0	8.5
One way, single lane	2	12.0	13.0	14.0	15.0	16.0	17.0
One way, dual lane	3	18.0	19.5	21.0	22.5	24.0	25.5
Two way, single lane	3	18.0	19.5	21.0	22.5	24.0	25.5
Two way, dual lane	6	36.0	39.0	42.0	45.0	48.0	51.0

$$SC_i = N \times C_M$$

$$= \left(\frac{W - 2c - 3w_s}{2\ell_s + c + 3w_s}\right)\left(\frac{L - 2c - 3n_a w_s}{w_s}\right) \qquad (2)$$

For single-level facilities, ramp and construction factors are taken as zero. Hence, Eq. 1 is reduced to

$$SC_i = \frac{2(W - 2\ell_s) - \Sigma n_w C_g}{w_s} + \frac{2(L - 2\ell_s) - \Sigma n_\ell C_g}{w_s}$$

$$+ 2\left(\frac{W}{2\ell_s + 3w_s} - 1\right)\left(\frac{L - 2\ell_s - 3n_a w_s}{w_s}\right) \qquad (3)$$

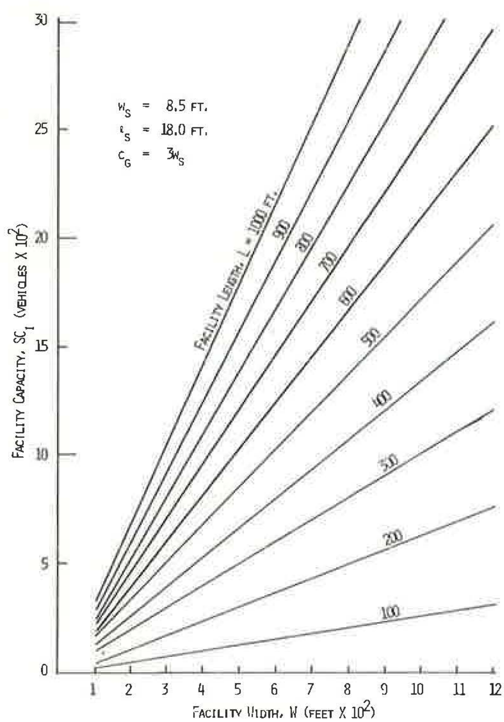

Figure 3. Capacity curves for standard facilities with standard vehicles.

When the parametrical equation (Eq. 3) is applied to a typical rectangular facility (Fig. 1), the facility capacity can be easily determined for a set of given variable dimensions. Given values for ℓ_s, w_s, n_a, $\Sigma n_w C_g$, and $\Sigma n_\ell C_g$, the facility capacity can be calculated as functions of W and L. To illustrate the functions, ℓ_s and w_s were arbitrarily assigned two standard values, and na, $\Sigma n_w C_g$, and $\Sigma n_\ell C_g$ were made invariant. The calculated capacities (SC_i) are plotted for various facility dimensions. The two sets of capacity curves—one set for the standard vehicle and another for urban fleet vehicles—are shown in Figures 3 and 4. For any given set of facility dimensions, W and L, the storage capacity, SC_i, for each size vehicle can be directly read from the respective group. In reality, the capacity curve should not be presented in a continuous form because the change in capacity performs a discrete distribution function. Therefore, the graphical solution only represents capacity approximations for alternative cases.

CAPACITY ANALYSIS OF FLEET PARKING FACILITIES

A fleet terminal with attendant parking operation is shown in Figure 5. This con-

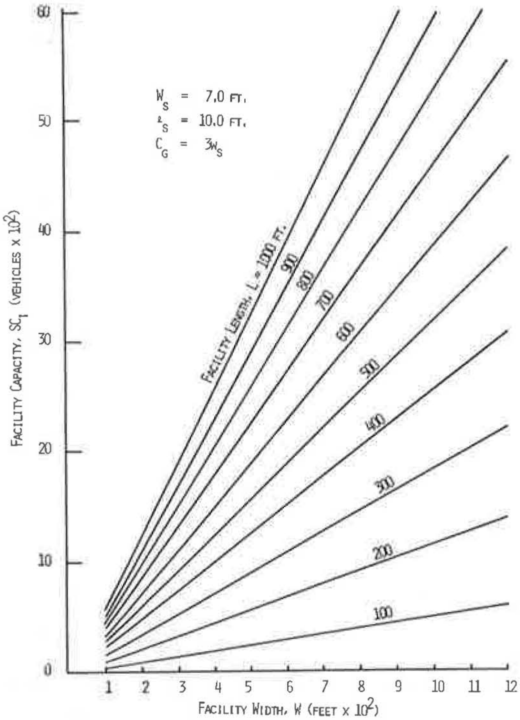

Figure 4. Capacity curves for standard facilities with small vehicles.

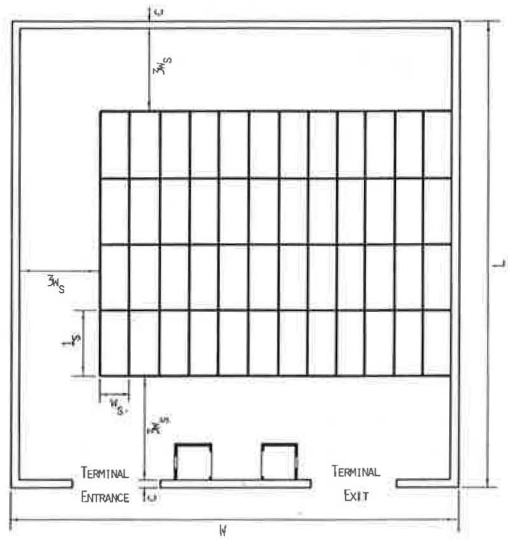

Figure 5. Typical configuration for fleet vehicle parking.

figuration can be used for terminals having limited frontage for gate construction. Many other design variations are possible because the configuration depends mainly on gate location. The gate location is generally determined by the location and dimension of a facility. For instance, if the location of a terminal permitted access at both ends of the terminal, the side access shown in Figure 5 could be used for parking. Other important considerations related to the facility capacity include needed maintenance areas and locations of separation barriers for walking clearance between lines of vehicles. For multilevel facilities, additional area must be provided for vehicular ramp or elevators and structure members.

As indicated, the capacity of the selected terminal configuration is somewhat reduced by the necessity for the side aisle. So, essentially any capacity improvement over standard facilities can be projected as a minimum expected increase. Based on this configuration, the capacity of a fleet-operated facility can be given by

$$FC_i = (C_{fW})(C_{fL}) - R$$

$$= \left(\frac{W - 3w_s - 2_c}{w_s}\right)\left(\frac{L - 6w_s - 2_c}{\ell_s}\right) - R \qquad (4)$$

where

FC_i = capacity of a fleet parking terminal level i;
C_{fW} = fleet width capacity;
C_{fL} = fleet length capacity; and
R = fleet correction factor—a general reducing factor that includes special terminal characteristics such as terminal ramps for multilevel facilities, walkways, and maintenance areas.

All other parameters in Eq. 4 have been defined previously. The gate factors, $\Sigma n_w C_g$ and $\Sigma n_\ell C_g$, are not applicable to a facility having a fleet parking arrangement.

Again, the nominal values expressed in integer quantities must be used for parameters C_{fW} and C_{fL}. Some standards regarding the arithmetic difference between calculated and nominal values should be followed:

1. If (C_{fW} calculated - C_{fW} nominal) ≥ 0.66, the value of C_{fW} is increased by one; and
2. If (C_{fL} calculated - C_{fL} nominal) ≥ 0.80, the value of C_{fL} is increased by one.

For single-level facilities, the assumption, which is the same as for standard facilities, is that the ramp factor and construction barriers may be neglected. When considering such a special case, Eq. 4 should be simplified as follows:

$$FC_i = \left(\frac{W - 3w_s}{w_s}\right)\left(\frac{L - 6w_s}{\ell_s}\right) \qquad (5)$$

For capacity analysis, variables are assigned some standard values in preparing the analysis curves. One set of curves (Fig. 6) is derived since only the size of fleet vehicles establishes the stall dimensions.

CAPACITY FACTOR ANALYSIS

For any given dimension of a facility, the parking capacity should, to a certain extent, be changed as vehicle stall sizes and types of parking operations are alternated. It is therefore desirable to compare the relative parking capacities for the three types of facilities (Types A, B, and C) as described earlier. Such a comparison will give some ideas about the effect of vehicle size reductions and fleet parking operations on capacity magnitudes. A capacity factor used to measure the amount of capacity change is simply defined as the percentage of capacity increase for facility variations (Types B and C) from the standard type facility parking standard vehicles (Type A). Mathematically, the capacity factor, R, is given as

$$R = \frac{C_{fs}}{SC_i}$$

where C_{fs} is the capacity of either Type B or C, and SC_i is the capacity of Type A.

Using Figures 3, 4, and 6, two sets of R-values—one for Type A versus B and the other for Type A versus C—are derived in order to determine the relationship between R-values and various facility dimensions. The R-value variations as functions of facility width (W) and length (L) are shown in Figures 7 and 8. First, in consideration of the R-values for Types A and B (Fig. 7), it is indicated that the percentage of capacity increase holds fairly constant as the overall facility dimensions are varied. It appears that, under the given set of facility characteristics, the vehicle size reduction multiplies the capacity of a standard design facility by 1.85 on the average; that is,

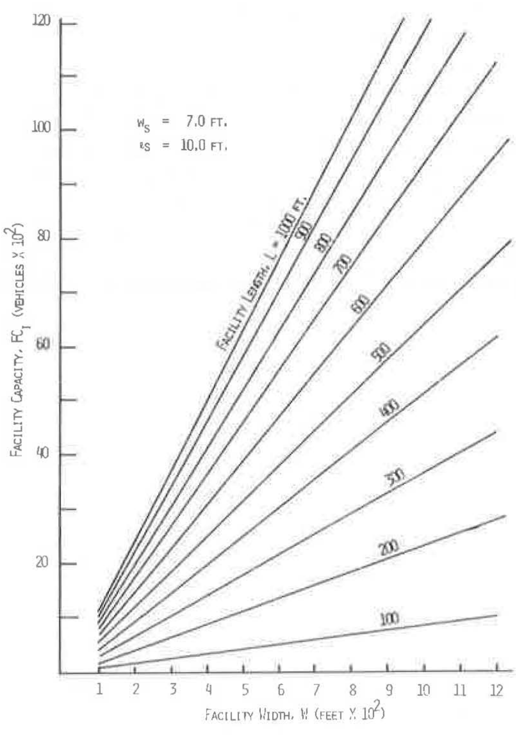

Figure 6. Capacity curves for fleet vehicle parking facilities.

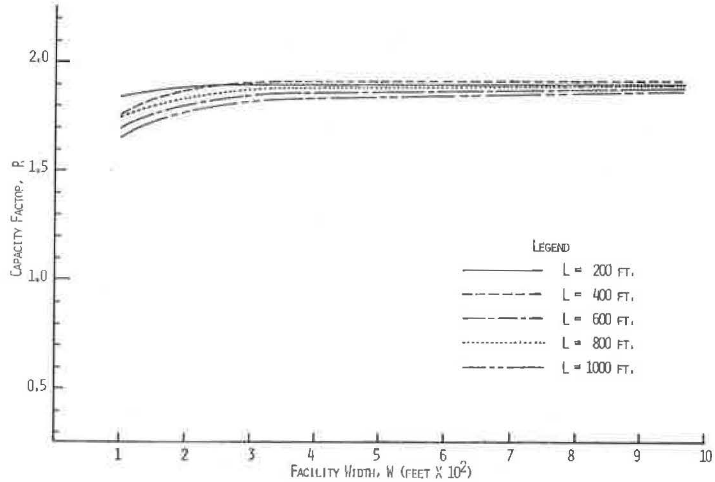

Figure 7. Capacity factor versus vehicle size variations for standard facilities.

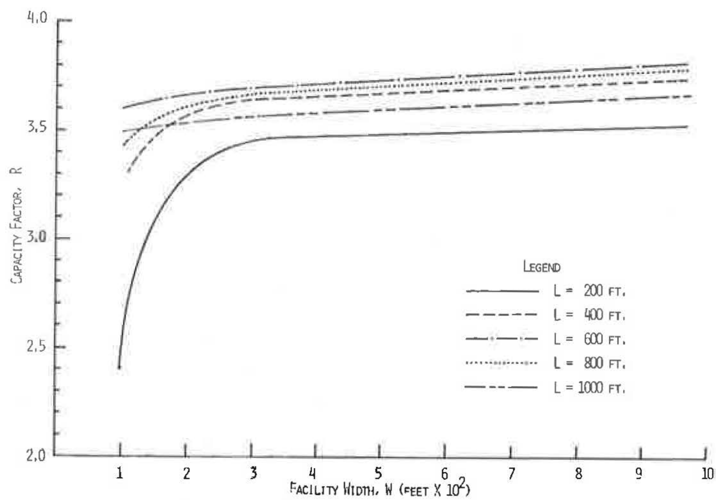

Figure 8. Capacity factor versus vehicle size variations for fleet parking operations.

the decrease in stall dimensions from 8.5 by 18 ft to 7 by 10 ft, without any change in the geometrical configuration, produces approximately an 85 percent increase in parking capacity.

As to a capacity comparison between Types A and C, the curves shown in Figure 8 indicate that as the facility width (W) is increased for a constant length (L), the R-value increases at a decreasing rate of change. As the facility width reaches approximately 300 ft or greater, the change of R-values for all facility lengths under consideration behaves somewhat linearly with a constant increase rate. It is also shown that employment of a fleet parking system and reduction of vehicle size (Type C) will multiply the capacity of a standard parking facility (Type A) by approximately an average 3.56. The percentage of the capacity increase will range between 236 and 380 percent for various sizes of rectangular parking facilities. Such a significant increase in parking capacity clearly demonstrates that the urban fleet vehicle system would provide a great potential for resolving the problem of parking space shortage in urban areas.

ECONOMIC CONSIDERATIONS OF FLEET PARKING

Of primary concern in this study is the capacity analysis of a fleet parking terminal versus a certain typical standard facility with standard parking operations. The study results indicate that the fleet parking operation would be encouraging from the standpoint of increased capacity in a parking facility with given dimensions. However, the capacity analysis is by no means an end in itself. Many other factors are also important in determining the economical feasibility of such a system. Although a detailed analysis of those economical factors is beyond the scope of this study, the recognition of their significance cannot be overemphasized.

One of the major stepping-stones will be the facility cost. It is evident that a high initial cost could be expected when such a fleet vehicle system is introduced to city use. These costs would primarily result from new parking facilities that would be constructed for the system implementation. However, with the large increase in the number of vehicles that can be stored, it would be even more profitable for the facility owners to use fleet-operated parking. As for the cost of the entire system, the larger the fleet facility the more economical the system becomes as the capacity increase grows larger. A system developed using large terminals in prime locations could lessen the significance of the cost factor in the success of the system. After all, public acceptability would have a strong bearing on the outcome of such an investment.

With all vehicles stored having the same size, weight, and maneuverability, the design of facilities should be much simpler and relatively less expensive. Facilities for private automobiles could be easily converted to accommodate fleet vehicles. Maintenance cost would be similar to the facility parking standard private automobiles. On the other hand, the convenience of the fleet-parking system is a big factor in its favor. The time reduction of parking and unparking vehicles would contribute a significant saving of users' time.

CONCLUSIONS AND RECOMMENDATIONS

The urban parking problem can be broken down into three major factors: (a) continuing rapid expansion in automobile traffic; (b) competition for urban street space between standing and moving vehicles; and (c) the high cost of parking space in today's crowded cities. To alleviate the parking problems, municipalities have formulated plans and constraints to deal with these difficulties.

The control of parking problems by introducing a fleet parking system has been analyzed in this study. The ability to pack more cars into the limited amount of space that can reasonably be devoted to car parking in town centers is an important factor to be weighed when considering the contribution of the urban fleet vehicle system to the solution of the urban parking space shortage. Accordingly, employment of such a concept is recommended as a new approach to the parking crisis.

Based on the result of this study, it has been concluded that the urban fleet vehicles, which are small and similar in size, can increase the capacity of existing parking facilities by a factor 3.0 to 4.0 for alternate cases and by 3.6 on the average. It is recommended, however, that a more complete economical analysis of the fleet parking operation be developed. Study of optimum parking system designs must also be completed before evaluating the effectiveness of the concept. These steps would aid in maintaining some order to parking system development in varied urban locations and would possibly establish some design goals for planners to use.

Because no data are available from facilities already constructed, the types of fleet-operated facilities are considered in this study only from a logical standpoint and not necessarily a practical one. Therefore, the capacity analysis and cost considerations should not be considered to be exact, but are only approximations based on facility items of which little is known. With more empirical data and better background, a more detailed analysis could be made. It can be safely assumed, however, that the fleet-operated parking operations could strongly influence the parking situation toward a more favorable outlook.

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Trends in CBD Parking Characteristics, 1956 to 1968

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•WE LIVE in a complex urbanized society. In 1920 more than half of the nation lived in a rural environment. By 1975, approximately 75 percent of the country's population will be living in 262 urban areas (1, Table C1). The rapid growth of American cities presents a direct challenge to the transportation planner. He must plan, design, construct, and maintain transportation systems for these metropolitan areas. These systems not only must provide for the safe, efficient movement of people and goods, but they also must be responsive to the needs and travel desires of the people.

The growth in the popularity of the automobile as the major mode of travel has resulted in the need to investigate and analyze automobile travel continually in order to plan adequate transportation systems to meet the demand. In 1968, 79 percent of all families in the United States owned an automobile, and they traveled 483 million vehicle-miles in urban areas or approximately 50 percent of the total vehicle-miles of travel (2). Recently the number of registered motor vehicles passed the 100 million mark. This increase in the number and use of motor vehicles underlines the need for adequately planned transportation facilities. Every automobile trip begins and ends with storage of the vehicle. As the number of vehicles and trips increases, so does the need for parking facilities to handle these trips. These needs are critical in urban areas, particularly in the center city, where the competition for space among various land uses is highest.

Although every city is unique, they all possess certain common characteristics. There is a functional relationship among the highway system, land use activities, and terminal areas that transcends individual cities. The similarity of these patterns becomes more predominant as the cities increase in size and density, for "as cities grow there is a tendency for land uses of like character to become concentrated in functional areas of commercial, industrial and residential activity"(3). A more definitive pattern takes form in urban areas of comparable size. The assumptions and conclusions of O-D surveys—that people are habitual in their activities and tend to establish patterns when categorized on a regional level—are applicable to parking characteristics. The patterns tend to be repeated in cities of similar size and are used for a comparative measure of parking patterns and characteristics in the CBD.

The objective of this paper is to investigate and analyze trends in CBD parking by urban area size from 1956 to 1968. The data for 1956 were taken from the "Parking Guide for Cities" (3). The data for 1968 are from 99 parking studies conducted in urban areas since 1960. These studies were assembled and the data extracted, codified, and tabulated. The results were then analyzed and summarized by city size. For analysis purposes, the studies are categorized into five population groups that correspond to those used in 1956 and that simplify comparative procedures. Urbanized area populations were used for both studies. Only urban areas with 50,000 population or greater are included in the report. This is because (a) fewer data are available for the smaller cities; and (b) problems in these areas are smaller and have fewer possible alternatives, and the solutions require less information.

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TABLE 1

NUMBER AND TYPE OF PARKING STUDIES—1960 TO 1968

Population Group	Number of Cities in Group	Number of Parking Studies			Percent of Cities in Sample	Mean Population of Sample	Mean Population of Group
		Type A	Type B	Total			
50,000-100,000	78	11	19	30	38	68,000	73,000
100,000-250,000	85	5	28	33	39	68,000	173,000
250,000-500,000	30	5	11	16	53	360,000	352,000
500,000-1,000,000	22	3	12	15	68	720,000	713,000
1,000,000 and over	16	2	3	5	16	3,700,000	3,236,000
Total	231	26	73	99	43		

The following data are provided as a general guide for cities considering a comprehensive parking study. They should not be used in lieu of an independent parking study. However, one meaningful analysis technique would be the comparative or analog method.

STUDIES AVAILABLE FOR ANALYSIS

In 1967 there were 231 urbanized areas (over 50,000) in the United States (4). The parking studies investigated were divided by population into five groups, as given in Table 1. The studies were classified into two types. Type A represents studies of a comprehensive nature and included extensive information on walking distance, trip purpose, trip duration, facility types, and the like. These represented approximately 26 percent of the total sample. Type B studies were of a lesser magnitude but still contained supply inventory and information on demand such as accumulation, purpose, and turnover.

The mean population for all cities in each group as well as the mean of the sample was calculated. These data were also compared to the means used in 1956 (Table 2). Significant shifts in population means can be seen in this period. The mean population for cities of 50 to 100 thousand decreased 15 percent. The cities of 100 to 250 thousand and 250 to 500 thousand experienced little change but did decrease 5 and 2 percent respectively. A radical change is noted in cities of more than half a million population. Cities between a half and one million grew 31 percent while the cities of more than a million increased almost 300 percent.

Although this report is not intended to be a demographic study of city growth, these changes in population size should be remembered when comparing the 1956 and 1968 data sets. Table 2 also compares the physical characteristics of the CBD's. The actual changes in area are consistent with the population shifts although not directly proportional. This table helps to dimension the physical size of the downtown and relate it to actual study areas.

TABLE 2

PHYSICAL CHARACTERISTICS OF CENTRAL BUSINESS DISTRICTS

Population Group	Year	Mean Population of Sample	CBD Area (sq mi)	CBD Blocks	Core Area (sq mi)	Core Blocks
50,000-100,000	1956	80,000	0.34	45	0.14	—
	1968	68,000	0.26	37	0.06	8
100,000-250,000	1956	167,000	0.38	60	0.09	—
	1968	160,000	0.38	70	0.08	17
250,000-500,000	1956	366,000	0.58	99	0.15	—
	1968	360,000	0.48	99	0.12	20
500,000-1,000,000	1956	549,000	0.50	139	0.11	—
	1968	720,000	0.89	115	0.29	36
1,000,000 and over	1956	1,306,000	0.99	162	0.22	—
	1968	3,700,000	1.74	224	0.45	62

TRAFFIC VOLUMES

One parameter related to downtown parking is traffic volumes into and out of the CBD. Over the study years, total volume into the CBD grew at a decreasing rate as population increased, and volume per 1,000 population steadily declined as city size increased. Table 3 compares the changes in volume per 1,000 population between 1956 and 1968. By studying these data, one can make the following general observations:

1. Cities of over 500 thousand population are experiencing a decreasing number of trips,
2. Cities between 100 and 500 thousand are experiencing an increasing number of trips, and
3. Cities of less than 100 thousand show little change.

The changes in trips per 1,000 population indicate that in the larger metropolitan areas, which usually have greater downtown congestion, fewer automobile trips are being made to the CBD. These trips either use other modes or are not made at all. However, in the medium-size areas, the degree of congestion is not as great, and the use of automobiles for downtown trips has increased.

SUPPLY

Parking supply data are essential for the analysis of downtown parking problems. A comprehensive parking facility inventory gives the actual number, type, and location of parking spaces. Periodic or continuous updating procedures will keep this information current.

The two data sets, 1956 and 1968, provide a chance to study changes in parking supply. Except for cities of 50 to 100 thousand, there is an overall increase in supply from 1956 to 1968. This reflects the growth of our cities. The fact that cities of 50 to 100 thousand had fewer spaces in 1968 than in 1956 is a result of the downward shift in the mean population of the group rather than an actual loss of spaces. A more equitable means of comparison is to contrast spaces per 1,000 population, which takes into account population changes (Table 4). All of the groups except cities of over one million show an increase of spaces per 1,000 population. Urban areas in the 100 to 250 thousand range had the greatest change (from 33.2 to 48.5 spaces per 1,000 or a nearly 50 percent increase). As previously mentioned, this group also experienced the greatest increase in traffic volumes, up nearly 30 percent. The number of spaces increased 33 percent in cities of one half to one million population. The other cities showed little increase in spaces per 1,000, while cities over one million actually decreased 10 percent.

Another important characteristic of parking supply is the distribution of spaces by facility type (Table 5). Between 1956 and 1968 there was a consistent decrease in the percent of curb or on-street parking spaces for all city sizes. The greatest change occurred in cities of 50 to 100 thousand, where the proportion of curb spaces dropped 55 percent. An interesting note is that, although the percent of curb spaces decreased, the percent of lot spaces increased for all city sizes at almost the same rate. For example, in the smallest urbanized areas, lot spaces increased from 33 to 60 percent

TABLE 3

TRAFFIC VOLUMES INTO CBD[a]

Population Group	Volume	
	1956	1968
50,000-100,000	476	457
100,000-250,000	236	307
250,000-500,000	168	179
500,000-1,000,000	135	122
1,000,000 and over	66	49

[a]Trips per 1,000 population (urbanized area) between 10 a.m. and 6 p.m.

TABLE 4

PARKING SPACES PER 1,000 POPULATION

Population Group	1956	1968
50,000-100,000	63.5	68.7
100,000-250,000	33.2	48.5
250,000-500,000	32.8	34.3
500,000-1,000,000	24.2	31.8
1,000,000 and over	18.1	15.9

TABLE 5

PERCENT DISTRIBUTION OF PARKING SPACES AVAILABLE IN CBD

Population Group	Year	Facility Type			
		On-Street	Off-Street	Lot	Garage
50,000-100,000	1956	59	41	33	8
	1968	35	65	60	5
100,000-250,000	1956	45	55	42	13
	1968	27	73	62	11
250,000-500,000	1956	28	72	57	15
	1968	20	80	64	16
500,000-1,000,000	1956	22	78	49	29
	1968	14	86	56	30
1,000,000 and over	1956	14	86	63	23
	1968	14	86	55	31

while the curb spaces decreased from 59 to 35 percent. Lots now represent between 50 and 60 percent of the supply regardless of city size, which was not true in 1956. There was little change and, in fact, some decrease in the distribution of garage spaces. Only in cities of over one million, where the change was from 23 to 31 percent, was there any real difference. However, there was a steady increase with city size in the percent of garage spaces. One final observation is that 1956 off-street spaces varied between 33 and 63 percent of the total supply, while in 1968 they ranged from 65 to 86 percent.

PARKING DEMAND

One of the major factors determining the parker's usage characteristics is his trip purpose. The primary reason for the automobile driver's trip is directly related to the parameters or parking characteristics of that trip. The trip purpose affects the duration of the trip, and duration affects the facility type used and the acceptable walking distance. Accumulation, or the measure of the number of parkers over a certain time period, shows the relative importance by purpose of each parking trip throughout the study period.

Table 6 gives the distribution of parkers by trip purpose. When the three main purposes of shop, business, and work were compared between 1956 and 1968 the following changes were found:

1. Shopping trips decreased an average of 3 percent for all population groups. This percentage is the average of the differences. For example, in cities of 50 to 100 thousand population, the percent of shopping trips decreased from 30 percent in 1956 to 24

TABLE 6

PERCENT DISTRIBUTION OF PARKING IN CBD BY TRIP PURPOSE

Population Group	Year	Purpose			
		Shop	Business	Work	Other
50,000-100,000	1956	30	30	17	23
	1968	24	31	20	25
100,000-250,000	1956	25	38	16	21
	1968	21	34	26	19
250,000-500,000	1956	17	42	23	18
	1968	19	33	30	18
500,000-1,000,000	1956	18	44	22	16
	1968	13	25	47	15
1,000,000 and over	1956	13	31	41	15
	1968	10	30	41	19

percent in 1968, or minus 6 percent. This is an actual change of 20 percent. The average actual change for all five groups was 12 percent.

2. Business trips experienced a similar decline; the average percent of difference was minus 6.5 percent, an average actual change for all give groups of minus 16 percent.

3. Work trips to the CBD had the most dramatic change. The average percent difference was 9 percent, an average actual increase for all groups of 45 percent. The most drastic change occurred in cities of one-half to one million population where the proportion of work trips increased from 22 percent in 1956 to 46 percent in 1968, an actual increase of 109 percent. The least change was in cities of one million and more, where the proportion of work trip parkers stayed constant at 41 percent.

Accumulations

The parking accumulation curves, number of parkers by time of day, are similar for 1956 and 1968. Both sets of curves show a general pattern of accumulation build-up during the 8 to 10 a.m. period, a relatively steady state between 10 a.m. and 4 p.m. (except for noon-hour trips in smaller cities), and a decline between 4 and 6 p.m. Regardless of city size, the total peak accumulation is less than total average supply. This occurs because many of the available spaces included in the supply are in the fringe areas of the CBD and are beyond acceptable walking distance.

A comparison of peak-hour accumulations, 1956 to 1968, shows that there was a relative percent decrease in peak accumulations and also a percent decrease in the range of facility utilization. In 1956 the average peak-hour usage by group was 78, 66, 66, 91, and 92 percent, while in 1968 the range was 65, 77, 75, 82, and 74 percent. From a strictly comparative point of view, the average ratio of peak-hour accumulation to available supply was 78 percent in 1956 and 74 percent in 1968. Although this change would indicate that there was less of a problem in 1968 than in 1956, one must consider other parameters such as the changing character of CBD trip purposes and the upswing in the number of all-day work parkers. There also was a significant change in number of spaces per 1,000 population since 1956.

Durations

As one would expect, average parking durations vary with the size of the urban area from approximately 1 hour in small urbanized areas to more than 3 hours in cities of over one million population. These and other results are given in Table 7. The average duration between 1956 and 1968 does show some variation. The greatest change occurs in the population range between ¼ and one million, where the average duration increased 0.8 hour. Cities in the 50 to 100 thousand and 100 to 250 thousand ranges increased 0.2 and 0.5 hour respectively, while cities of more than one million changed from 3 hours to 3.1 hours.

TABLE 7

AVERAGE PARKING DURATION (IN HOURS) FOR VARIOUS TRIP PURPOSES IN CBD

Population Group	Year	Purpose			
		Shop	Business	Work	All
50,000-100,000	1956	0.7	0.7	3.8	1.4
	1968	0.6	0.8	3.3	1.1
100,000-250,000	1956	1.0	0.9	3.8	1.6
	1968	1.3	0.9	4.3	2.1
250,000-500,000	1956	1.3	1.1	4.8	1.9
	1968	1.3	1.0	5.0	2.7
500,000-1,000,000	1956	1.3	1.3	4.8	2.2
	1968	1.5	1.7	5.9	3.0
1,000,000 and over	1956	1.8	1.5	5.6	3.0
	1968	1.1	1.1	5.6	3.0

An interesting note is that, between the two dates, trips of less than ½ hour increased in the smaller areas from 51 to 60 percent but decreased in the largest area from 28 to 16 percent. Naturally, the converse is true, with the larger cities showing an increase in the longer duration trips.

The average duration of the shopping trip did not change significantly from year to year or from group to group. The average duration was slightly more than ½ hour in the small areas to about an hour in large urban areas. Business trips showed little difference, with the duration of the average business trip ¾ hour in small urban areas and 1½ hours in large urban centers.

A more dramatic change occurred in the work trip durations, which were perhaps the most significant data analyzed. Except for the small cities, the parking duration of the work trip increased. The greatest increase was in cities between a half and one million population, where the average work trip parking duration jumped 1.1 hours from 4.8 to 5.9. When the results of the trip purpose and duration studies are compared, it is obvious that there was a large increase in work trips to the CBD and that their associated longer duration resulted in more parking spaces being used for long-duration work trips. These effectively reduced the actual available supply to other types of trips, a condition particularly prevalent in larger cities.

Turnover

Parking turnover measures the utilization of a parking space; it indicates how many times the space is used by different vehicles during a specified time period, usually 8 hours. In the two data sets the average turnover rates for all facilities combined decreased as population increased, and in 1968, regardless of facility type, turnover rates decreased with increased population. In both years, curb parking spaces averaged turnover rates three to four times higher than off-street spaces, and lot spaces averaged higher turnover rates than garages. The actual ratios are given in Table 8.

Between 1956 and 1968, there was a gradual reduction in the turnover rates for all city sizes, with little change in off-street turnover rates and with curb turnover rates increasing in some cases and decreasing in others (higher for low populations, lower for high populations). The lower turnover rates resulted from a change in the distribution of parking spaces. The proportion of curb spaces to total supply decreased for all cities (Table 5), and the increase in the proportion of off-street spaces, with their lower turnover ratios, led to a reduction in average turnover ratios.

Walking Distance

Perhaps the most difficult data to collect and analyze concern the distance that people walk from their parking place to their trip destination. As one would reason, acceptable walking distance is a function of trip purpose, duration, and the particular characteristics of the parker such as income level and occupation. The 1968 study data were

TABLE 8

PARKING TURNOVER RATIOS IN CBD

Population Group	Year	Parking Facility				
		On-Street	Off-Street	Lot	Garage	Total
50,000-100,000	1956	5.7	2.0	2.2	1.0	4.0
	1968	6.1	1.9	2.0	0.8	3.5
100,000-250,000	1956	5.8	1.5	1.6	1.0	3.3
	1968	5.7	1.5	1.6	1.0	2.7
250,000-500,000	1956	5.5	1.5	1.5	1.2	2.6
	1968	5.2	1.4	1.4	1.1	2.2
500,000-1,000,000	1956	6.9	1.5	1.6	1.2	2.9
	1968	4.5	1.2	1.2	1.4	2.0
1,000,000 and over	1956	4.4	1.6	1.7	1.3	2.0
	1968	3.8	1.1	1.2	1.0	1.3

TABLE 9

AVERAGE WALKING DISTANCE (IN FEET) BY TRIP PURPOSE IN CBD

Population Group	Year	Trip Purpose				Total
		Shop	Business	Work	Other	
50,000-100,000	1956	391	327	483	—	353
	1968	350	290	410	260	325
100,000-250,000	1956	539	416	539	—	397
	1968	470	390	500	340	422
250,000-500,000	1956	824	606	728	—	502
	1968	570	450	670	380	532
500,000-1,000,000	1956[a]	656	528	698	—	523
	1968	560	590	650	500	631
1,000,000 and over	1968	388	398	673	310	500

[a]1956 data calculated for cities of 500,000 and over.

TABLE 10

AVERAGE WALKING DISTANCE (IN FEET) BY TRIP DURATION IN CBD

Population Group	Year	Duration (hour)						
		0 to ¼	½ to 1	1 to 2	2 to 3	3 to 4	4 to 5	5 and More
50,000-100,000	1956	238	347	425	471	523	532	—
	1968	176	310	350	355	377	366	430
100,000-250,000	1956	276	491	552	598	606	592	—
	1968	258	420	380	495	490	499	440
250,000-500,000	1956	392	580	688	768	801	747	—
	1968	275	440	510	546	565	613	740
500,000-1,000,000	1956[a]	350	508	571	633	673	677	—
	1968	262	480	480	544	505	610	910
1,000,000 and over	1968	334	520	560	619	661	701	—

[a]1956 data calculated for cities of 500,000 and over.

summarized by trip purpose and duration and compared to 1956 data in Tables 9 and 10. Aside from certain obvious facts, it is difficult to develop any significant trends in relation to walking distance because so many other parameters are involved. For 1968 the average walking distances were shorter in smaller cities. Shopping and business trips had shorter average walking distances than work trips. There was a slight trend toward longer average walking distances except in the small cities, where average total walking distance decreased from 353 to 325 ft. Further observations are left to personal interpretation.

One interesting note is that the minimum average walking distance is 325 ft and the maximum is 631 ft, a difference of 300 ft. Although this represents an increase of 100 percent, it is far from the percent increase in population and on a relative scale does not have the magnitude of variation one might expect. This points to what is considered to be one of the more important criteria in parking facility location: to minimize walking distance or walking time.

SUMMARY

The major changes in CBD parking characteristics between 1956 and 1968 were examined. The physical changes such as populations, traffic volumes, and parking supply were discussed. The most noted variation was the 50 percent increase in spaces per 1,000 population in cities of 100 to 250 thousand and their 30 percent increase in inbound traffic volumes.

The demand side of parking was analyzed. The decline of shopping and business parking trips was observed. The 45 percent average increase in work trips to the CBD represented the most radical change. The greatest increase in work trips occurred in cities of one-half to one million population.

The rest of the data varied somewhat from 1956. Accumulation, duration, and turnover all reflected the increase in the number of longer duration work trips. Data on walking distance were the most difficult to classify except for the slight trend toward longer average walking distance.

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