# Development of Computerized Analysis of Alternative Parking Management Policies

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This paper describes the development and application of a computer model for the analysis of policies for the supply and management of parking facilities. The model, developed to analyze parking problems in the Oakland area of Pittsburgh, is a micromodel that allocates vehicles to parking spaces at the block level within a defined study area. The parking model is based on the origin-constrained entropy-maximizing gravity model. The destinations are the spaces in which drivers park their cars in the study area. Since all spaces need not be used, the destinations are unconstrained. The locations, to which the drivers then walk, represent the origins. As these are fixed and known, the model's origins are constrained. The study area is divided into two-zone systems that overlay each other. Land use zones represent the origins, and parking zones contain the destinations. The attraction of a parking zone is a function of the number and general cost of each type of parking space in that zone. The parking problems in the Oakland area of Pittsburgh arose from the conflicting needs of two universities, five hospitals, several cultural institutions, and residential and commercial areas. The alternative policies examined include residential sticker parking, parking pricing and time limit changes, and the location and size of new parking buildings. The results from the model indicate that the parking problems for the area could be overcome by a coordinated program of management changes and construction of parking buildings. Several predictions of the model have been confirmed by subsequent detailed feasibility studies. The model developed should be generally transferable with some recalibration of cost and walking distance trade-off parameters. The current application dealt with a situation of inelastic demand. If the demand were elastic, then the model would have to be used in combination with a travel-demand package.

This paper presents a model for the analysis of the supply and management of parking facilities. The model was developed to analyze the parking problems of the Oakland area of Pittsburgh, which is the second largest traffic generator in the metropolitan area, second only to the downtown. The Oakland area contains a mix of residential, commercial, and cultural activities along with the University of Pittsburgh and the University Health Center, which includes five major hospitals. These activities provide a varied range of conflicting parking requirements that are met by on-street parking and publicly available, private off-street parking facilities. For this varied range of parking problems and possible solutions, a streamlined analysis capability was essential, and thus the computerized model was developed.

Existing computerized parking models consist of two main types. The first is the optimization approach, where a variable such as total walking distance is minimized. Typical of this class of models are those of Ellis and others (1) and Whillock (2). The other type of model is the gravity-distribution type, where parking location is allocated relative to the destination of the driver according to some distance-deterrence function. These models include those by Bates (3) and Austin (4).

For this particular study, the gravity-distribution model was chosen. The reasons for this choice over the optimization approach were as follows:

1. A large number of the parkers to the area are relative strangers (visitors to the hospitals) and it is doubtful that they, in fact, minimize their walking distance;
2. A considerable amount of parking in the area is illegal, which the gravity model was modified to accommodate;
3. Many parkers use legal spaces illegally; for example, long-term parkers feed short- and medium-term parking meters; the gravity model accommodates this activity; and
4. The characteristics of the parkers and the spaces available vary widely.

With the development of the gravity parking model, the following specific issues were to be studied:

1. Changes in the pricing of the existing parking facilities,
2. Changes in the time limits for existing parking,
3. The introduction of residential sticker parking programs,
4. The needs for employee parking by large employers, and
5. Various proposals for new off-street parking lots and buildings at several locations in the study area.

## MODEL THEORY

To carry out the analysis of parking for an area, the area is first divided into land use zones and parking zones. The land use zones represent the ultimate destinations of persons who park their cars, and in the Oakland study these were defined by census blocks. The parking zones contain the locations where the cars are parked. The land use zones and the parking zones overlay each other but are completely separate. These distinct zone structures were created for two main reasons.

1. A land use zone should contain complete city blocks and the streets form natural boundaries, whereas a parking zone should contain complete street blocks and off-street parking facilities accessible from that street block. The natural boundaries for parking zones are the midpoints of city blocks. Thus, the two-zone systems logically divide into distinct entities.
2. A key function in the model is the distance-deterrence function for which the main parameter is the distance between zone centroids. Because the origin zones are distinct from the destination zones, this measure is always finite and never approaches zero.

The theoretical model used is the origin-constrained entropy-maximizing gravity model as defined by Wilson (5). In its application as a parking model, the origins are the land use zones in which the vehicle is parked. Thus, the trip in the model is the walking trip of the car driver. Since the exact number of drivers destined for each land use zone is known, the model is origin constrained. On the other hand, the model is unconstrained for destinations because there is no requirement that all parking spaces in a parking zone be used.

In its Oakland application, the model deals with three classes of parker, short term (less than 2 h), medium term (2-4 h), and long term (greater than 4 h). It models the peak-parking load (at 2 p.m.) for a normal weekday. This was sufficient for the policies studied in the Oakland case. The model, however, could be adapted for dynamic analysis throughout the day.

Three classes of parker were determined by the characteristics of the parking demand and supply. The short and medium definitions coincided with on-street parking time limits, which were mostly of 2- or 4-h duration. These definitions also clearly differentiate the distinct duration groupings of hospital visitors and university students.

The model equations are

$$T(i,j,k) = O(i,k) \cdot A(j,k) \cdot X(j) \cdot B(i,j,k) \cdot D(i,j)^{-r(k)} \quad (1)$$

where

i = land-use zone of origin (i = 1, ..., m),
j = parking zone of destination (j = 1, ..., n),
k = type of parker (short, medium, long),
T(i,j,k) = persons from zone i who park in zone j for type k,
O(i,k) = total persons from zone i who are parkers of type k,
A(j,k) = attractiveness of zone j as a parking location for type k parkers,
X(j) = capacity calibration factor for parking zone j,
D(i,j) = distance between centroids of zones i and j,
r(k) = distance-deterrence parameter that is a function of parker type k, and
B(i,j,k) = the balancing coefficient given by

$$B(i,j,k) = \left\{ \sum_j [A(j,k)\, X(j)\, D(i,j)^{-r(k)}] \right\}^{-1} \quad (2)$$

The O(i,k) for all i and k are inputs to the model. They are the basic parking demands and are obtained from survey data and growth forecasts if appropriate. The A(j,k) is the attractiveness of a parking zone as a parking location. It is based on two assumptions related to the number and type of parking spaces available. The first is that the attractiveness of parking will be proportional to the size of the parking facility or the number of spaces available. This is similar to the attraction basis of most gravity model applications. It appears to be a reasonable assumption in that the larger the parking facility, the better known it will be.

The second assumption derives from a basic characteristic of this parking model. Although demand and supply are divided into three classes, parking allocations are not exclusive to class. If the demand is great enough, for example, long-term parkers may be allocated to short-term spaces. In practice, this would be done by feeding parking meters or by paying high charges in a building that favors short-term users. In the model, the relative attractions of the different types of parking spaces are handled by weighting factors that could be considered as general cost coefficients.

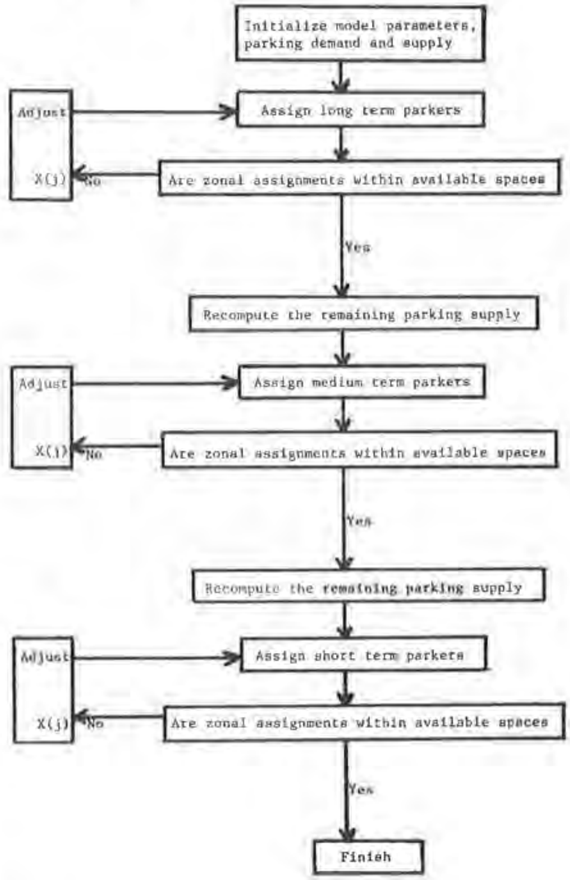
The attraction of a parking zone is given by

$$A(j,k) = \sum_{s=1}^{6} [a(k,s) \cdot n(j,s)] \quad (3)$$

where

a(k,s) = inverse of the cost coefficient of type s parking spaces for type k parkers;
n(j,s) = number of type s parking spaces in parking zone j;
k = long, medium, or short; and
s = long, medium, or short for off-street or on-street parking.

Figure 1. Operation of parking model.




X(j) is an adjustment factor that modifies the zonal attractions for each model iteration until the parking in all zones is within the capacity of those zones. X(j) is explained further under the model's operation. The term D(i,j) is the walking distance from the centroid of land-use zone i to the centroid of parking zone j.

## Model Operation

The operation of the parking model is illustrated in Figure 1. Parkers are allocated sequentially in the order long, medium, and short, which is the order in which they would acquire the spaces. After each type of parker has been allocated, the spaces that they have used are withdrawn and only the remaining empty spaces are used for recalculating the new zonal attractions for the next type of parker.

The allocations for each type of parker are performed iteratively. The initial allocation, with X(j) = 1.0 for all j, gives the unconstrained allocation for each parking zone. For any zones where the number of available spaces has been exceeded, X(j) is reduced in proportion to the excess and another iteration is made. The iterations continue until the capacity overloads are insignificant. Usually three iterations are sufficient.

For the allocation of short-term parkers, the experiences with the model in Pittsburgh led to one particular modification. In parking zones where demand far exceeds the supply, the available spaces will be completely used by long- and medium-term parkers, and nothing is left for short-term parkers, who thus will not be allocated to those zones. In practice, when this situation arises, a great deal of short-term illegal parking takes place both on street and in restricted off-street areas. To replicate this behavior, all parking zones in the model always have a minimum number of short-term spaces available. If an insufficient supply of legal short-term spaces is available, then the balance is made up by hypothetical illegal spaces, which are never available for long- or medium-term parkers. The number of illegal spaces provided will depend on the application.

In Pittsburgh, the figure of 10 spaces/zone was derived from a survey of illegal parking. These hypothetical illegal spaces were never made available to medium- or long-term parkers because local enforcement prevents any measurable illegal parking by these classes. As described earlier, however, the model does allow these latter classes to illegally use legal parking spaces.

The outputs of the model are provided for each iteration of each type of parker allocation. The first iteration is the unconstrained allocation and thus gives the fundamental supply-demand balance for each parking zone, for each type of parker. In the final iteration, the value of the adjustment $X(j)$ gives a measure of the actual supply-demand balance. If $X(j) = 1$, then supply is adequate for the existing demand patterns. If $X(j) < 1$, then it is a measure of the parking deficiency in the zone. In the case of short-term parking, the degree of use of the illegal spaces in the final allocation gives a measure of the short-term problems in each parking zone.

For the comparison of alternative parking policy scenarios, therefore, an assessment can be made by first looking at the unconstrained assignments, then checking the final values of the $X(j)$'s, and finally reviewing the allocations of illegal parking.

In the Pittsburgh application, parking demand was inelastic with respect to the parking characteristics so the constant demand could be maintained over all scenarios. If demand were elastic, then it would have to be adjusted by iterating the output values for parameters such as cost and walking distance from the microparking model, back through the overall travel demand model for the area, until equilibrium was obtained.

## Model Application

The parking analysis model was developed for application to the Oakland area of Pittsburgh. The study area contains a mixture of residential, commercial, institutional, and cultural activity. The major generators are five hospitals and two universities. The residential population of the Oakland area is 22 600 persons, and total employment is 25 000 in the district. On a normal weekday, between 6:30 a.m. and 6:30 p.m., about 75 000 persons come to Oakland in all forms of transportation, including 42 000 automobiles. There are 18 000 public and private parking spaces available for these visiting cars and those of the area residents who do not park on their own property.

The maximum vehicle accumulation in these spaces is about 14 000 vehicles at 2 p.m. Thus, there is a net surplus of parking supply in the area. This situation, together with the very low level of choice transit ridership into the study area, led to the assumption of an inelastic parking demand.

The parking component of the Oakland transportation study was concerned with the following problems:

1. Shortages of employee parking especially for the large employers,
2. Shortages of suitable parking for hospital visitors and university students,
3. Lack of convenient short-term parking space for commercial patrons,
4. Saturation of on-street residential areas by commuter parking, and
5. Aggravation of all of the above by continued growth in the area.

The particular parking policies that needed examination were as follows:

1. Proposals for residential sticker programs for five districts within the study area,
2. Provision of more short-term parking in existing facilities through changes in their pricing structures,
3. Impact of moving a major hospital to a new site,
4. Location and size of several proposed parking buildings throughout the area, and
5. Additional restrictions on streets and parking lots owned by the University of Pittsburgh to reduce their availability to the general public.

## INVENTORIES AND DATA COLLECTION

The study area was divided into 90 land use zones, as shown in Figure 2, and 62 parking zones, as shown in Figure 3. These zone delineations were digitized and the centroids calculated.

Travel interviews, carried out as part of the overall transportation study, provided the data for trip generation for each land use zone. This included mode of travel and length of stay. For the hospitals, universities, and large office buildings, the surveys also provided the parking location of car drivers.

A detailed inventory of each parking zone included the amount, type, and charge for the on-street and off-street parking spaces. The current use of the parking zones was provided by conventional parking surveys. The final data files for the parking model included the number of car drivers present in each land use zone at 2 p.m. on a normal weekday and the length of their stay.

### Calibration and Validation

Several parameters in the parking model needed calibration. Generally, these calibrations were done by running the model with current data and comparing its output with the known parking distribution and also by comparing model outputs with values given in the literature.

The interzonal distance $[D(i,j)]$ was taken to be the direct distance between centroids. No attempt was made to correct this for any network factor since the streets in Oakland form a fine grid and many of the blocks that have heavy pedestrian traffic have short cuts through buildings and alleys.

The distance-deterrence parameter $[r(k)]$ was calculated by testing the model outputs for various values of r against distributions of walking distance given by the literature (6,7). The values used were $r = 1.5$ for short-term, $r = 2.5$ for medium-term, and $r = 4.0$ for long-term parkers.

The cost coefficient matrix $\{a(k,s)\}$ for the development of the parking zone attractions $[A(j,k)]$ were arbitrarily chosen initially and were later refined in the validation process. The final matrix was

$$a(k,s) = \begin{matrix} 10 & 4 & 1 & 6 & 3 & 1 \\ 9 & 5 & 2 & 5 & 4 & 2 \\ 8 & 6 & 6 & 4 & 4 & 4 \end{matrix} \qquad (4)$$

The validation of the model involved the valida-

Figure 2. Land use zones.

Figure 3. Parking zones.

tion of individual parameter values and the validation of the model as a whole. These validations were carried out by running the model with existing data and comparing the outputs with the observed patterns of parking. Close agreement was obtained for the following known characteristics:

1. The limits of the penetration of commuter long-term parking into residential areas,
2. The saturation of two medium-price parking buildings by long-term hospital parkers,
3. The use of two fringe-parking lots owned by the University of Pittsburgh, and
4. The use by short- and medium-term parkers of a large off-street lot near the university and the museums controlled by parking meters.

In addition to these overall validations, some specific checks were made on the distribution of walking distance for some large land use trip generators. A good comparison is shown in Figure 4, which shows a close agreement for medium-term parkers destined for the main university travel zone. The trip interchanges for this application of the gravity model need not have an exact statistical fit, since it is the destination zone totals that must be forecast accurately.

## Policy Alternatives

Several parking problems were examined in the Pittsburgh application of the model.

### Deficiencies in the Parking Supply

The model was run by using existing data and the deficiencies in parking supply in the Oakland area were highlighted. These are shown in Figure 5. The major deficiencies occurred in the areas of the major hospital systems. Here parking demand was overwhelming. Of particular concern was the acute shortage of short-term parking for hospital patients and visitors. This problem had already been suggested by the great amount of illegal parking noted in the parking surveys.

A surprise in these first runs was that supply deficiencies around the University of Pittsburgh were only minor. Although parking spaces in this area are always filled and employees and students claim great parking difficulties, the actual deficiencies are not large and not concentrated in any particular zone. Only where the campus area and the hospital area adjoin are the shortages significant. Elsewhere in Oakland, the supply deficiencies were localized.

### Parking Management Programs

The model was run with residential sticker programs and pricing changes in parking buildings to increase short-term availability. The results indicate that the programs would achieve their goal of reducing commuter parking in residential areas and ease slightly the short-term deficiencies around the hospitals, as shown in Figure 6.

The impact on the hospital employees and university students by the residential sticker program was not as great as had been feared. The actual number involved turned out to be quite a small proportion and their redistribution throughout the area produced only marginal impacts.

### New Hospital Parking Facilities

The proposal for a 1200-space parking building on a hillside behind the hospital area in parking zone 10 was tested. The analysis indicated that the facility would not attract patronage sufficient to fill it and, accordingly, it would have to be used primarily for employee permit parking. The impact of the building is shown in Figure 7. It does ease parking deficiencies in the hospital area and substantially reduces the deficiencies around the University of Pittsburgh. The new facility would have no direct impact in the latter case, but the changes are caused by a ripple effect through the whole area as parking migrates toward the new supply point.

Figure 8 shows the great improvement that would occur if the 1200 new spaces were put into the center of the hospital area with buildings in zones 19 and 21. Both buildings would fill up easily and parking throughout Oakland would be reasonably freely available. In the most deficient areas,

**Figure 4. Distribution of walking distances for medium-term parkers from land use zone 46.**

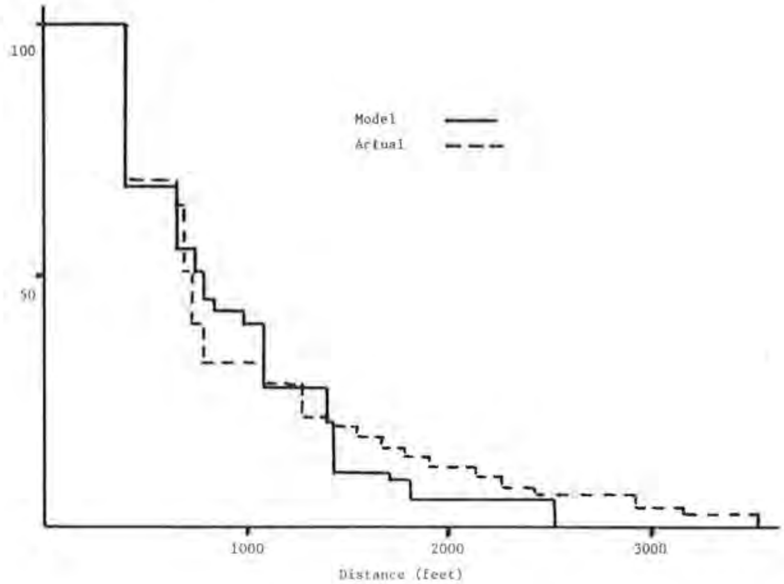



**Figure 5. The current situation.**

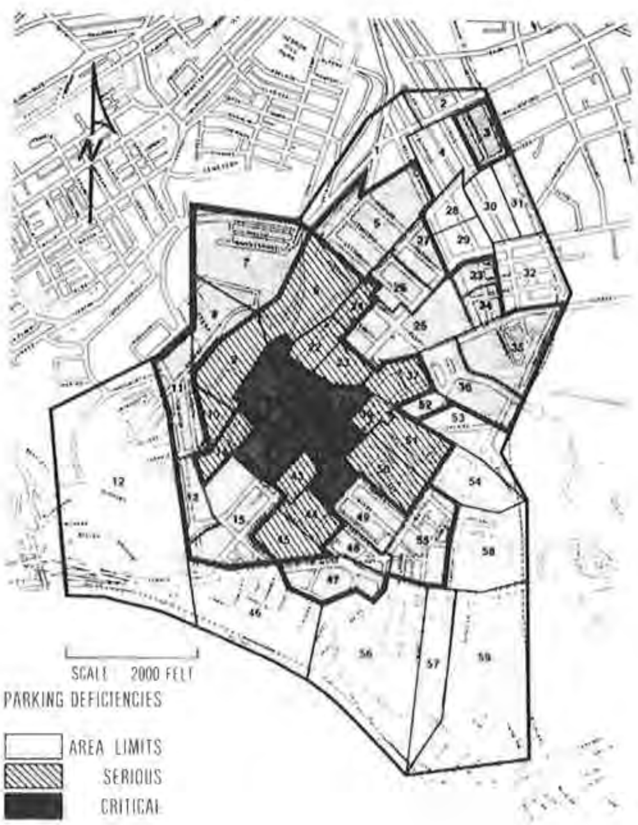



**Figure 6. Parking management policies only.**

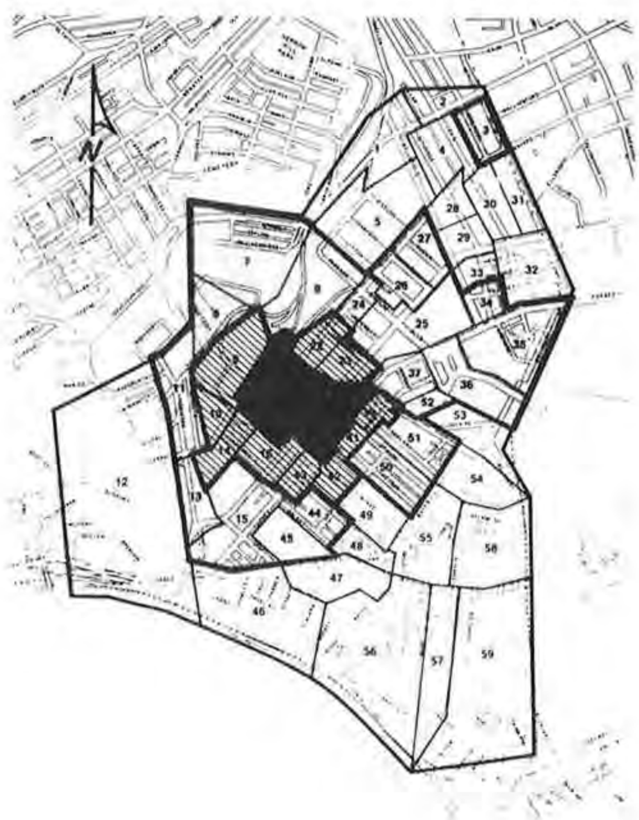


Figure 7. One 1200-space building in zone 10.

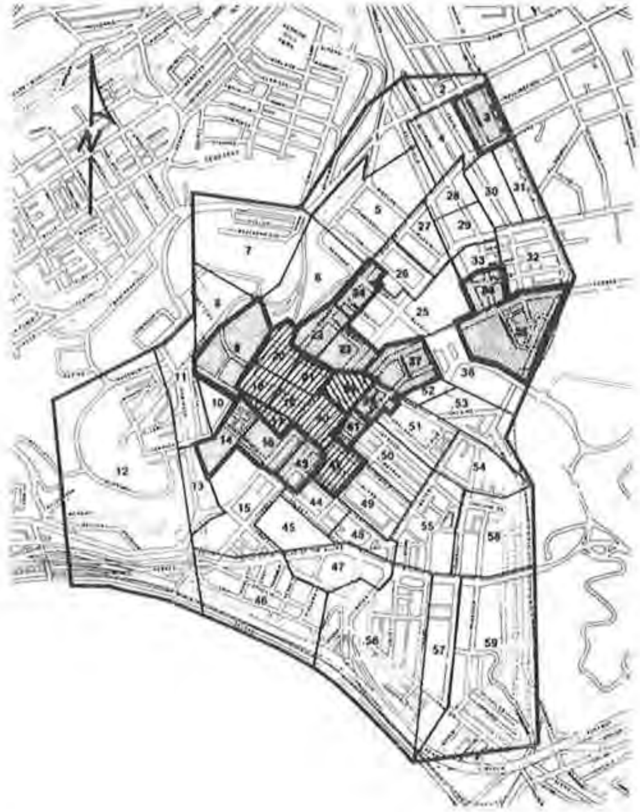


Figure 8. Two 600-space buildings in zones 19 and 21.

short-term parking will still be available within a walking distance of 0.25 mile.

### University of Pittsburgh Parking Needs

As previously indicated, the model initially failed to confirm that any substantial deficiency in parking supply existed in the university area, a result that did not sit well with the university community. To test the situation further, a hypothetical parking building of 400 spaces was tested at all feasible construction sites in the area. In most locations, this building never reached capacity. In parking zone 53, long considered a prime candidate for new parking, the building reached only 30 percent of capacity.

The university parking problem illustrates the conflict between desire and reality. There is a great desire for parking at $0.25/h. There is little demand, however, for parking at $1.00/h, which is closer to the actual cost of new supply. Further analysis indicated that the university could meet its needs by greater use of its existing facilities.

### Other Analyses

The model was run for many other scenarios, particularly for several development proposals that included new hospitals, a new hotel and conference center, and shopping developments. For all of these proposals, parking needs and impacts were estimated.

## CONCLUSION

The parking model described proved to be successful in meeting its objectives. It appeared to be accurate in modeling the parking behavior in the Oakland area of Pittsburgh and provided a mechanism for quick analysis of a large number of alternatives that cover a wide variety of parking policies. In application, the model provided many insights into the local parking problems and contributed to a wide range of solutions that were recommended in the final report (8).

Three independent detailed feasibility studies for new parking buildings in the area have subsequently been made. They confirmed the results of the model. The hospitals have now commenced construction of the first new parking building in zone 18 and Pittsburgh is actively pursuing the residential sticker parking proposals.

The model described is a micromodel for parking allocations at the block level within a defined area. As such, it should be readily transferable. The major recalibrations required would be in determining the cost and walking distance trade-offs. If the parking demand were elastic with respect to walking distance, cost, and availability, then the parking model would have to be coordinated with travel-demand models for the area.

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*Abridgment*

# Opportunities for Small-Car Parking

**J.G. PIGMAN AND J.D. CRABTREE**

**The reduction in automobile size provides an important opportunity for more-efficient use of parking space through a corresponding reduction in the dimensions of parking facilities. Many types of classifications have been offered for the classification of vehicles by size; however, guidelines suggested by the National Parking Association appear to be the most reasonable for a two- or three-group classification. There is still considerable room for additional effort in this area. Due to the wide range of existing parking-area dimensions and layouts, it is very difficult to recommend criteria for redesign without analysis of the specific parking facility in question. The problem is further complicated by the uncertainty in trends in vehicle preference. However, by using a two-group classification of vehicles, a recommendation is made for small-car stalls to be 16.5 ft long x 8.0 ft wide for 90-degree parking. A layout for parking at angles other than 90 degrees can be determined by simply rotating the basic stall for 90-degree parking to the desired angle and using geometry to determine the associated dimensions. Two alternatives discussed for the design of new parking facilities are to accommodate the present population of cars or to give more consideration to inevitable increases in the percentage of small cars. Of the several types of parking facilities evaluated, those that have the greatest potential for redesign to accommodate small cars have rigid control over the users. Included are employee parking areas provided by employers and a variety of special-use parking areas. Many college and university campuses have particularly high potential for implementation of small-car parking.**

The reduction in the size of automobiles provides an important opportunity for more-efficient use of parking space through a corresponding reduction in the dimensions of parking facilities. The shift toward smaller cars has been brought about by several factors, most related to a diminishing supply of oil. Dramatic increases in the price of gasoline and a sudden shift in driver preferences have increased the number of small cars significantly. Statistics reported by the National Parking Association show that the percentage of small cars in the traffic stream has increased from 25 percent in 1975 to 45 percent in 1980 (1). This trend is expected to continue, and the percentage of small cars will increase to 75 percent by 1985 (1). Another factor that enters into the projected increased use of small cars is the mandate by the federal government that requires automobile manufacturers to produce a fleet that can achieve an average of 27.5 miles/gal by 1985. This probably cannot be achieved without additional reduction in vehicle size and weight.

Obviously, the opportunity and need exist to reduce the sizes of parking stalls, which will result in more-efficient use of available space. Escalating costs of land and construction have increased the expense of providing adequate parking, especially in urban areas. The cost per parking space frequently ranges up to $5000 for some parking structures; therefore, the potential for savings brought about by reduced stall and aisle dimensions is considerable. Unfortunately, substantial reductions in the sizes of all parking spaces would not be practical. Large cars currently comprise about one-half of the average traffic stream, and provisions must be made to ensure adequate stall dimensions for these vehicles. A solution to this problem is to reduce the size of some spaces but allow others to remain full-size. This approach allows the creation of additional spaces through stall size reduction while larger cars are still accommodated.

## WHAT IS A SMALL CAR?

Before we can attempt to make special provisions for small cars, we must determine just what is a small car. First, consideration is usually given to some dimension of the vehicle. Overall length, overall width, wheelbase, and height are often included. Some classifications of automobiles are based on the overall weight. The U.S. Environmental Protection Agency's Gas Mileage Guide is based on the interior capacity of the vehicle (2). The Motor Vehicle Manufacturers Association annually produces a list of domestic vehicles and their respective dimensions (3). Another compilation of vehicle statistics is published by Road and Track Magazine for each model year (4). Road and Track presents a more-comprehensive list, which also includes most of the foreign-made automobiles. Still, these lists classify vehicles as minicompact, subcompact, compact, intermediate, medium, standard, full-width, and luxury, and it becomes difficult to decide what is small and what is large. The National Parking Association has provided guidelines to classify automobiles into either two or three groups, based on overall length and overall width (5). By multiplying the overall length times the overall width and converting to square meters, a number is obtained that can be used to easily classify a vehicle based on either the two- or three-group classification. The accepted procedure is to drop the decimal part of the measurement and use only the integer portion for classification. In the two-group classification, any car that covers an area less than 9.0 $m^2$ is considered small, and anything greater than or equal to 9.0 $m^2$ is large (6).