PARKING SPACE ALLOCATION BY COMPUTER MODEL

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

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

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

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

PARKING STUDY PROCEDURES USED IN THE PAST

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

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

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

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

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

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

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

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

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

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

BASIC DATA

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

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

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

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

FIELD SURVEYS

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

PARKING SPACE ALLOCATION MODEL

Data Input

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

Computer Operations

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

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

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

Figure 1. Seattle central business district.

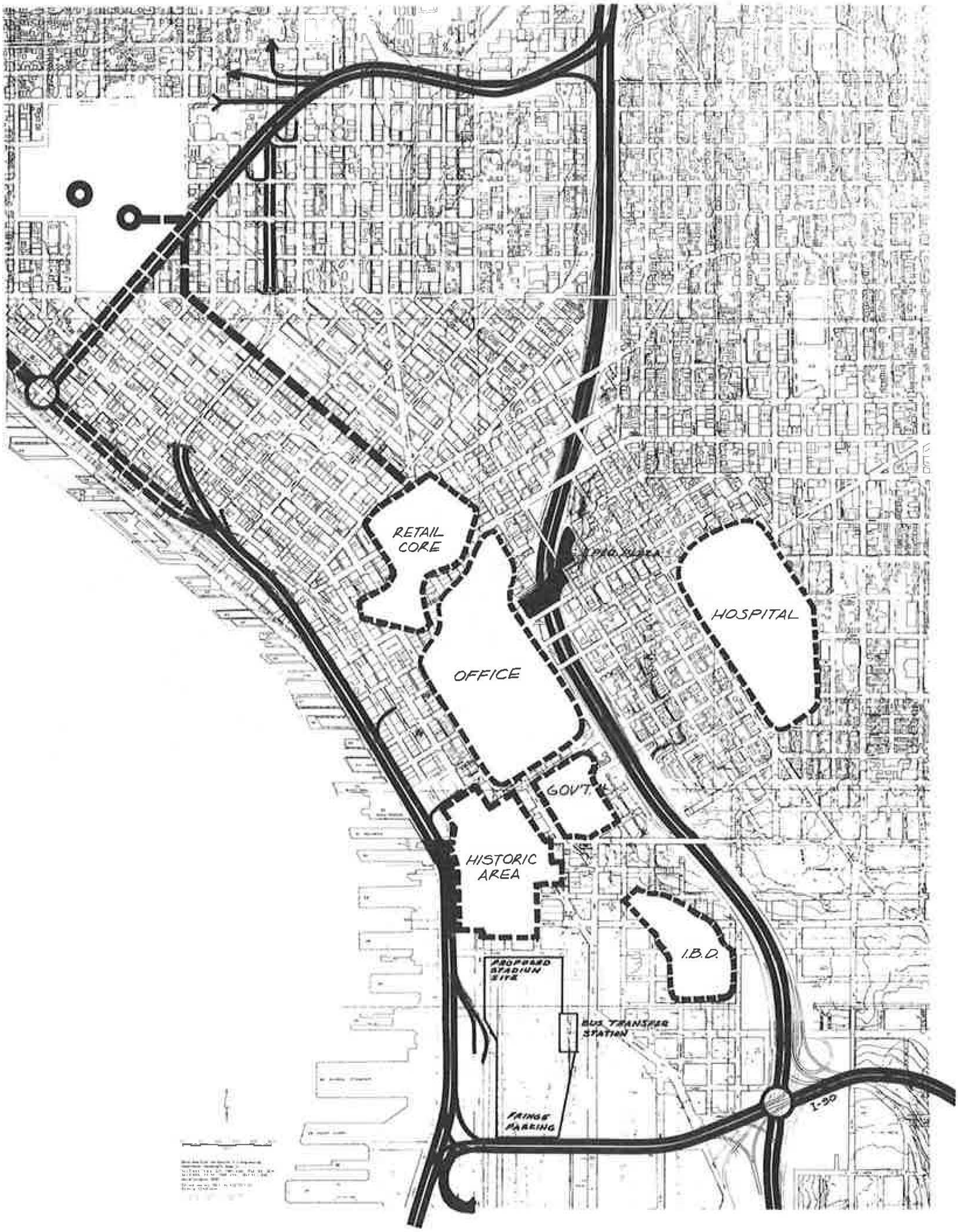


Figure 2. 1970 parking demand.

Figure 3. Demand categories.

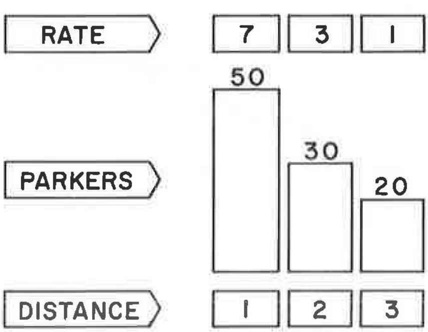
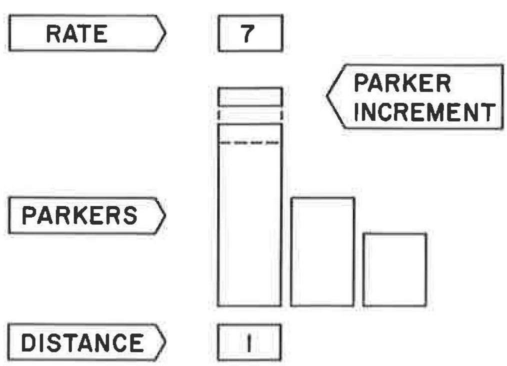


Figure 4. Parker increment.



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

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

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

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

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

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

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

INTERPRETATION, CALIBRATION, AND VARIATIONS

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

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

Figure 5. Qualifying supply blocks.

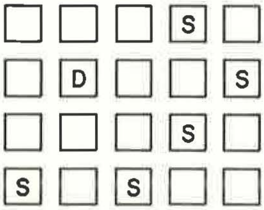


Figure 6. Assignment of parkers.

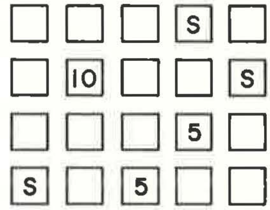


Figure 7. Parking deficiency.

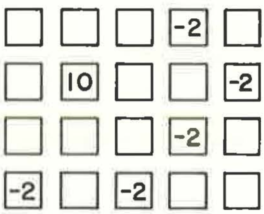


Figure 8. Block rotation.

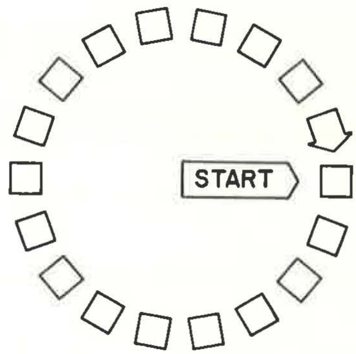


Figure 9. Parking deficiencies within study area.

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

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

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

OTHER APPLICATIONS OF SPACE ALLOCATION

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

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

CONCLUSIONS

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

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

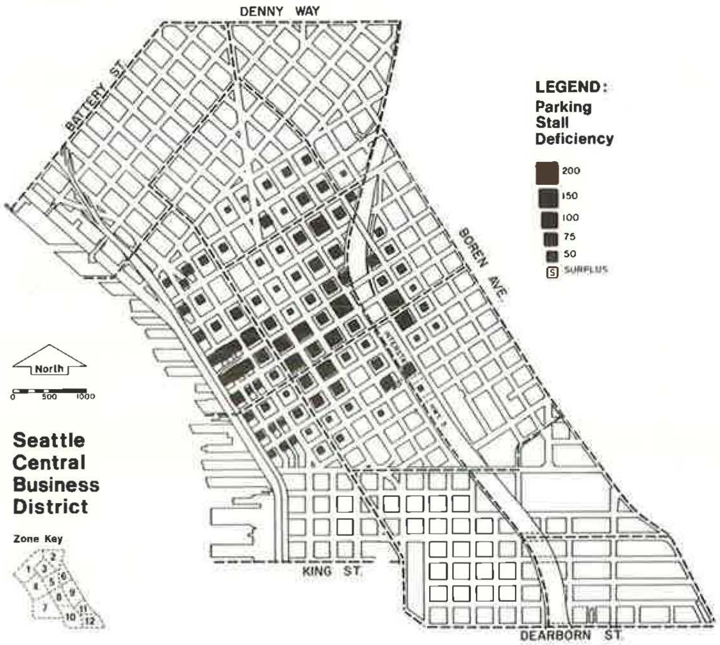


Figure 11. 1975 parking allocation considering limited walking distance.

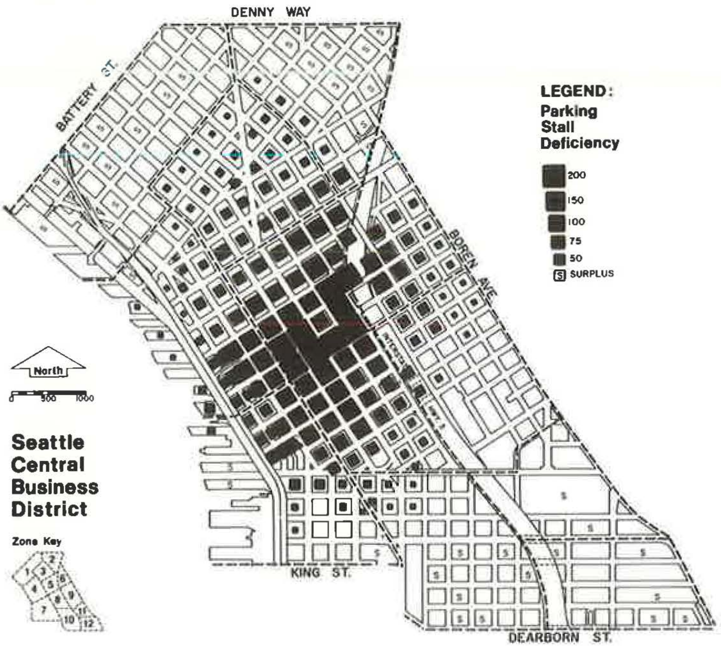
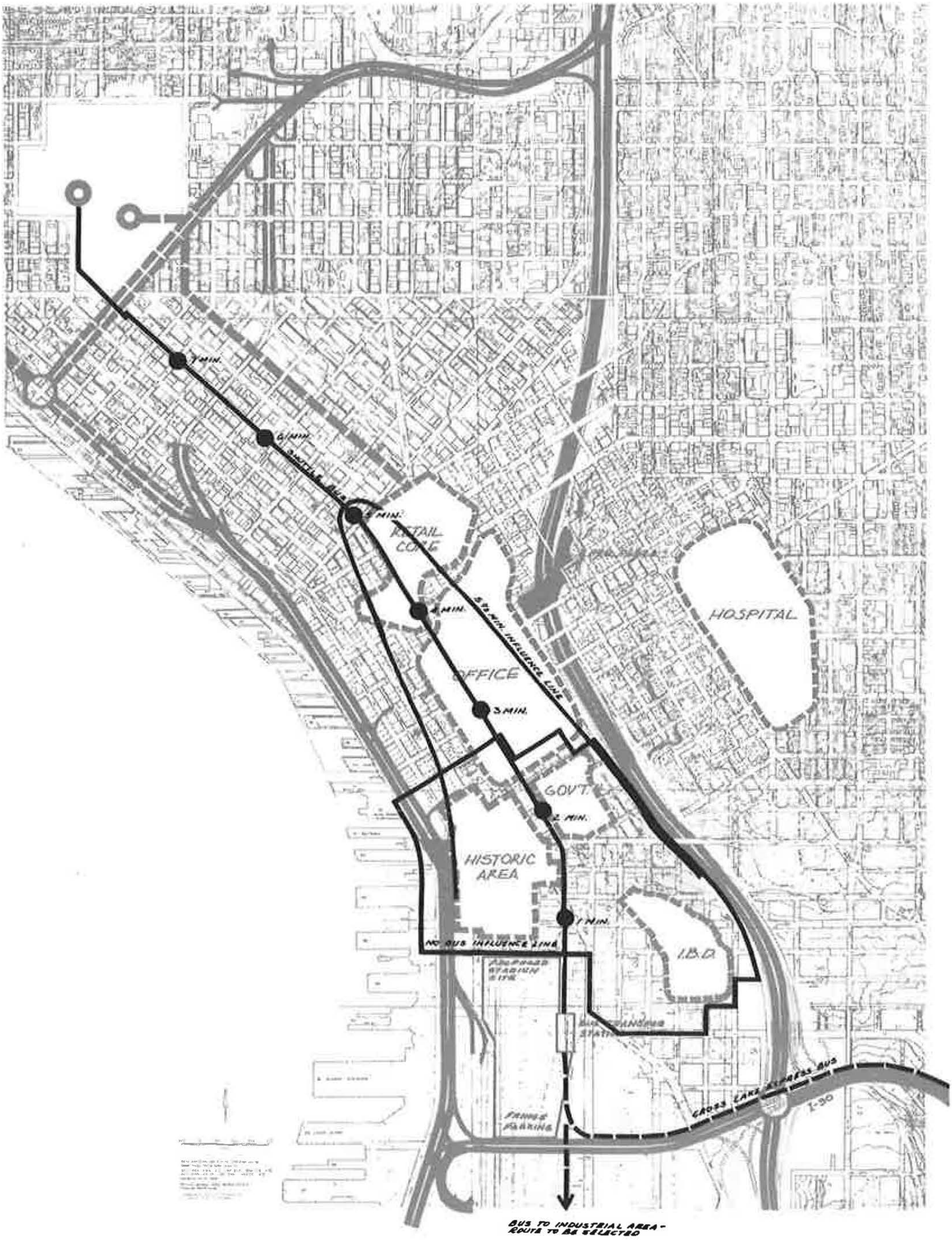


Figure 12. Transportation terminal and shuttle influence area.



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