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VEHICLE BEHAVIOR IN AND AROUND COMPLEX SOURCES AND RELATED COMPLEX SOURCE CHARACTERISTICS VOLUME IV - PARKING FACILITIES

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Water Programs
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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by

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ABSTRACT

The report presents a general methodology for interpreting parameters which characterize a complex source into descriptions of traffic behavior in and around the source. The methodology is implemented in quantitative fashion for the fourth of seven types of complex source, municipal parking facilities; the information generated, relating parking facility parameters to the associated traffic behavior, will now be used by the sponsor to generate guidance for studying the impact of new parking facilities on air quality.

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CONCLUSIONS

1. A general methodology has previously been developed which permits relating parameters descriptive of traffic behavior associated with developments (complex sources) to the available descriptive characteristics of the complexes themselves. These relationships are subsequently to be used by the sponsor to develop guidance for relating the complex's characteristics to air quality.

2. The methodology has been successfully applied to the fourth (parking facilities) of seven types of complexes, with quantitative results presented in this task report.

3. It is now appropriate to proceed to the next type of complex, and apply the methodology appropriately.

SECTION II

RECOMMENDATIONS

It is recommended that, as planned, the project officer employ this methodology to develop guidance for relating the traffic characteristics of parking facilities to typical and peak air pollution concentrations.

SECTION III

INTRODUCTION

INTRODUCTION

OBJECTIVE AND SCOPE

The ability to estimate traffic characteristics for proposed developments and the resulting effects on air quality is an important prerequisite for promulgating State Implementation Plans which adequately address themselves to the maintenance of NAAQS. Prior to estimating the impact of a development (complex source) on air quality, it is necessary that traffic characteristics associated with the source be identified and related to parameters of the development which can be readily identified by the developer a priori. The purpose of this study is to identify traffic characteristics associated with specified varieties of complex sources and to relate these characteristics to readily identifiable parameters of the complexes. The end product of this task will then be used to develop an Air Pollution Technical Document which will provide guidance to enable control agencies to relate readily identifiable characteristics of complex sources to air quality.

The work is being performed in seven sub-tasks. Each sub-task is devoted to examining vehicle behavior and its relationship to readily obtainable parameters associated with a different variety of complex source. The seven categories of complex sources are:

1. Shopping centers (Report No. EF-263)
2. Sports complexes (stadiums) (Report No. EF-265)
3. Amusement parks
4. Major highways
5. Recreational areas (e.g., State and National Parks)
6. Parking lots (e.g., Municipal) (the present report No. EF-266)
7. Airports (Report No. EF-264)

This, the fourth task report, describes the methodology developed, and the analysis and results of its application to parking facilities.

APPROACH

Due to internal constraints, the sponsor has been forced to impose a tight schedule on this project, permitting only two to three weeks for the analysis and reporting of each sub-task. Accordingly, the employment of readily available traffic design information for each type of complex has been suggested as the general approach.

The approach was designed to permit the development of answers to the following questions posed by the sponsor, using available traffic design and behavior data, and available data on parameters of the complex:

1. How much area is allotted or occupied by a single motor vehicle?
2. How much or what percentage of the land occupied by the complex source (and the source's parking facilities) can potentially be occupied by vehicles? What is the usual percentage?
3. What portion of the vehicles within the complex are likely to be running at any given time during a 1-hour period? During an 8-hour period? We are interested in both peak and typical circumstances here.
4. What is the typical and worst case (slowest) vehicle speed over 1-hour and 8-hour periods?
5. How are moving and parked vehicles distributed within the complex property? (e.g., uniformly?)
6. What are the design parameters for each type of complex which are likely to be known by the prospective developer beforehand?
7. Which ones of the design parameters in number 6 can be most successfully related to traffic and emissions generated by the complex? What is the best estimate for relationships between readily obtainable parameters and emissions?
8. What are the relationships of parking "lot" design to parking densities and vehicle circulation? What represents a typical design and/or a design which has highest parking densities, lowest vehicle speeds, longest vehicle operating times?
9. What meteorological conditions (i.e., atmospheric dilutive capacity) are likely to occur during periods of peak use? What use level is likely to occur during periods of worst meteorology (i.e., atmospheric dilutive capacity?)

The technical approach developed and implemented in this report consists of, first, structuring a methodology for describing engine operating modes which considers both the principal modes in automobile operation in and around complexes, and the emission significance of each mode. In our analysis this leads to an important emphasis on engine operating time, with only secondary significance attached to operating speed and distance.

For the complex being studied, an analysis is made of the typical movements of vehicles, and their movements under conditions of congestion, caused by peak traffic loads or by awkward design elements of the complex, or both. This highlights the traffic operational modes which have greatest effect on running times, and assists in seeking out the elements or parameters of the complex which influence these running times most.

The running times in critical modes are usually found to be dependent on the usage rate of the complex as a percent of capacity. In addition, absolute values of usage as a function of time are needed as a direct input for estimating emissions. Therefore, data on usage patterns of the complex by season, day of the week, and hour of the day are collected and related to capacity parameters. The results are used in two important ways:

1. To develop quantitative relationships between running times and various percent-usage parameters; and

2. To provide general usage patterns from which the usage pattern for a complex of interest can be inferred, if no measured data are available.

Basic parametric values are then derived which define typical base line running times and use rates; these are used both to provide a point of departure for the peak case calculations, and as input to the estimate of typical conditions.

For any parameter of capacity (e.g., entrance, exit), resulting increases in running time for each mode are estimated as they may be functions of the exceedance of that capacity. The base running time is then used in conjunction with typical use rates to generate typical combinations of running times and numbers of vehicles running. Finally, peak (1-hour and 8-hour) use rates are compared to capacities in order to calculate, using the above derived functionalities, the associated peak values of number of vehicles running, and running times.

It may often be possible, in addition, to develop and provide qualitative guidelines which can provide further insight into factors which may aggravate or alleviate congestion. These are provided separately from the quantitative relationships.

Finally, the meteorological conditions associated with the occurrence of the peak "(vehicle number) (running time)" values are defined; in addition periods of the most adverse meteorological conditions are determined, and the use rate data examined to determine associated use rates and running times.

The methodology is considered to be completely general, and to apply to all the complex sources of concern here, with the possible exception of the "major highway" case cited in the section titled Objective and Scope. That special case is recognized in the work statement as a potentially unusual one, requiring different treatment in the context of the other six sources.

The remainder of the report describes the implementation of this methodology for parking facilities, and the results obtained.

SECTION IV

CHARACTERISTICS OF PARKING FACILITIES

Literature on parking facilities is extensive, and covers such varied and inclusive areas as trip generation, facility type selection and design, operational considerations, and functional data. Section IX lists some of the voluminous literature on the subject, emphasizing those studies which were most directly applicable to this subtask.

In general terms, parking facilities are classified by size (number of parking spaces), lots (flat) or buildings (garages), location (core or fringe), and whether self-parking or attendant-operated.

It will not be our intent here to cover all facets of all parking facility types, but rather to give a broad picture of most types, and focus on the more significant ones for detailed analyses. While our eventual focus will be on attendant-operated multi-story parking garages, the principles of analysis will be readily seen to be applicable to study of any type of lot; where important differences exist, they are pointed out.

The material which follows is generally extracted and/or adapted from the principal parking documents listed in Section IX on Data Sources, and is intended to set a background stage for the parameter derivation and analysis which follows.

All cities are expanding their downtown parking supply to meet rising off-street parking demands. Even the central business districts of older cities attract an increasing number of visitors by car and are acquiring additional off-street parking.

Downtown's off-street parking demands have increased more rapidly than its daytime population, and reflect the increasing auto-orientation of both urban residents and downtown land uses. Parking indices - required spaces per thousand feet of gross floor area - average five for banks and bus depots; four for libraries, governmental buildings, and grocery stores; three for department stores; nearly two for offices; and less than one for furniture stores and hotels.

Supply and use of downtown parking spaces and characteristics of downtown parkers vary with city size - the more populous the city the higher the percentage of total spaces in garages. In larger cities, a higher proportion of downtown trips are made to or from work; consequently, average durations and walking distances are longer and parking turnover is less. The maximum accumulation of parkers occurs about noon in all cities.

Parking spaces needs depend on downtown's daytime population, the proportion of CBD (Central Business District) trips made by automobile for work and non-work purposes, and public parking policies. Comparisons between parking space supply and "realized" demand (i.e. the number of parkers actually accommodated in the area) show a slight space surplus when the entire central business district is considered. Core areas of most CBD's, however, usually have a deficiency.

Because more downtown travelers will come from auto-oriented suburban areas in future years, downtown parking space demands and space needs will continue to rise in all cities.

Downtown parking space demands car be estimated from a "parking space factor" applied to central business district person trip destinations by auto. for an urbanized population of 100,000, approximately 0.16 spaces are desirable for each CBD destination by auto; when urban population reaches one million, 0.26 spaces are desirable for each destination.

Values associated with convenient access and parking for workers, shoppers, and other components of downtown's daytime population are increasingly recognized. Downtown parking has become a vital community concern - an integral part of the urban transport system.

Cities, therefore, have expanded their downtown space supply in recent years through various combinations of public and private approaches although the vast bulk of all off-street parking in the United States has been developed by private enterprise.

Today, many parking facilities are being constructed to serve department stores, office buildings, and financial institutions. Even in cities with existing or proposed rapid transit, the number of downtown department stores for which convenient parking has been provided is continuing to rise.

The development of off-street parking facilities near outlying radia freeway interchanges and rapid transit or commuter railroad stations in larger urban areas will help afford maximum convenience to users and achieve more efficient use of trunk-line highway and transit routes. Such facilities are particularly desirable in urban regions of more than two million population, where they may equal about one third of the downtown parking supply. Their success requires fast and frequent express transit or highway service, short distance between parking lots and transit stops, easy access to and from major traffic arteries, ample parking capacity for downtown-oriented travelers, and reasonable parking costs. They often could be coordinated with commercial and civic developments at major interchange points.

Parking space requirements for the nation's city centers can be predicted with reasonable accuracy, once the important factors influencing parking demands are identified and assessed. These factors relate closely to city size, downtown intensity and land use, and vehicle ownership. Parking characteristics, patterns, and demands are surprisingly similar among cities in the same population groupings.

This consistent behavior of parkers suggests a systematic approach to the dimensioning of downtown's parking needs. The existing parking space supply provides the logical point of departure. In turn, parking characteristics and habits reflect the socio-economic aspects of downtown parkers, and provide bases for evaluating locations and usage of proposed facilities. Finally, supply-demand comparisons serve to measure parking space deficiencies and needs.

Such information is an outgrowth of downtown parking surveys conducted in many of the nation's cities. These surveys are essential for the intelligent planning of off-street facilities, and include inventories of existing curb, lot, and garage spaces. Motorists are interviewed to obtain information on length of stay, distances walked, trip purposes, average fee paid, orgin of trip, place of parking, and downtown destination. The block-by-block assessment of demands and deficiencies is a straight-forward process, once the survey is completed.

Business trips account for one third of all downtown parkers regardless of city size. In small communities, about one third of all parkers are shoppers as compared with about one tenth in large cities. In the largest urban areas, all-day employee-parkers comprise about 40 per cent of the total and consume about 70 per cent of available "space-hours."

Accompanying this increase in downtown work trips is a decrease in parking turnover (parkers per space per day), a lengthening of average parking duration, and a rise in average walking distances. With outlying shopping areas developing as cities expand, most convenience goods may be purchased close to home. Therefore, more downtown shoppers seek specialized commodities, make less frequent shopping trips, and stay longer.

This is an appropriate point to introduce a fundamental concept in this analysis of parking facilities, which differentiates this complex source from the others being studied (shopping centers, airports, sports arenas, etc.). In those other cases it is possible to define the automotive trips which are generated by the existence of the source itself. In the case of parking facilities per se, the trips are generated by the existence of other trip generation sources in the area (businesses, stores, and entertainment), and any given parking facility provides only a service function along with other similar facilities. As a matter of fact, the subject of trip generation as it relates to the complex of activities which comprise an urban area represents a principal area of study in the field of urban transportation, and is far too large and complex a topic to be condensed here. For parking facilities, the key parameters will be shown to be parking capacity and use rate.

Parking garages may be classified by their general type - above ground, underground, or integral - or by their means of interfloor travel - ramp or elevator-mechanical. Ramp garages permit either self-parking or attendant operation, while mechanical garages require attendants.

Underground Facilities - Underground parking garages are normally developed on sites where property is publicly owned, land is very expensive, and/or certain esthetic values must be preserved. Although ventilation, illumination, and utility relocation costs are high, these facilities are usually developed with little or no land costs, since the surface can be retained for other uses. Where high-rise buildings are located on garage sites, development costs closely conform with those for above-ground multideck structures.

Mechanical Garages - These garages utilize some form of electric or hydraulic elevators and machinery to position cars in stalls. They permit construction of a greater number of levels and adapt to small and irregular properties. An often critical disadvantage, however, is their inability to accommodate heavy peak-hour incoming or outgoing movements.

Ramp Garages - Ramp garages provide either (1) parallel floors with ramp connections at one or more locations, or (2) sloping floors which permit parking on both ramp surfaces and builiding floors (see Figure 1 and 2). Sloping floor garages have continuous grades, and cars are driven in an elongated spiral pattern to upper floors and brought down by the same system of aisles. Some designs feature spiral ramps which facilitate rapid descent from upper floors. Facilities may incorporate one or more levels of underground or basement parking, and take advantage of topography to provide multilevel entrances or exits.

Design Standards

The size, dimension, and over-all weight of modern automobiles and trucks have been key factors in determining off-street parking standards. Throughout the United States, building codes are constantly being revised to accommodate necessary live loads required in final designs for both multideck and roof level parking garages.

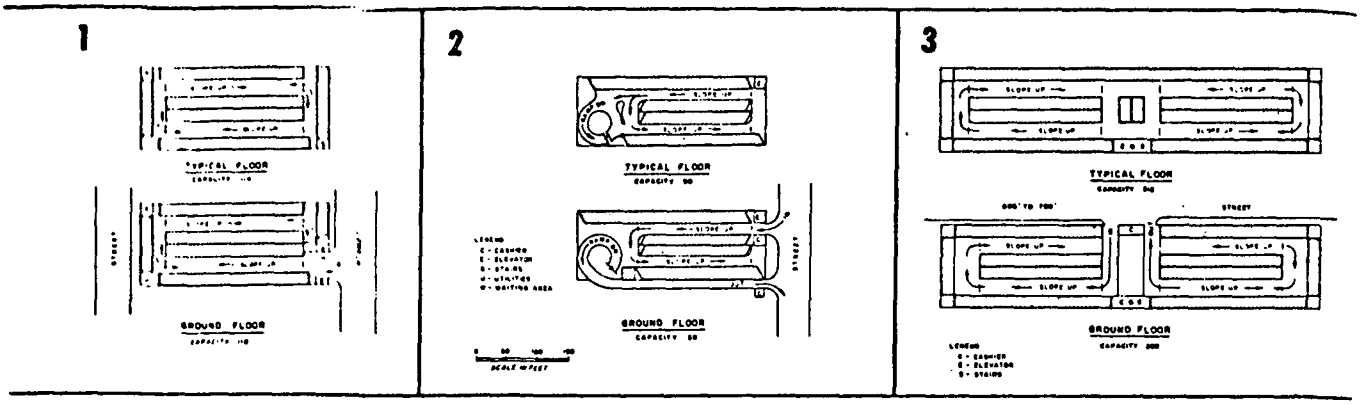

Figure 1. TYPICAL SLOPING FLOOR GARAGE DESIGNS

(1) Conventional Single Sloping Floor; (2) Single Sloping Floor with Express Exit Ramp; and (3) Double Sloping Floor.

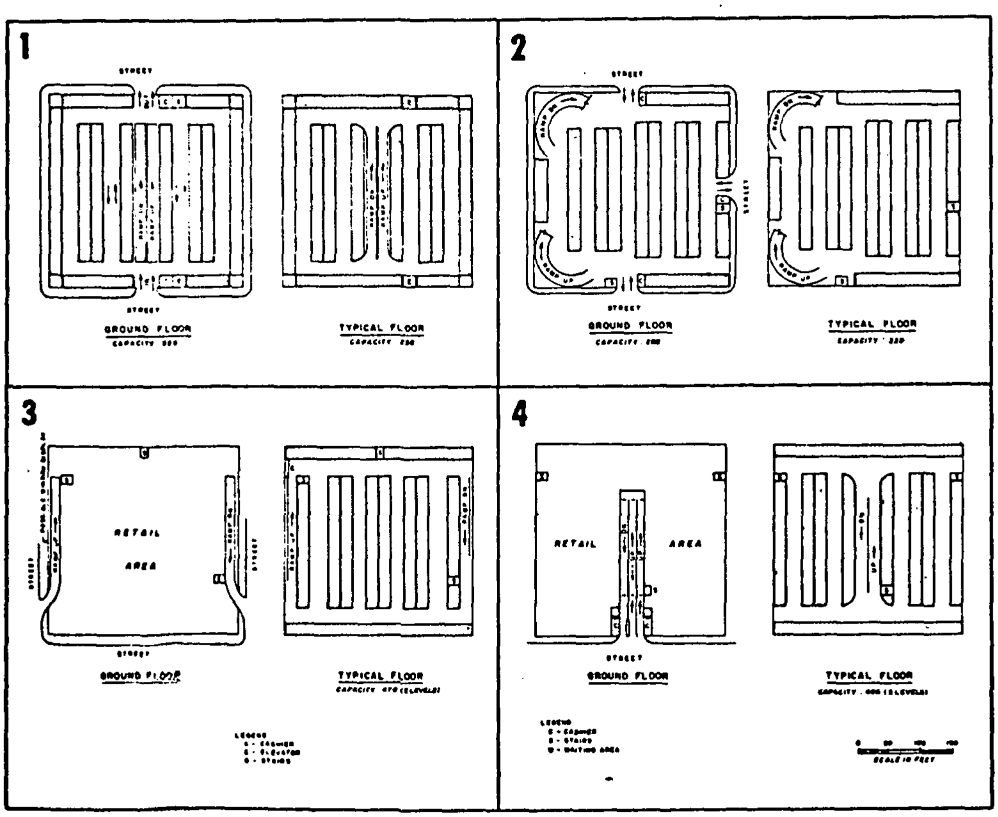

Figure 2. TYPICAL RAMP GARAGE DESIGNS

(1) Straight Ramp; (2) Spiral Ramps; (3) Directional Ramps with Retail area; and (4) Straight Ramps with Retail Area.

Modern design standards for self-parking garages pertaining to access points, unit parking dimensions, column spacings, floor heights, and ramp grades are briefly summarized herein. Only general criteria are presented, for the detailed design of parking garages is a complex study in itself. Attendent-served garages differ slightly in some characteristics, e.g., stall spacings.

Entrance and Exit Lanes - Access points between garages and surrounding streets should avoid back-ups and congestion. At least one outbound lane usually should be provided for each 300 spaces and one inbound lane for every 500 spaces. Lanes should be 12 feet wide except at points of ticket issuance or cashier collection, where they should taper to about 10 feet.

Unit Parking Dimensions - The parking unit (including two parking stalls and an aisle) varies with the "parking angle." Although angle parking is sometimes more readily acceptable to many shoppers and business-trip parkers, greater space economy is usually achieved from 90-degree parking. Suggested unit parking dimensions for 45, 60, and 90-degree parking are given in Table 1.

Minimum stall widths should be 8.5 feet for angle parking, 9 feet for 90-degree parking, and approximately 10 feet for parallel parking. The length of a stall (measured on an axis parallel with the vehicle after it is parked) should be 18 feet. For parallel parking, this length should range from 22 to 24 feet.

Table 1. SUGGESTED UNIT PARKING DIMENSIONS

ANGLE OF PARKING	DIRECTION OF AISLES	UNIT PARKING DIMENSION
45°	One-Way	48 to 53 feet
60°	One-Way	57 to 60 feet
90°	Two-Way	62 to 65 feet

Column Spacing and Clear-Span Construction - Traditionally, columns have been spaced at intervals of three parking spaces. This results in a 28.5-foot spacing, assuming 90-degree parking and 18-inch columns. Because columns are located three feet in from aisles, a parking unit of 62 feet requires an over-all minimum column spacing of 31 by 28.5 feet. For larger columns, this spacing should be increased accordingly to maintain adequate clearances.

The "column-free" or "clear-span concept" has been widely used to provide spans up to approximately 65 feet for 90-degree parking. Various theories and revisions in materials, design concepts, and building methods have aided in making this concept a reality. These include "ultimate strength" design, pre-stressed concrete, post-tensioned construction, and new steel and concrete products with greater tensile and compressive strengths which permit longer spans with less deflection.

Floor Heights - Floor-to-floor heights usually depend on construction methods. A minimum clear height of approximately 7.5 feet will normally dictate a 9.5 to 10-foot floor-to-floor height.

Ramp Grades - A maximum grade of five per cent should be used for sloped portions of sloping floor garages where ramps provide direct access to stalls. Where conventional interfloor ramps are used (either straight or helical), grades should not exceed 10 to 13 per cent; grades of seven to eight per cent are preferable. Parking should not be permitted directly off conventional interfloor ramps.

Lighting Intensity - Garage illumination should approximate three to five foot-candles in parking areas, and 30 foot-candles in cashiering and waiting areas.

A general comment on parking facility design stems from an overall appreciation of a wide variety of comments made in the literature on design and operation: good design and good operating procedures, which are aimed at effective, economical and profitable operation of a facility, all contribute to the type of operation which minimizes running time of automobiles in the facility, and hence pollutant emissions.

SECTION V

PARKING FACILITY PARAMETERS

The basic parameters which concern us here are the type and size (number of spaces) of the facility, its physical characteristics, parking facility use rates, and their variation with season, day of the week and hour of the day.

Parking facility developers have a large amount of general information available on parking demand, parking facility design, and use rate characteristics as functions of the type of district (business, shopping, entertainment). In addition, the literature strongly indicates that almost all urban areas of reasonable size have been subjected to individual studies in some detail, so that the key parameters and data which are treated in this section and in the later Analysis Section should be available to, or derivable by, the developer.

Some parking lots permit self-parking, others have attendant-parking. Attendant-parking is used at most commercially operated lots because it permits more efficient use of space. A commonly used plan of attendant-parking is shown in Figure 3.

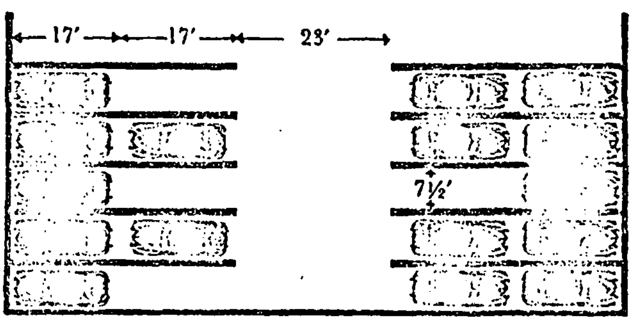

Figure 3. NINETY DEGREE DOUBLE-STALL ATTENDANT-PARKING USES ABOUT 170 SQUARE FEET PER CAR. IT IS OFTEN THE ONLY FEASIBLE PARKING PLAN WHERE LAND COST IS HIGH.

A self-parking lot offers a minimum of inconvenience and a maximum of ease. Although the following principles of parking lot design and operation pertain largely to self- or customer-parking, they apply also to the development of attendant-parking lots.

Parking lot sizes, measured in terms of cars accommodated, generally range from twenty-five to five hundred or more. Lots that accommodate from one hundred to two hundred cars are efficient and practical. A few small lots, strategically sited, will usually serve better than a single large one.

Parking lots of large capacity can cause congestion on bordering streets, especially during peak-traffic hours. If capacity is small and the number of lots large, the potential traffic congestion tends to spread over several areas and thus minimize its effect.

If attendant-operated, moderately-sized lots develop better operational efficiency than large ones. Parking and unparking of cars is accomplished much more rapidly in lots of low capacity. The distance traveled by attendants is shorter, service is faster.

For efficient land use, the self-parking lot should provide three hundred square feet for each car space. Depending on design features, three hundred square feet is an acceptable standard for quickly estimating capacity for possible development of a convenient parking facility. A smaller per-car space area will necessitate narrower stalls and aisles. A higher figure will allow wider stalls and aisles, more maneuvering space, greater safety and convenience, and simpler, faster operation.

To minimize conflicts with street traffic, parking lot exits and entrances should be well-defined and as few in number as practicable to provide for peak-hour operation. They should be at least fifty feet from intersections. When the lot fronts on a heavy-traffic street, separate entrances and exits are best.

Where possible, parking lot openings should be oriented to favor right-hand turns for entering and exiting traffic. Where such design is not possible and there is considerable street traffic, it may be necessary to prohibit left turns into and out of the parking lot.

Reservoir space at entrances and exits is of particular importance in lots on busy traffic streets. Space to accommodate accumulation of incoming cars prevents back-ups into traffic lanes if claim-ticket issuance delay, a confused driver, or other conditions temporarily block entering lanes. Area within the parking lot to accommodate some cars at the exit permits groups of leaving cars to take advantage of gaps in traffic.

Single-lane entrances to parking lots should be at least fourteen feet wide. Exits should be a minimum of ten feet. A combined entrance-exit should be not less than twenty-six feet wide. Al should have suitable curb returns.

The minimum area required to park a car is one hundred and forty-four square feet-a rectangle, eighteen feet long, and eight feet wide. These dimensions are minimum size for self-parking lots. Stalls eight and one-half feet wide are preferable. Most shopping centers use nine-foot widths as a concession to woman shopper and driver. No reduction in the eight-foot stall is recommended because of the trend towarder wider frames and doors.

Comparison of per-car area required in lots using self-parking, and those using attendant-parking shows that driver-parking requires almost twenty-five percent more space. Tables 2 and 3 give this comparison for a number of lots. Table 2 shows the area per car for eleven parking lots that use driver-parking. Area requirements vary from a maximum of three hundred and seven to a minimum of one hundred and ninety-six square feet, with an average of two hundred and forty-three square feet.

Table 3 shows similar information for twenty-four lots employing attendants. The per-car areas vary from two hundred and fifty-one to one hundred and twenty-seven square feet, averaging two hundred square feet per car.

Table 2. AREA PER CAR IN LOTS EMPLOYING CUSTOMER-PARKING

Parking Area in Square feet	Number of Cars	Area per Car in Square Feet
20,000	65	307
30,000	100	300
39,360	137	283
33,550	121	277
32,800	128	256
60,000	251	239
61,224	260	235
14,644	65	225
23,834	110	216
27,780	130	213
44,160	225	196
	Average	243 square feet

Table 3. AREA PER CAR IN LOTS EMPLOYING ATTENDANT-PARKING

Parking Area in Square Feet	Number of Cars	Area per Car in Square Feet
24,645	98	251
25,725	110	234
11,620	50	232
16,200	70	231
17,925	78	229
19,236	85	226
33,575	147	221
29,335	133	220
27,109	128	211
15,500	75	206
32,640	163	200
12,780	65	196
15,225	78	195
13,800	73	189
16,900	85	187
25,320	135	187
17,289	95	182
15,380	86	178
12,000	70	171
9,900	58	170
10,150	60	169
19,792	118	167
8,180	55	148
7,656	60	127
	Average	200 square feet

Varying the angle of parking changes the length of curb and width of aisle required for each car. The parking angle determines the efficiency of lot design because it governs the car space area.

Normally the most efficient use of space is obtained when parking stalls are laid out perpendicular to the aisles. This plan provides more stalls per unit area and permits parking and unparking in either direction. Angled parking yields fewer stalls for a given length of parking curb and permits parking and unparking in one direction only. However, angle parking is more convenient. Drivers find it easier to maneuver in and out of angled stalls; also it is easier to spot empty spaces.

Back-in parking requires narrower aisles than drive-in, but backing in requires more maneuvering ability than drive-in angle parking and takes more time. Most designers are reluctant to use back-in parking in customer-parking facilities because its difficulty may neutralize the driver-convenience that so often motivates parking lot development.

For space-saving, however, back-in parking is often used in lots with parking attendants. Twenty of the twenty-four attendant-operated lots reported in Table 3 use back-in parking. The average area per car of these twenty lots is one hundred and ninety-seven square feet. The average area of the remaining four lots that employ head-in attendant-parking, is two hundred and twenty-four square feet per car.

Lots with angled stalls require continuous aisles because unparking cars are always headed in their original direction. The best aisle-plan for such is a series of continuous one-way aisles that alternate in direction. This requires that the angled stalls be laid out in an interlocked rather than herringbone pattern. See Figure 4. One-way aisles are desirable because they are most economical of space and eliminate head-on and side-swipe accidents.

When ninety-degree parking is used, cars can unpark to the right or left and may use the aisle in either direction. Two-way aisles reduced travel distance-parking and unparking cars can take the most direct route to their destinations. Some lots may necessitate a few dead-end aisles to use all available area. In those cases, ninety-degree parking must be used.

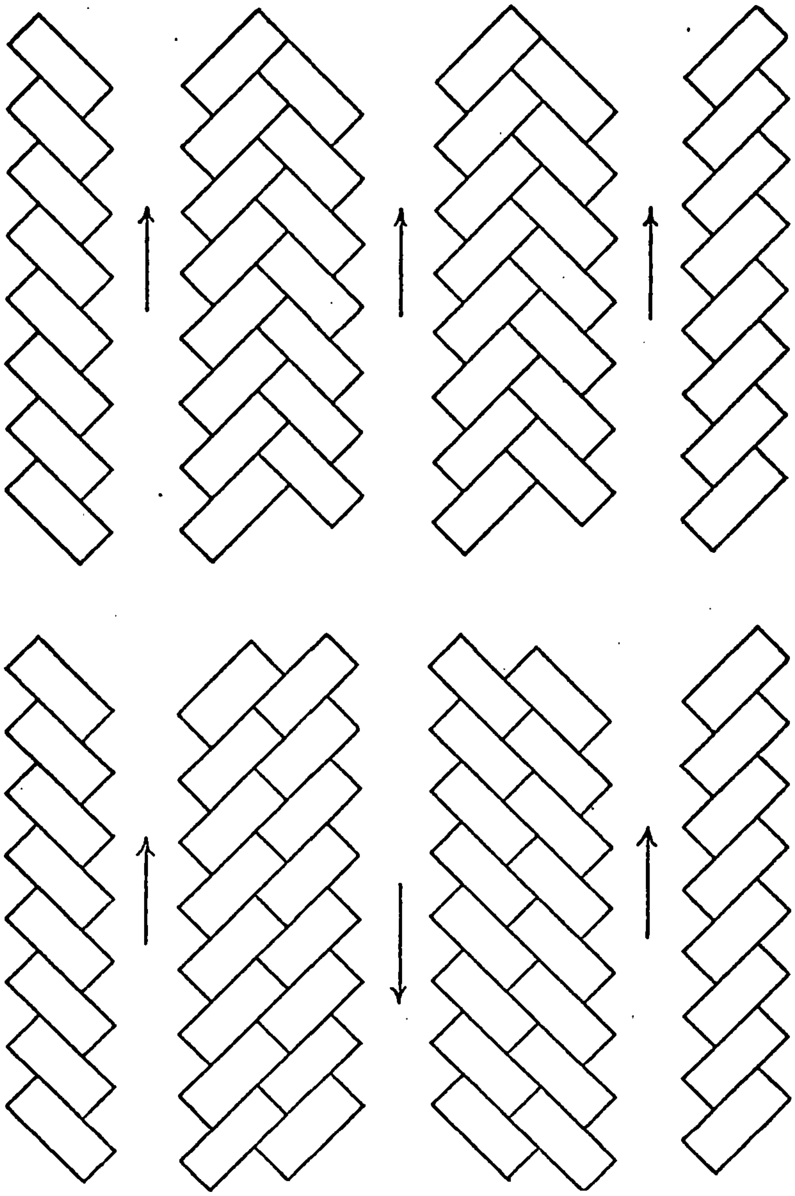

Figure 4. THE 45-DEGREE INTERLOCK LAYOUT ALLOWS DRIVER TO RETURN VIA THE ADJACENT AISLE IF ALL STALLS ARE OCCUPIED IN AN AISLE. STALL-BUMPER LAYOUT IS FAIRLY SIMPLE; EVEN IF THE BUMPERS ARE NOT ESPECIALLY EFFECTIVE, THERE IS LITTLE CHANCE FOR COLLISION DAMAGES.

Circulation aisles within the parking lot should be laid out to reduce travel distance and the number of turns. A poorly designed system of aisles, requiring excessive travel and turning for drivers to find an empty stall, develops confusion and hazard. Directional signs, prominently displayed, can help create orderly and safe inter-lot circulation.

Parking lot aisles should be as wide as practical. Wide aisles permit the entering driver to spot empty stalls quickly and encourage quick, easy parking. The faster an entering car is parked, the less it contributes to congestion.

Parking facility characteristics are given in the following summary material:

Facility Size	
Minimum Capacity	200 cars
Maximum Capacity	500 cars
Maximum Number of Levels	500 cars
Entrances and Exits	
Number	1, with multiple lanes. As far from street intersections as possible, oriented to favor right turns.
Width of Lanes	12 feet
Reservoir Space	
Inbound	
Capacity	Fraction of average peak inbound flow as determined from Figures 5 and 6
Lane WIdth	12 feet
Number of Lanes	4
Outbound	
Lane Width	12 feet
Number of Lanes	at least 2
Ceiling Height	
Main Floor	12 feet
Storage Floors	7 feet, 6 inches
Ramps	
Slope	15 per cent maximum
Width	
Straight Ramps	11 feet
Curved Ramps, inside lane	12 feet
Curved Ramps, outside lane	10 feet, 6 inches
Curvature	32 foot diameter to inside lane edge

Parking Stalls	
Type	
Attendant-parking	back-in
Self-parking	drive-in
Angle of Parking	90 degrees
Length	18 feet
Width	
Attendant-parking	8 feet
Self-parking	6 feet, 6 inches
Access Aisles	
Width	
Attendant-parking	22 feet
Self-parking	24 feet
Curbs	
Height	6 inches, maximum
Width	18 inches, mimimum

The average time required for an attendant to park one car and return to reservoir area for another is the rate of storage or rate of parking. It can be computed from the formula,

$$P = \frac{60N}{T}$$

as shown in Figure 6. P is the parking rate in cars an hour. N is the number of attendants. And T is the average time in minutes required by an attendant to park a car and return to the reservoir area for another.

The best physical arrangement of reservoir space is in the form of lanes leading from the entrance to the ramp. As cars come into the garage, they are directed into successive lanes. Drivers are asked to drive into the garage as far as possible, thus filling the reservoir area one lane at a time. After cars are ticketed, they are moved out of the reservoir area to storage floors in order of arrival, one lane at a time, where several lanes are used.

Appearance of the reservoir area in an attendant-operated garage is important. It, the cashier's booth, and the waiting room are the only parts of the garage that customers see. The reservoir lanes should be kept well-cleaned and properly lighted. They should also provide adequate space for safe pedestrian movement.

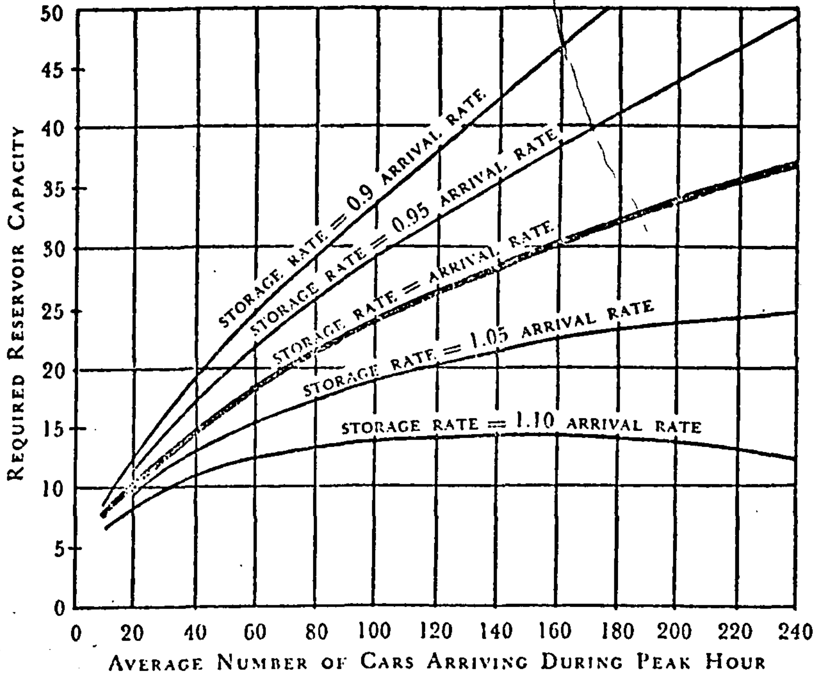

Figure 5. RESERVOIR SPACE

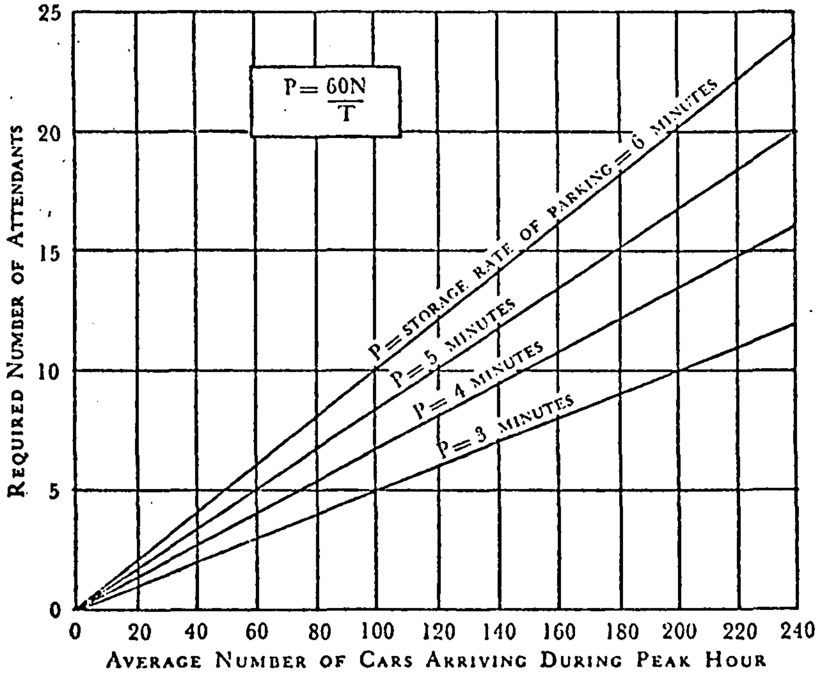

Figure 6. STORAGE RATE

Width of reservoir lanes should be enough to permit customers to get out of their cars comfortably and without danger from moving cars in the adjacent lane. Twelve-foot lanes are recommended. White-painted walkways will serve the dual purpose of directing pedestrians along the safest path and adding to the well-kept appearance.

Layout

Layout sketches comparable to those in Figures 1 and 2 are useful in helping define the running times required for Section VI on Traffic Parameters.

Trip Generation

As indicated in the preceding section, the concept of trip generation is relevant to the activities (business, shopping, entertainment) in the area served by the parking facility of interest (along with others in the area), and not to the facility itself.

Trip generation thus governs the overall flow of traffic into and out of parking facilities, but the specific use rates are as strongly governed by the parking capacity (number of spaces) of the individual facility.

It is important to note that, while parking facilities associated with other complex sources (shopping centers, e.g.) may encounter demands which exceed their capacity, a parking facility per se, subject to any degree of control, will almost never be subject to a capacity exceedance. In fact, it will rarely reach capacity. In other words, whether self-parking or attendant parking is involved, when there is any degree of control attempts to enter will be turned away (as by "sorry-full" signs) whenever occupancy approaches capacity. Thus, where other complexes are responsive to some extent to trip generation concepts, a parking facility's parking capacity is the principal determinant as regards its use rate.

Note that the absolute magnitude of trip generation does play a part, but that it operates on a higher level of consideration - city planners are concerned with trip generation for a broader metropolitan area, consisting of a variety of use purposes (work, shopping, entertainment) and severed by a number of types and sizes of parking facility. Thus, given that a determination is made that general trip generation studies by city planners show sufficient requirements to suggest that need for a parking facility, the techniques of this report can be used to study that facility's traffic characteristics, and fluctuations in overall trip generation will cause corresponding fluctuation in use rate of a given facility.

Spaces and Use Rates

Characteristic space data has been given earlier in this section. Here we will show some general data on typical hourly, daily and seasonal use rates, and some more specific, but still characteristic, data on diurnal variations in use rates.

These data are representative examples of information obtained through analysis of parking garages - on the rate of inbound and outbound movements, peak hours, and variations in use rates by hour, day and month.

The peak use occurs during the christmas shopping period. The remainder of the annual cycle ranges from the low point during mid-winter (usually February) to a secondary peak in late spring (usually April). Variation by month and season is illustrated in Figure 7a.

The cycle by days of the week is seen in Figure 7b, and for an average business-oriented day (little or no evening activity), the hourly variation in use is represented in Figure 7c.

Figures 8, 9, 10, and 11 present data on entrance and exit rates as a function of time of day for, respectively: Figure 8 the overall average weekly pattern by hour of the day; Figure 9 an average midweek day with little or no evening activity; Figure 10 a combination of the usual daytime pattern of workers, visitors and shoppers, with theater traffic in the evening; Figure 7 the usual daytime pattern, with evening shopping.

Example data for times spent in various steps in parking and unparking in an attendant-parking facility are as follows (actions marked with an asterisk are relevant to running times):

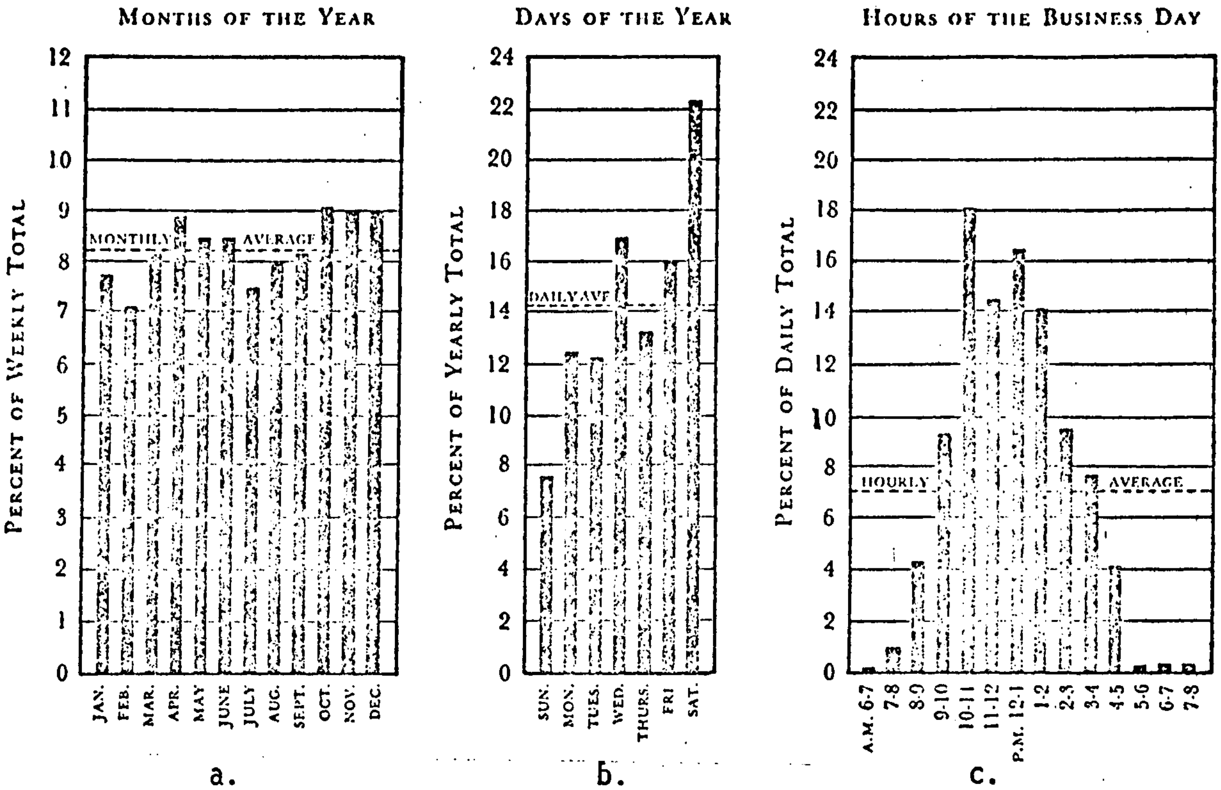

Figure 7. VARIATION IN PARKING GARAGE USE

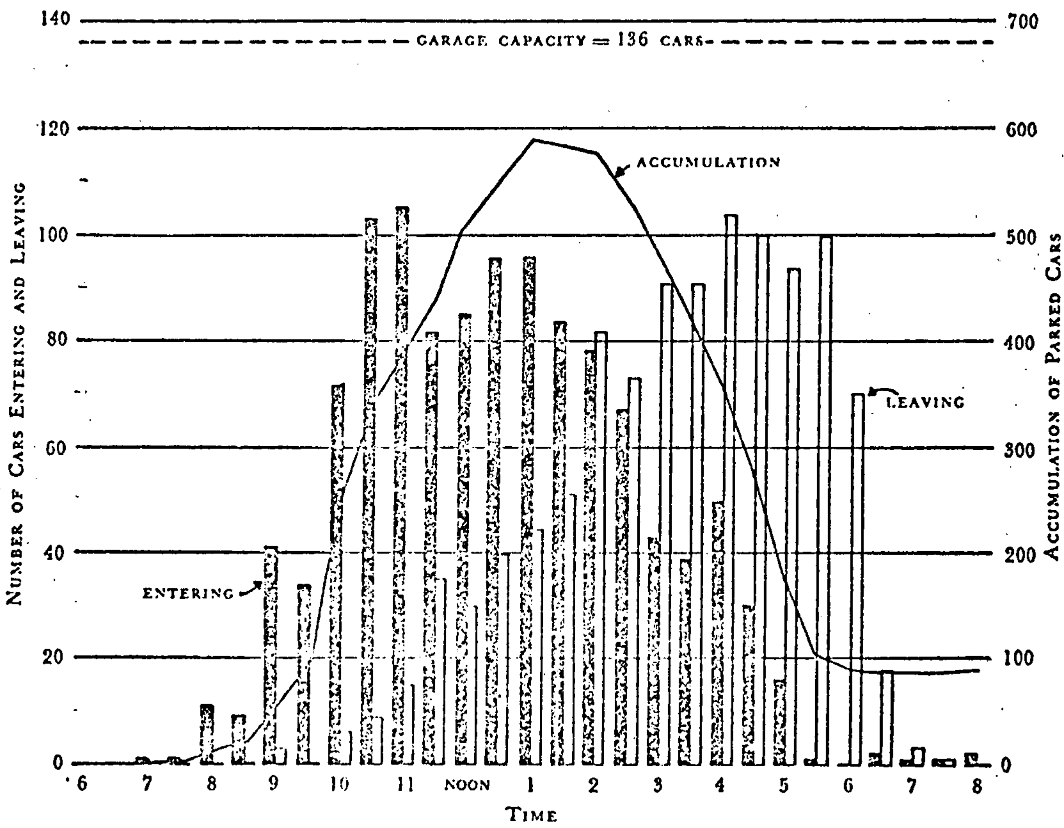

Figure 8. ACCUMULATION OF PARKED CARS FOR A LARGE CUSTOMER-PARKING GARAGE AVERAGED OVER THREE MONTHS.

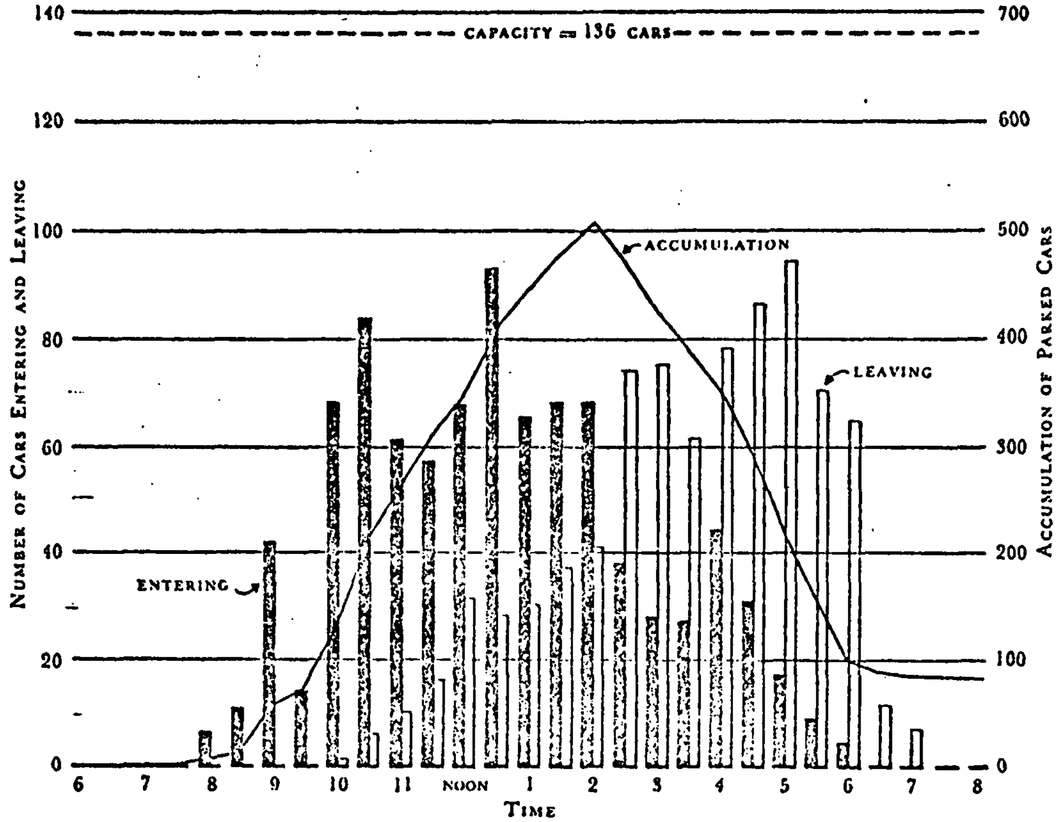

Figure 9. MID-WEEK-DAY'S MOVEMENTS IN A TYPICAL PARKING GARAGE

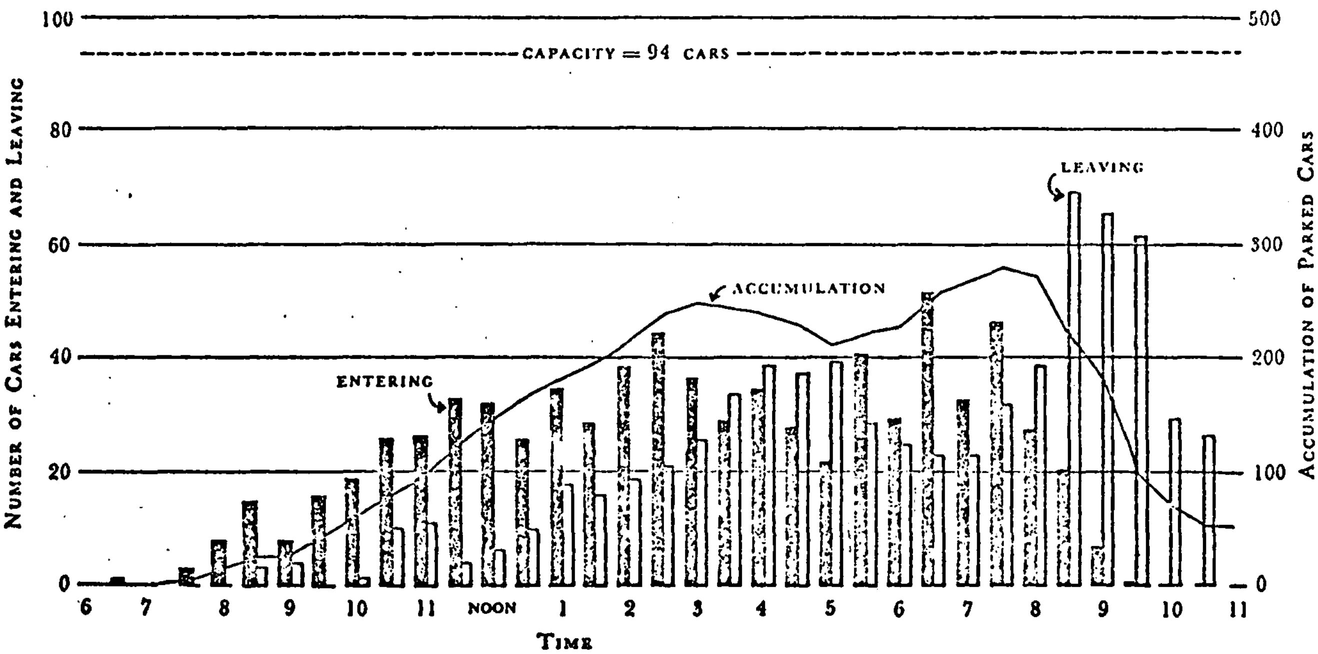

Figure 10. GARAGE IN THREATRE AREA NEAR BUSINESS DISTRICT.

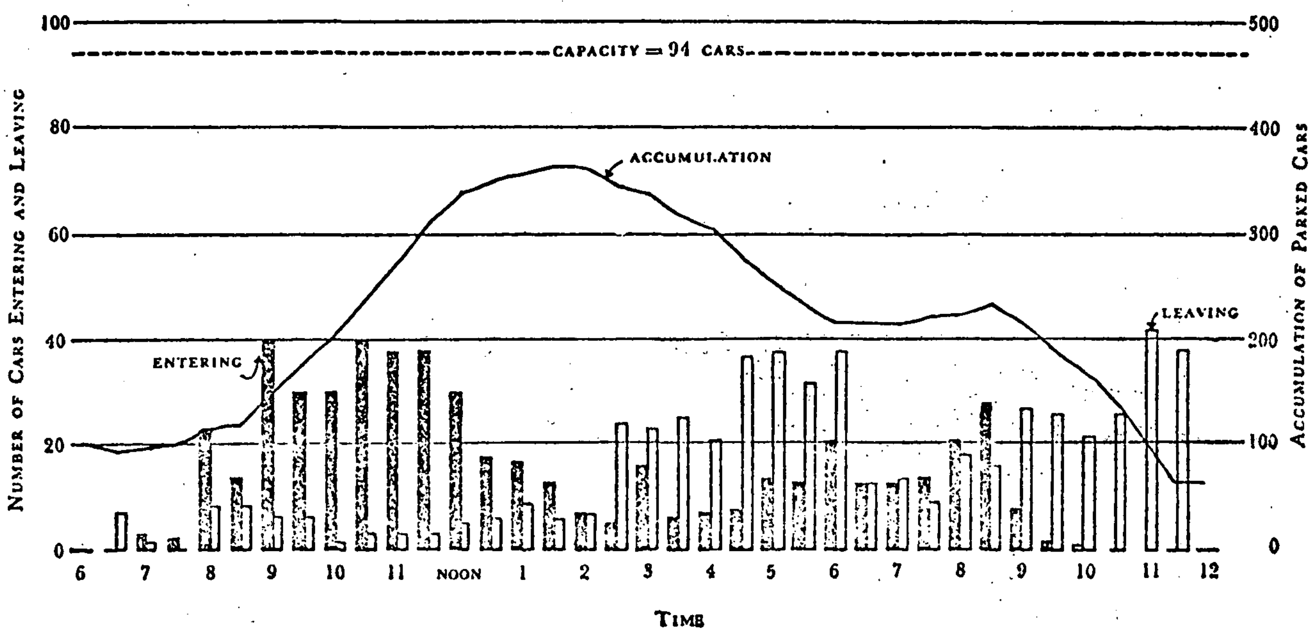

Figure 11. LATE OPENING AND CLOSING STORES

PARKING

Attendant accepts car, gets in and starts it*	8 seconds
Drives on main floor to ramp*	4 seconds
Drives on ramps (average of 2 levels at 12 seconds a level)*	24 seconds
Average delay on ramps*	15 seconds
Drives on storage floor*	6 seconds
Maneuvers into parking stall (back-in)*	18 seconds
Stops car and gets out*	6 seconds
Notes location of car on office portion of identification ticket	31 seconds
Walks to elevator (plus 6 seconds average wait for elevator)	45 seconds
Rides to main floor in elevator	20 seconds
Walks to Cashier's booth to deliver identification ticket	8 seconds
	185 seconds

UNPARKING

Attendant accepts identification ticket at Cashier's booth	5 seconds
Walks to elevator	8 seconds
Rides to storage floor in elevator	20 seconds
Walks to parking stall	45 seconds
Checks identification of car	20 seconds
Gets in car and starts it*	8 seconds
Unparks and drives on storage floor*	8 seconds
Drives on ramps*	24 seconds
Average delay on ramps*	15 seconds
Drives on main floor*	6 seconds
Stops car in delivery area and gets out*	6 seconds
Accepts customer's ticket and delivers car to him*	10 seconds
	175 seconds

The data presented in this section are employed subsequently in the sections on Traffic Parameters, on Analysis, and Results.

SECTION VI

TRAFFIC PARAMETERS, VALUES AND DERIVATIONS

CONCEPT OF EMISSIONS PER UNIT TIME

In municipal parking facilities, maximum vehicle speeds rarely exceed 10 mph, and average speeds are much lower. The usual procedure for estimating motor vehicle emissions as a function of vehicle speed is not very accurate at these low speeds due to:

a. Difficulty in estimating average operating speed; and

b. Variation in observed emission rates per unit distance travelled with slight change in average operating speed.

For parking facilities, analysis shows that traffic operations and their related emissions are better considered in units of time (grams/minutes) rather than units of distance (grams/mile), for the following reasons:

1. The variations in emission per unit time at different speeds are relatively significant at the lowest speeds;* and

2. Traffic movement in a parking facility can be described more accurately and more easily in terms of minutes of running time, than in terms of average speed, particularly when engine idling can predominate during congested periods.

Values for atuomotive pollutant emissions in grams/minute at idle are available from A Study of Emission from Light Duty Vehicles in Six Cities.[10] They are summarized in Table 4. These test data compare well with emission factors calculated from the current edition of AP-42,[12] when converted to grams/minute at various speeds and then extrapolated to zero speed.

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*Less than 50 percent increase from idle to 15 mph.

Table 4. VEHICLE EXHAUST EMISSIONS AT IDLE IN GRAMS PER MINUTE*

Pollutant	Emissions, gm/min
Carbon monoxide	16.19
Hydrocarbons	1.34
Oxides of Nitrogen	0.11

*These values do not include emissions due to the cold start of engines or to evaporation of gasoline at the end of a trip ("hot soak"). If subsequent investigation of the relative magnitude of these emissions, compare to the totals generated by the methodology of this report, indicates that they are significant, appropriate values for each cold start and hot soak can be inserted as the total emissions for the start and stop modes, respectively. Since data for cold start and hot soak emissions would be reported per occurrence, there is no need to determine an associated running time or emission period for the modes.

In applying the recommended procedure of emission estimation, total emissions from the parking facility at any time would be the product of the number of vehicles, times average vehicle running time, times the appropriate emission factor from Table 4.

$E_{Total} = (V)(RT)(EF)$, where

V = Traffic volume during period of concern

RT = Average running time, minutes

EF = Emission factor, grams/minute.

Operational Modes in Parking Facilities

For purposes of analysis, traffic movement in a parking facility has been divided into eight characteristic operational modes. These are summarized below.

Approach (A) - The time or distance along the immediate access road that total traffic movement is strongly affected by the vehicles entering and exiting the parking facility. Because, as discussed in Sections IV and V, trip generation is caused by the urban activities and not the parking facility, we suggest a small, nominal value for this, of the order of the average time to traverse a city block.

Entrance (I) - Movement through the entranceway, including waiting time in a entrance queue.

Movement in (MI) - Driving time (or distance) from the entranceway to the average parking space (third floor in a five-floor garage, e.g.).

Stop (S) - Parking of the vehicle and shutoff of the engine.

Start (St) - Starting of the engine and egress from the parking space.

Movement out (MO) - Driving time or distance from the parking space to the exitway.

Exit (E) - Movement through the exitway, including waiting time in a exit queue.

Departure (D) - The time or distance along the immediate access road that movement continues to be influenced by traffic from the parking facility. See the note above on the Approach mode.

The average running time in each of these modes can be quantified for a specific parking facility as a function of its physical dimensions, traffic control devices, traffic volume, and type of operation.

Base Running Time

There is an average minimum vehicle running time for each parking facility that is associated with periods of low or zero traffic congestion. This concept of a minimum or base running time is important because it usually is the most common (typical) operating condition at the parking facility, and because at most facilities it is expected to be exceeded only during periods of relatively high entrance or exit volumes. The base running time can usually be determined from a plan of the facility, with additional knowledge of any traffic control devices, probable driving pattersn, and operational customs.

Base running times for two example parking facilities have been constructed, both by time measurement during typical driving cycles, and by estimates based on dimensions of the facilities, entrance/exit configurations, and expected driving patterns. Total base running times and average times in each operational mode are shown in Table 5. Certain of the self-parking times are longer because of idling periods which exist during self-parking, but not in the attendant case, since the engines are shut off while cars are stopped.

Table 5. BASE RUNNING TIMES BY OPERATING MODE AT TWO EXAMPLE PARKING GARAGES

Operational Mode	Base Running Time, Minutes	
	Attendant-Operated	Self-Parking
Approach	0.5	0.5
Entrance	0.2	0.3
Movement in	0.8	1.0
Stop	0.3	0.3
Start	0.1	0.1
Movement out	0.9	1.0
Exit	0.1	0.5
Departure	0.5	0.5
Total BRT	3.4	4.2

Relationship Between Running Time and Traffic Volume

As traffic volume in or out increases, running times may become longer due to congestion. Some of the constraints to movement that contribute to the longer running times are:

- Queues at entrances and/or exits due to approaching entrance/exit capacity
- Queues created as vehicles attempt to exit onto uncontrolled access roads
- Increased time required to find space as parking space capacity is approached techniques for estimating increases in running times are discussed in the Analysis section.

Identification of Critical Modes for Parking Facilities

The following discussion is more relevant to self-parking facilities than to attendant-parking, because of the fact that attendant operation involves shut-off of engines while standing in the entrance mode, and no idling at exit for payment.

Examination of the eight operational modes that were identified indicates that for parking facilities, running times in some modes are relatively constant, but that times in others may increase from the base running time during peak usage conditions. For parking facilities, the three modes whose times may be most affected by traffic congestion, in order of decreasing impact, are:

1. Exit
2. Movement to a parking space
3. Entrance

Exit and entrance times are functions of the egress and ingress capacities, respectively, of the individual parking facility exit/entrance ways. As these capacities are approached or exceeded, running times in the two modes increase. Waiting times in the resulting queues become the primary factors in determining total running times. However, because of diurnal variations in the number of vehicles entering and leaving shopping centers, egress and ingress capacities generally are not exceeded simultaneously.

Movement time into a parking space, the remaining critical mode, is a function of the number of free parking spaces. The time in this mode increases somewhat with parking facility usage, until the number of parked cars approaches the capacity of the facilities. Then, in controlled facilities, no further entrance is permitted.

The parameters developed above are analyzed further with the parking facility parameters in the Analysis section, and findings employed in the Methodology section.

SECTION VII

ANALYSIS

In this section we make the necessary interpretation and inferences for converting the data of the section titled Parking Facility Parameters into the relationships needed for input to the methodology of the section titled Results. In the section titled Traffic Parameters, Values and Derivations, we identified the entrance/exit capacities, and the parking capacities, as the parking parameters which could, under conditions of exceedance, increase either, or both, the vehicle running times and the number of vehicles running.

We require information on parking capacity, entrance/exit capacities, use rates, and running times.

PARKING SPACE CAPACITY

Parking capacities are fixed input values for any specified facility, and are given in Section V as ranging from 200 to 500 and up. It is important to emphasize here that controlled parking facilities almost never let parking reach capacity, and that of the order of 80%, or possibly on rare occasions 90%, of the capacity is as much as is ever reached.

ENTRANCE/EXIT CAPACITY

Characteristic entrance capacities are derivable by considering the factors given in Section V for attendant-parking. Characteristic values for lots in the 500 to 700-space size are in range of 100 to 150 cars per hour. They may be increased during peak periods by increasing the number of attendants, as by overlapping shifts, for example. Generally the operation will be planned to minimize the posibility of any exceedance of entrance/exit capacity, essentially by adjusting the capacity to meet the demand rate, or alternatively by adjusting the demand rate (i.e., stopping attempted entrances for a period) to match the capacity.

Use rates are exemplified by the data given in Section V. The number of vehicles running during any given 1-hour or 8-hour period is equal to the sum of the vehicle entrances and vehicle exits during that period. If the entrance times and exit times approximate each other, then the total figure may be used; otherwise the "in" mode time must be paired with the numbering of entering cars, and the "out" mode with the exiting cars. Example totals from the figures of Section V are given in Table 6.

The peak monthly use rate occurs in December (9% compared to the 8.3% monthly average use rate); the day of the week peak is on Saturday (22% compared to the 14% average); and the peak one hour period may occur at various times, depending on the type of neighborhood. Where shopping governs, the peak usually occurs early on Saturday afternoon. If shopping and entertainment are combined, then the peak may shift into late afternoon or early evening. The peak 8-hour period will generally run from around 10:00a.m. to 6:p.m.

ENTRANCE/EXIT CAPACITY EXCEEDANCE

While it has been pointed out that such exceedances will rarely occur in attendant-parking facilities, they may occur in self-parking facilities. First, running times in queues at under capacity may be calculated by the equation given in previous reports in this series:

$$RT = b\left(\frac{a}{1-a}\right) \text{, where}$$

$$a = \text{utilization factor} = \frac{\text{traffic flow, veh/unit time}}{\text{gate capacity, veh/unit time}}$$

b = average service time, min/veh (inverse of gate capacity)

For those periods when flow exceeds capacity, the queue continues to build during each time increment by the amount that traffic volume exceeds capacity. Average running time for this (unlikely) situation can be estimated by a stepwise procedure as given in the first report in this series, EF-262 on Shopping Centers.

Table 6. TOTAL (VEHICLES ENTERING PLUS VEHICLES EXITING) USE RATES FOR TWO SIZES OF PARKING GARAGE FOR DIFFERING CONDITIONS

	Large Size (approx. 700 spaces)		Medium Size (approx. 500 spaces)	
Half-Hour Period	Average Weekly Pattern	Midweek Day	Business/ Theater	Evening Shopping
6:00-6:30a.	0	0	0	0
6:30-7:00a.	0	0	2	7
7:00-7:30a.	2	0	0	4
7:30-8:00a.	2	0	3	2
8:00-8:30a.	12	7	8	32
8:30-9:00a.	9	13	19	23
9:00-9:30a.	46	43	13	47
9:30-10:00a.	34	15	17	37
10:00-10:30a.	78	70	20	31
10:30-11:00a.	112	90	37	43
11:00-11:30a.	120	72	39	40
11:30-12:00p.	118	73	38	40
12:00-12:30p.	115	100	38	35
12:30-1:00p.	136	122	37	24
1:00-1:30p.	141	95	52	25
1:30-2:00p.	135	106	43	18
2:00-2:30p.	160	110	56	14
2:30-3:00p.	140	110	66	29
3:00-3:30p.	135	103	64	38
3:30-4:00p.	130	89	63	31
4:00-4:30p.	154	122	73	28
4:30-5:00p.	130	118	65	46
5:00-5:30p.	109	112	60	51
5:30-6:00p.	102	78	70	44
6:00-6:30p.	70	70	57	58
6:30-7:00p.	20	12	75	24
7:00-7:30p.	6	7	55	25
7:30-8:00p.	4	0	80	22
8:00-8:30p.	4	0	66	37
8:30-9:00p.	0	0	90	43
9:00-9:30p.	0	0	74	35
9:30-10:00p.	0	0	63	27
10:00-10:30p.	0	0	27	26
10:30-11:00p.	0	0	0	42
11:00-11:30p.	0	0	0	38
11:30-12:00a.	0	0	0	0

SECTION VIII

RESULTS

THE METHODOLOGY

In general terms, the methodology proceeds as described in the first paragraph which follows. We wish to emphasize that this description is of the technique, shown in schematically in Figure 12, in its most general form, and as such will provide the starting for each of the complexes to be studied in subsequent tasks. Differences in implementation are expected to arise in the case of each complex.

Starting from the physical, geographic, and demographic characteristics of the complex, we use the concepts of operational traffic modes to generate best estimates of typical and peak trip generation rates, and of base running times for cars associated with the complex. We also define the parameters of the complex which significantly and adversely impact traffic behavior. The typical trip rates and base running times provide the data for typical conditions for the required time periods. Quantitative relationships are defined or estimated for the controlling parameters of the complex and of the affected traffic modes, and these in turn are superimposed on the base running times to generate peak running times. The peak running times are then associated with peak trip generation rates to create the peak information for the required time periods. We next see how this generality becomes more specific for a given type of complex.

In the case of parking facilities, trip generation is not relevant, as discussed in V and VII; as shown in Figure 13, the methodology proceeds from basic information about a given parking facility (see the section titled "Parking Facility Parameters"), via traffic behavior data (see the section titled "Traffic Parameters, Values and Derivations"), and

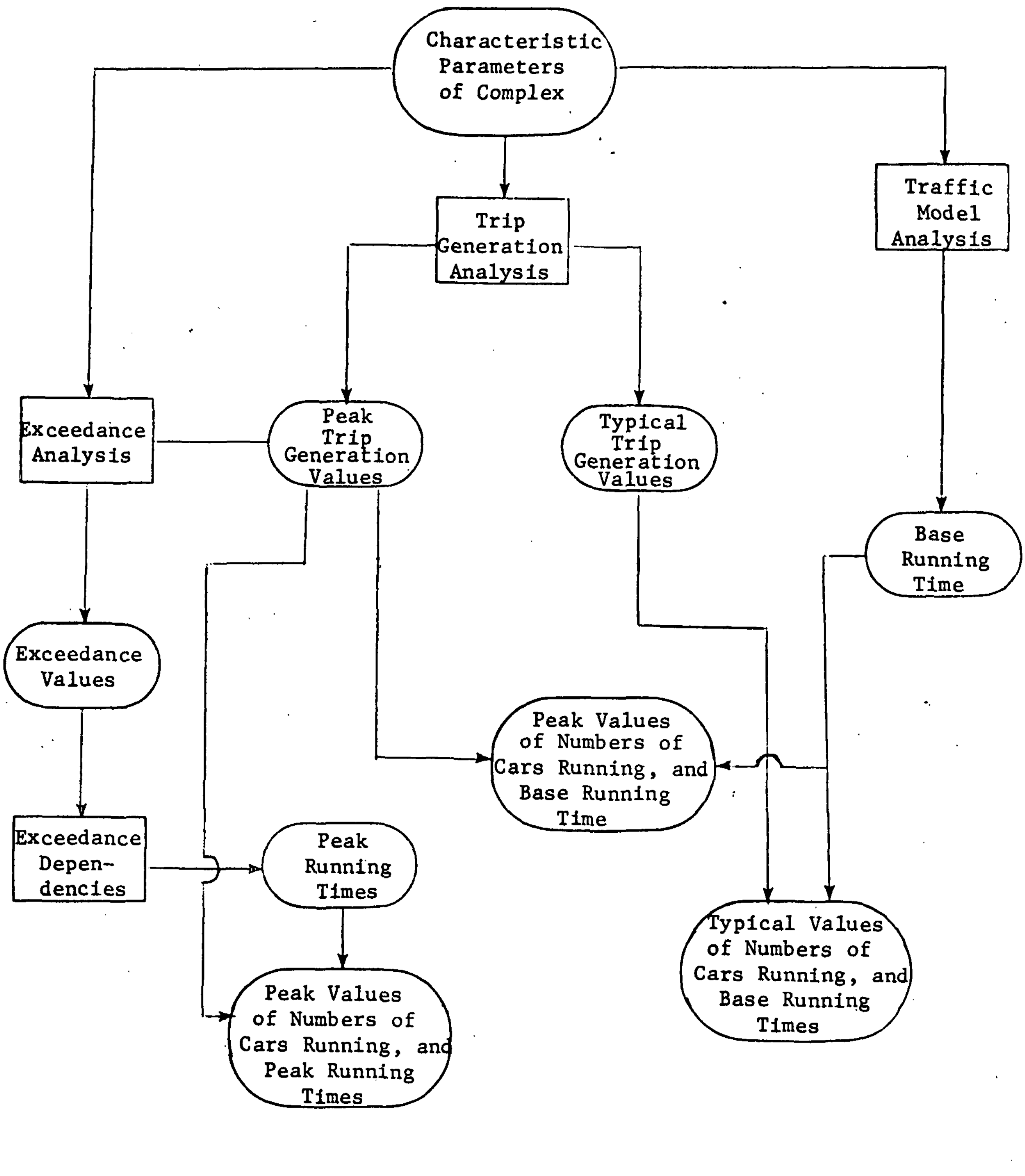

Figure 12. GENERALIZED METHODOLOGY

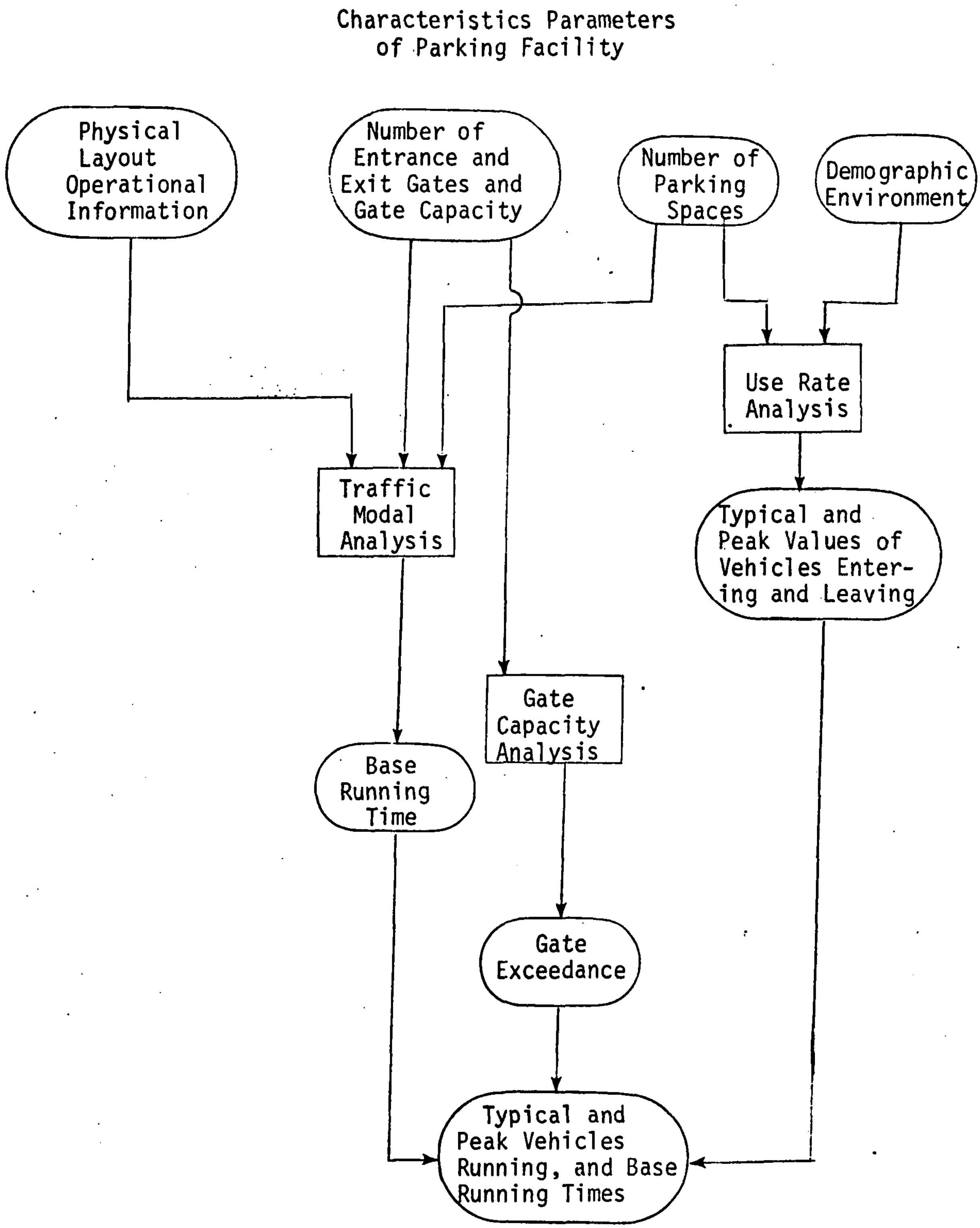

Figure 13. GENERALIZED METHODOLOGY APPLIED TO PARKING FACILITIES

typical use rate data (see the section titled "Use Rates"), to generate estimates of typical numbers of vehicles running and associated running times for 1-hour and 8-hour periods; these are two of the required end products of the task. For the peak case, peak use rates are estimated (see the section titled "Use Rates") and then used to obtain exceedance estimates for gate capacity the principal controlling parameter (see the sections titled "Entrance/Exit Capacity and Capacity Exceedance") these latter generate the associated increases in both numbers of vehicles running, and vehicle running times. These increases are combined with the base numbers described above, to provide the other two major products, the peak running times and vehicle numbers for one-hour and eight-hour periods.

The specifics of the procedure are presented in the following paragraphs. It is first important to note that the concept of trip generation, which has been fundamental to the analysis of the other Complex sources in this series of reports, is not directly relevant in the case of an individual parking facility, but rather to a demographic area, as discussed in Sections V and VII. Second, each facility will be unique in its detailed design, and in its use context, so no rules of thumb are considered feasible. Accordingly, we define our parking facility in terms of physical layout (including reservoir* specifications and other such details), plan of operation (number of attendants and schedule, e.g.,), number of entrance and exit gates and their capacity, number of parking spaces, and the demographic environment and expected uses (business, shopping, entertainment) and their distribution in time. By analyses like those exemplified in Section V and VII, we generate characteristic and peak inflow and outflow rates. We maintain these separately until we determine whether the typical and peak running times show significant differences between total movement-in times and total movement-out times. If they are different, we maintain the separation; otherwise thay may be combined and used as total running times. A traffic modal analysis (Section VI and VII) provides base running times, separable by movement-in and movement-out if necessary. If gate capacities are indicated to be exceeded at peak times, then the gate exceedance analysis of Section VII is applied to determine the corresponding increases in running times and numbers of vehicles running.

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* Reservoirs (space reserved at entrances and exits for waiting cars) assist in determining entrance/exit capacities.

The resulting increases in times are added to the base running time to give peak running time; the peak use rates will, as for the typical case, give the base peak number of vehicles running, to which we add any additional vehicles running because of entrance/exit exceedance.

We thus have the four basic numbers required for each of the two time periods for input to the emission rate calculations: typical and peak numbers of vehicles running during one-hour and eight-hour periods, and their associated typical and peak values of vehicle running times.

GEOGRAPHIC DISTRIBUTION

Running times, and hence emissions, from a parking facility can usually be considered as being distributed fairly uniformly through the facility area during typical operating periods (base running times). For most analyses, an assumption of a geographically uniform emission density is thus sufficiently accurate.

Peak traffic conditions may result in either the entrance or exit capacities being exceeded, or both. If gate capacity is exceeded, a substantial part of the total running time and emissions become concentrated at the entrance/exit ways.

For parking garages, the proposed construction should be studied for its ventilation characteristics. Open construction means the emissions should emerge uniformly around the building edges, but distributed at different levels, depending on the number of floors. Closed construction should be examined for the principal emission sites.

METEOROLOGICAL ASPECTS

The meteorological characteristics which most importantly affect atmospheric dilutive capacity are mixing height, wind speed and atmospheric stability. A convenient summary of mixing height and wind speed characteristics which affect air pollution potential is given in the Office of Air Programs Publication No. AP-101 (Holzworth 1972). Atmospheric stability may be determined in terms of cloud cover, solar radiation and wind speed by a method proposed by Pasquill and shown in Table 7. For ground level, and

Table 7. KEY TO STABILITY CATEGORIES (after Turner 1970)

Surface Wind Speed (at 10 m), m sec^{-1}	Day			Night	
	Incoming Solar Radiation			Thinly Overcast or $\geq$ 4/8 Low Cloud	$\leq$ 3/8 Cloud
	Strong	Moderate	Slight		
<2	A	A-B	B		
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	C	D	D	D

The neutral class, D, should be assumed for overcast conditions during day or night.

NOTE: Class A is the most unstable, class F the most stable class. Night refers to the period from 1-hour before sunset to 1-hour after sunrise. Note that the neutral class, D, can be assumed for overcast conditions during day or night, regardless of wind speed.

"Strong" incoming solar radiation corresponds to a solar altitude greater than 60° with clear skies; "slight" insolation corresponds to a solar altitude from 15° to 35° with clear skies. Table 170, Solar Altitude and Azimuth, in the Smithsonian Meteorological Tables (List 1951) can be used in determining the solar altitude. Cloudiness will decrease incoming solar radiation and should be considered along with solar altitude in determining solar radiation. Incoming radiation that would be strong with clear skies can be expected to be reduced to moderate with broken (5/8 to 7/8 cloud cover) middle clouds and to slight with broken low clouds.

near ground level, sources, such as automobiles in parking facilities, the ground level concentrations, both in the vicinity and downwind of the sources will be inversely proportional to wind speed and mixing height and directly proportional to atmospheric stability (i.e., the more stable the atmosphere, the higher the concentration).

The season of peak use of parking facilities is cited as the shopping days preceding Christmas, with the highest day usually being the Saturday before Christmas. The peak hour of use on any given Saturday is generally 3 to 4p.m. The peak 8-hour period is generally 10a.m. to 6p.m. A Secondary 1-hour peak use period may occur during weekday evening hours at various times between 7 and 9p.m.

Since the pre-Christmas period occurs during the transition from autumn to winter, the meteorological conditions which characterize the period of peak use of shopping centers should be estimated by interpolating between autumn and winter means. Mean afternoon wind speeds and mixing heights for autumn and winter, for locations in the contiguous United States, are shown in Figures 14 through 17, taken from Holzworth, 1972. For most locations the diurnal variation in mean wind speeds is small, and the values shown for afternoon means may also be used for the secondary evening peak use period. Also, since the transition to a strong restraining nighttime mixing height has generally not occurred by early evening hours, the afternoon mixing height can serve as a useful estimate for the evening peak use period. For the Saturday afternoon peak, atmospheric stability classes B, C and D may occur with classes C and D being the most prevalent. During the evening hour peak, classes D and E may occur. Atmospheric dispersion calculations reported by Turner (1970) for stability classes D and E show that ground level concentrations from ground level sources will generally be twice as high for class E as for class D. Therefore, the secondary evening peak use period, which is associated with more stable conditions, is the more critical period for air quality considerations from the viewpoint of joint consideration of peak use and adverse meteorology.

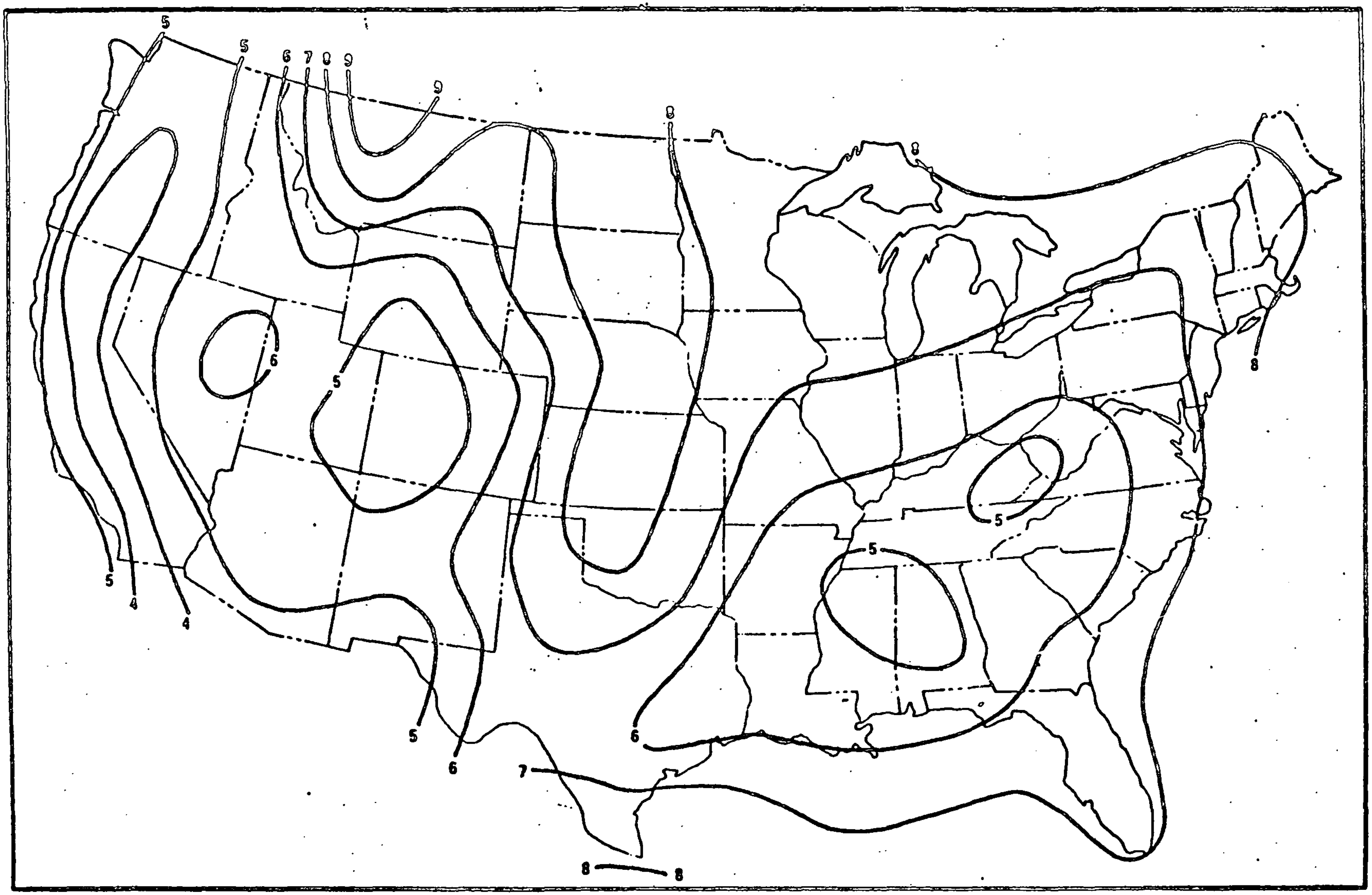

Figure 14. ISOPLETHS (m sec^{-1}) OF MEAN AUTUMN WIND SPEED AVERAGED THROUGH THE AFTERNOON MIXING LAYER

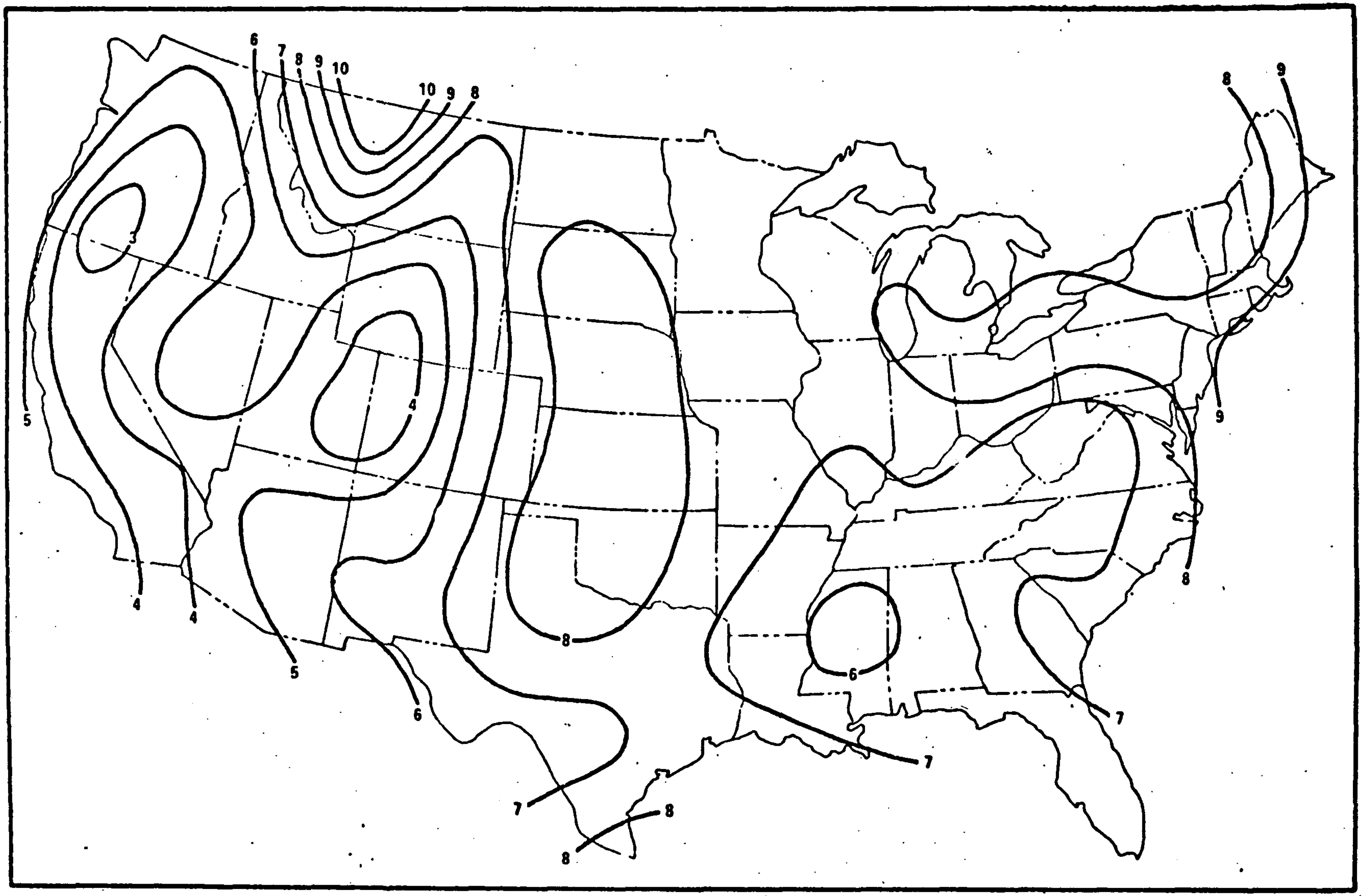

Figure 15. ISOPLETHS (m sec^{-1}) OF MEAN WINTER WIND SPEED AVERAGED THROUGH THE AFTERNOON MIXING LAYER

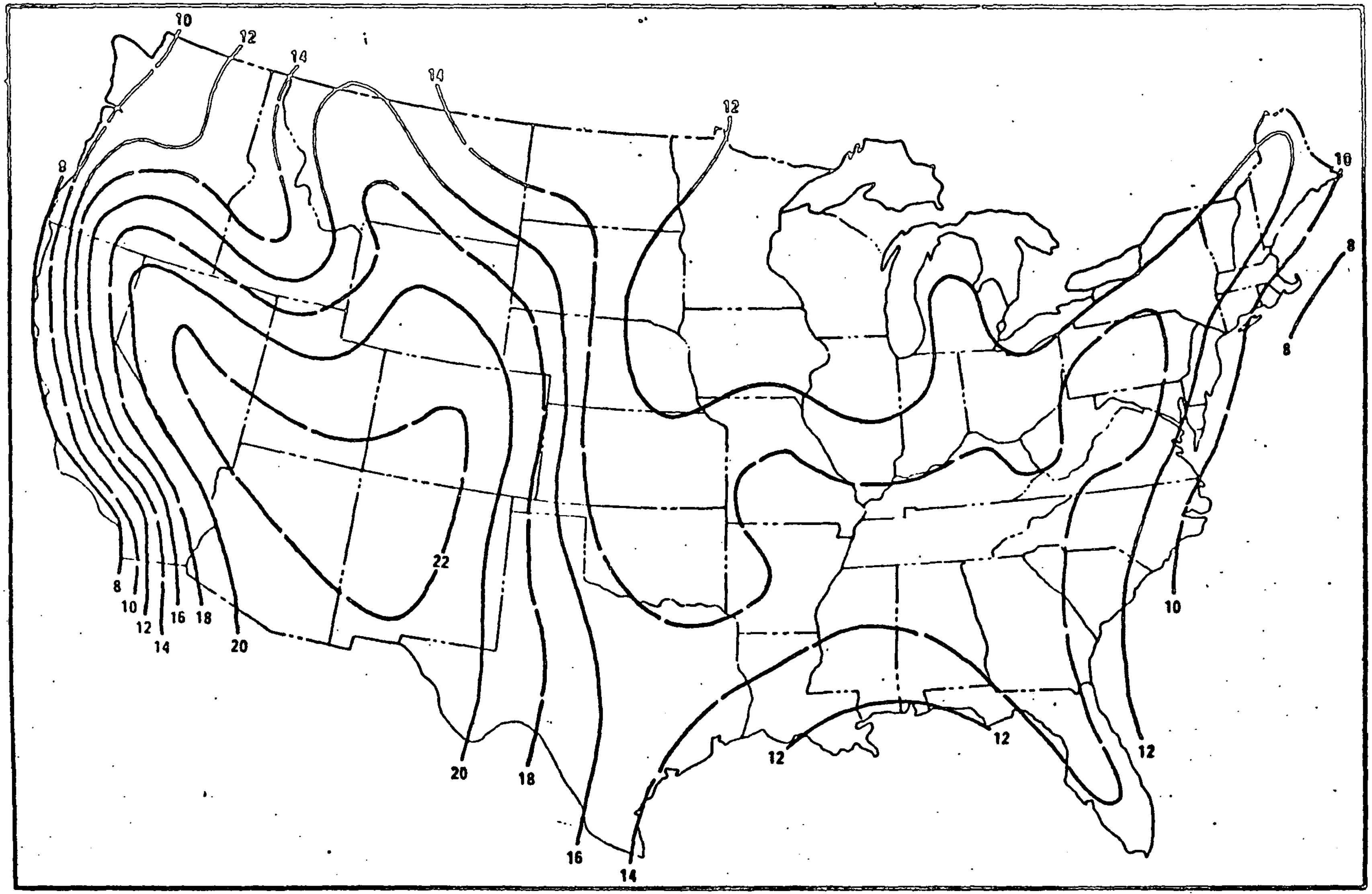

Figure 16. ISOPLETHS (m x 10^2) OF MEAN AUTUMN AFTERNOON MIXING HEIGHTS

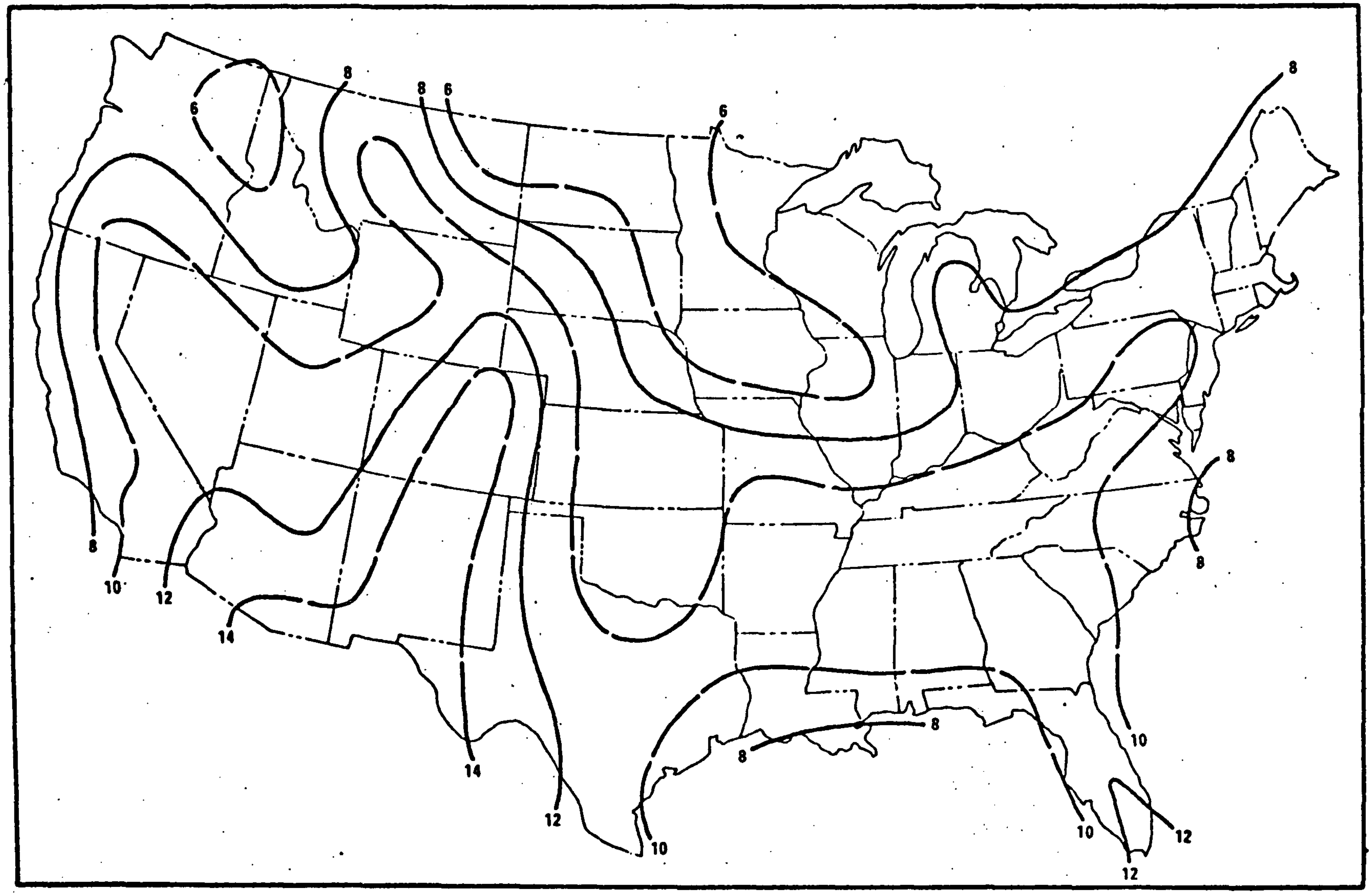

Figure 17. ISOPLETHS (m x 10^2) OF MEAN WINTER AFTERNOON MIXING HEIGHTS

The period when meteorological conditions are least favorable for diluting pollutants is the period when parking facilities are essentially not in use. This would be from very late evening until a few hours after sunrise. It is most often during this period that mixing heights are lowest, wind speeds are lowest, and atmospheric stability is greatest. For most parts of the country, autumn is the season when the least favorable conditions are most likely to occur.

If one now considers that operating hours for parking facilities are generally 7a.m. to 11p.m., then, from a meteorological point of view, the single hour least favorable for dispersing pollutants during that period is from 10 to 11p.m. during the autumn season. The least favorable 8-hour period would be from 3 to 11p.m. Use levels for parking facilities during these periods may be derived by appropriate techniques.

QUALITATIVE GUIDELINES

In addition to the quantitative evaluation procedures developed above, the review of parking facilities as complex emission sources should also include the following considerations which are not presently reducible to quantitative terms:

1. Main entrance/exit ways whould preferably be on a highly visible local secondary street that feeds into the nearest arterial, so that the transition from highway driving to parking lot driving and vice versa are not too abrupt.

2. Any left turn movement across traffic flow that is used by a significant number of the parking facility patrons is a potentially large congestion point and emission problem.

3. All available information on logical, effective, profit-oriented and efficient design for parking facilities indicates that, the better design is from these points of view, the less likely is the congestion which causes lengthy running times associated with large numbers of vehicles running. This is a case where good design improves (lessens) emission characteristics. Accordingly all design and operating features should be examined critically to insure that they contribute to smooth flow and short running times.

THE NINE QUESTIONS

While the specific information called for by the task work statement has been provided in the sections from Regional Shopping Centers Parameters through Meteorological Aspects, the nine questions spelled out as part of the work statement warrant specific response to demonstrate that they are treated.This is given here, with the questions abbreviated.

1. Area allotted to or occupied by a single vehicle? The area varies widely - see Sections IV and V.

2. Percentage of land and parking spaces potentially occupied by vehicles? The usual percentage? See Sections IV and V.

3. Typical and peak values (absolute or fractional) of vehicles running for 1- and 8-hour periods? This question is treated in Sections IV, V and VII.

4. Typical and worst case (slowest) vehicle speeds? In the context of our approach, this question is only relevant to analysis of the "Major Highway" complex source task. It will be dealt with in that task report.

5. Vehicle distribution within the complex? See section titled Geographic Distribution.

6. Design parameters of the complex likely to be known before hand? See section titled Parking Facility Parameters.

7. Design parameters in question (6) which can be most successfully related to traffic, and hence emissions? See section titled Analysis.

8. Relationships of parking lot design to parking densities and vehicle circulation? What is typical design? Design with highest parking densities, lowest vehicle speeds, longest vehicle operating times? To the extent to which these questions are relevant to our methodology, they are answered in the section titled Parking Facility Parameters through the sections titled Traffic Parameters, Analysis and Qualitative Guidelines.

9. Meteorological conditions likely to occur during peak use? Use level during periods of worst meteorology? See section titled Meteorological Aspects.

SECTION IX

DATA SOURCES

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PRIVATE COMMUNICATIONS

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Eno Foundation for Transportation, Saugatuck, Conn.

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16. ABSTRACT

A general methodology is presented for relating parameters of traffic behavior at parking facilities, including vehicle running time, facility use rate and numbers of vehicles running, to more readily available characteristics of the facilities, including physical layout, number and capacity of entrance and exit gates, parking capacity and demographic environment. Such relationships are to be used to relate parking facility characteristics to air quality.

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