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VEHICLE BEHAVIOR IN AND AROUND COMPLEX SOURCES AND RELATED COMPLEX SOURCE CHARACTERISTICS VOLUME V - AMUSEMENT PARKS

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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SECTION I

CONCLUSIONS

1. A general methodology has 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 fifth (amusement parks) 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 (highways), 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 amusement parks to typical and peak air pollution concentrations.

SECTION III

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 EF-263)
2. Sports complexes (stadiums) (Report EF-265)
3. Amusement parks (Report EF-268 - the present report)
4. Major highways (Report EF-267 - in preparation)
5. Recreational areas (e.g., State and National Parks)
6. Parking lots (e.g., Municipal) (Report EF-266)
7. Airports (Report EF-264)

This, the fifth task report, describes the methodology developed, and the analysis and results of its application to amusement parks.

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 weeding out the elements or parameters of the complex which influence these running times most.

The running times in critical modes are 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 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., parking, 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 exception of "major highway" case cited in Section III titled Objective and Scope. That special case is recognized in the work statement as an unusual one requiring different treatment in the context of the other six sources. In any event, and in the words of that statement, "for highways it may simply be necessary to tie existing guidelines into a concise package."

The remainder of this report covers special considerations required in the case of amusement parks, and describes the implementation of this methodology for these parks, and the results obtained.

Unlike most of the other complex sources investigated, amusement parks are privately owned rather than municipal developments. Also, this industry apparently is highly competitive. For these reasons, there is a noticeable void in published information concerning the design and operation of amusement parks; no technical or planning survey articles on the industry were found in the literature. Only general information could be obtained in telephone surveys of park managers.

Most of the data presented in this report were obtained from two sources: news releases and articles appearing in the weekly trade newspaper Amusement Business during the past three years; and general design data compiled by Economics Research Associates, a leading consultant to amusement park developers. One result of the data coming from these two sources is that it is probably much more current than that used in task reports for the other complex sources.

SECTION IV

CHARACTERISTICS OF AMUSEMENT PARKS

Amusement parks can be classified into two general categories, each having several distinguishing characteristics: (1) "theme" parks patterned after the original idea of Disneyland, (2) and the traditional amusement parks with thrill rides and midway games. All new amusement parks in recent years have been theme parks. The increasing popularity of theme parks is attributed to their orientation to family groups and a single admission charge for all attractions, rather than individual charges for each ride.

Theme parks also draw large numbers of tourists, whereas the traditional amusement parks depend on local patronage for their revenue. Tourists tend to come in family groups and prefer attractions that do not split them up, i.e., sit-down shows and slower-paced fantasy rides. However, according to C.V. Farman, Manager of Atlanta's Funtown Park, "rides are what bring in the people."[1]

In number, theme parks now account for only 10 percent of amusement parks in the U.S., but they garner 25 percent of the total attendance and 40 percent of the revenue.[2] General information on several amusement parks is presented in Table 1. Most of these are theme parks, due to lack of available data for traditional amusement parks. From the standpoint of traffic, however, there do not appear to be any strong distinctions between the two types of amusement parks. Therefore, both are considered in the traffic analyses in this task report.

Amusement parks are a slightly unusual complex source in one respect--they are generally privately owned rather than municipal. The importance of this fact is that much of the data on source parameters and traffic

Table 1. GENERAL INFORMATION ON AMUSEMENT PARKS

Park	Location	Area of Park, Acres	Annual Attendance, Millions	Cost, Million $
Astroworld USA	Houston, Texas	60*	1.2	n.a.
Cedar Point	Sandusky, Ohio	n.a.	2.3	27
Carowinds	Charlotte, N.C.	203	1.5	30
Disneyland	Anaheim, Calif.	n.a.	9.5	n.a.
Disney World	Orlando, Fla.	3,000	11.2	400
Hersheypark	Hershey, Pa.	60*	0.9	n.a.
King's Island	Cincinnati, Ohio	n.a.	2.2	40
Land of Oz	Beech Mtn., N.C.	30*	0.4	n.a.
Magic Mountain	Valencia, Calif.	200	1.3	35
Opreyland	Nashville, Tenn.	n.a.	1.5	n.a.
Playland	Rye, New York	200	1.2	n.a.
Riverside	Springfield, Mass.	n.a.	1.0	n.a.
Six Flags over Mid-America	St. Louis, Mo.	200	1.4	n.a.
Six Flags over Texas	Dallas, Texas	145	2.1	n.a.
Worlds of Fun	Kansas City, Mo.	500	1.1	21
King's Dominion (under const.)	Richmond, Va.	800	1.6 (est.)	40

n.a. = data not available

* for amusement area only

at amusement parks cannot be obtained for competitive reasons. The scarcity of published information applicable to the present investigation has already been mentioned.

Another characteristic of amusement parks is their seasonal operation. Most parks have a reduced operating schedule during the winter months, and some are completely closed during this season. Amusement parks are usually located either in popular vacation areas or in large metropolitan areas.

In the past many patrons used public transit to travel to amusement parks in large cities. However, most of these in-town parks, such as New Jersey's Palisades and Olympic parks, Coney Island's Steeplechase Park, Baltimore's Bay Shore Park, and Houston's Playland Park, have closed and the newer parks are now reached almost exclusively by automobile.

The continuing success of the theme parks indicates that they are not just a fad.

Announcements of theme parks to open in the next few years include three $40 million parks planned by the Marriott Corporation, a $40 million park in Richmond, Virginia planned by Taft Broadcasting, and one new park per year (after 1975) planned by the Six Flags group. Nevertheless the anticipated number of new parks per year - three or four -- is relatively low in comparison with the numbers of new complex sources in other categories.

SECTION V

AMUSEMENT PARK PARAMETERS

The important parameters in characterizing amusement park traffic patterns are attendance rates and temporal--daily, weekly and seasonal--variations in attendance. Since these design-related values are not known prior to the opening of a new amusement park, the developer must estimate attendance rates and temporal variations based on the findings of feasibility or market studies and/or the records of other amusement parks, respectively.

ATTENDANCE

Attendance generally is considered to be the best available parameter for estimating traffic volumes. Annual attendance figures, which generally are included in feasibility studies, are of limited use for the design of facilities at amusement parks; however, they are useful for this study since a typical day's attendance can be estimated by deviding annual attendance by the number of annual operating days. The value of importance to amusement park designers is the average attendance on the 10 to 15 busiest days of the year, referred to as the capacity crowd. All park facilities, including traffic and parking, are sized to adequately handle this number of people.[3] Average and capacity daily attendance figures for several parks are shown in Table 2.

Amusement parks are probably the most flexible complex sources in terms of layout and capacity. Their number of attractions and employees can be readily expanded or reduced to meet attendance demands. Therefore, it is incorrect to refer to the capacity of an amusement park as a permanent fixed value. Rather, capacity is the maximum attendance that can be accommodated with the existing park configuration.

Table 2. ATTENDANCE, EMPLOYMENT, AND PARKING AT AMUSEMENT PARKS

Park	Average Daily Attendance	Capacity Daily Attendance	Summer Employment	Parking Spaces
Cedar Point	16,500	46,000	n.a.	n.a.
Carowinds	11,000	Weekend 40,000	1,300	12,000
Disney World	35,000	70,000	11,000	Main lot 12,000 Overflow ?
Hersheypark	7,800	22,000	n.a.	8,000*
King's Island	17,600	38,000	2,000	10,600
Land of Oz	2,500	10,100	100	n.a.
Magic Mountain	7,200	30,000	1,200	9,000
Opryland	10,300	27,000	n.a.	4,600
Playland-Rye	9,000	40,000	n.a.	n.a.
Six Flags Over Mid-America	9,000	30,000	1,600	Guest 4,600 Employee 500 Overflow 500
Six Flags Over Texas	13,000	40,800	n.a.	n.a.
Worlds of Fun	8,000	23,000	1,200	4,800

n.a. = data not available

* parking lot also used for sports stadium and other adjoining tourist attractions

Like shopping center usage, amusement park attendance has definite seasonal variations and differences between weekday and weekend crowds. However, only limited data could be found to quantify these variations. The largest crowds at almost all parks occur on Saturdays during July and August, and the design capacity crowd described above is probably equivalent to the normal July or August weekend-day's attendance. Reduced hours of operation or closing of parks during winter months accentuates this seasonal variation.

The number of people and cars in a park at any specific time of day is less than the total daily ticket sales, since some visitors do not arrive until late afternoon or evening while others come in the morning and leave in the afternoon. One developer who was questioned about this design parameter indicated that 75 percent of the total daily attendance is in a park at the most crowded time of the day.[4] However, published survey data indicate that this percentage may be too low, especially for weekend days when the largest crowds usually are present. For example, attendance at Opryland on the peak day in 1973 was 27,.74; at 5:00p.m., there were 25,892 persons, or 95 percent of the day's total attendance, at the peak. At Carowinds, which admittedly has a typical attendance pattern, a survey of arrivals by hour showed that 85 percent of the total patrons for the day entered before noon.

While published data for arrival and departure by hour are sketchy, they are readily available to amusement park developers for use in designing their facilities.[4] For this study, hourly arrival and departure data were obtained from Economics Research Associates (ERA), the leading consultant to the recreation industry on the feasibility and layout of amusement parks. Composite arrival and departure data prepared by ERA for approximately the same parks listed in Table 2 are presented for a summer weekday (typical day) in Table 3 and for a peak or design summer weekend day in Table 4.

Since arrival and departure patterns constitute a critical input to the traffic analysis outlined in this report, data specific to the park under review must be obtained from the developer. The data should be requested in the same format as Tables 3 and 4.

Table 3. REPRESENTATIVE DISTRIBUTION OF HOURLY ARRIVALS AND DEPARTURES AT MAJOR THEME PARKS IN THE UNITED STATES ON A NORMAL SUMMER WEEKDAY

Time Period	Arrivals	Departures
10 a.m. - 11 a.m.	23%	-
11 a.m. - 12 noon	21	-
12 noon - 1 p.m.	19	-
1 p.m. - 2 p.m.	14	1%
2 p.m. - 3 p.m.	8	1
3 p.m. - 4 p.m.	5	3
4 p.m. - 5 p.m.	3	9
5 p.m. - 6 p.m.	3	10
6 p.m. - 7 p.m.	2	9
7 p.m. - 8 p.m.	1	7
8 p.m. - 9 p.m.	1	13
9 p.m. - 10 p.m.	-	21
10 p.m. - 11 p.m.	-	20
11 p.m. - 12 midnight	-	6
Total	100%	100%

Source: Economics Research Associates.

Table 4. REPRESENTATIVE DISTRIBUTION OF HOURLY ARRIVALS AND DEPARTURES AT MAJOR THEME PARKS IN THE UNITED STATES ON A JULY OR AUGUST WEEKEND DAY

Time Period	Arrivals	Departures
10 a.m. - 11 a.m.	17%	-
11 a.m. - 12 noon	24	-
12 noon - 1 p.m.	21	1%
1 p.m. - 2 p.m.	13	1
2 p.m. - 3 p.m.	9	1
3 p.m. - 4 p.m.	6	4
4 p.m. - 5 p.m.	3	9
5 p.m. - 6 p.m.	3	11
6 p.m. - 7 p.m.	2	8
7 p.m. - 8 p.m.	1	8
8 p.m. - 9 p.m.	1	12
9 p.m. - 10 p.m.	-	20
10 p.m. - 11 p.m.	-	18
11 p.m. - 12 midnight	-	7
Total	100%	100%

Source: Economics Research Associates.

AVERAGE STAY

Another parameter of amusement parks which is related to the daily attendance pattern is the average length of stay of patrons. Independent references indicated that seven hours was the average stay for a well-run amusement park.[3,4] No data were found to substantiate that the average stay is different for weekdays and weekends, but the evening entertainment attractions which many parks promote during the week would certainly lead to that conclusion.

If the 7-hour average stay is compared with the 12 hours of operation per day common to many of the family amusement parks,[5] it appears that more than 75 percent of the days' attendance would be in the park at the peak period. Therefore, the interpretation of the 7-hour and 75 percent values that corresponds best with other collected data is as follows: the 7-hour average stay is for the weekend periods with capacity crowds, when attendees have an entire day to spend at the park, when the large crowds cause congestion and longer waiting lines for rides and other attractions, and when more than 75 percent of the total attendees are at the park during the peak period. In contrast, the weekday stay is probably less than 7 hours, and this is the period for which the 75 percent of daily attendance at the peak period is normally applicable.

EMPLOYMENT

A relatively large staff is required at an amusement park, especially at a theme park with shows. Summer (peak) employment at several of the parks is shown in Table 2. Employees average 15 percent of daily attendance for the parks listed in Table 2, indicating that they are a significant park of the traffic and parking volume at an amusement park.

SIZE

Amusement parks are often described by their size in acres. The acreages of several parks are presented in Table 1. Except where noted, these values include parking, buffer, expansion, and other areas in addition to the amusement park proper. Park acreage apparently is not a good indicator of either park acitivity or related traffic volume. This is because large portions of total park areas may be dedicated to such diverse activities as man-made lakes, gardens, wildlife or conservation areas, picnicing, and camping.

PARKING CAPACITY

The number of available parking spaces is a critical parameter for any complex source, and amusement parks are no exception. The total parking spaces at several parks are shown in Table 2. In relation to maximum daily attendance, the available parking spaces for a capacity crowd average 0.24 spaces per patron for the eight parks having data, with a range of 0.17 to 0.36 spaces per patron.

According to one amusement park designer, parking needs are determined by dividing the projected peak attendance by an estimated average vehicle occupancy, then adding 25 percent as a factor of safety.[4] However, the values reported above indicate that this excess capacity, or factor of safety, is not found at the existing parks. Like other accomodations at an amusement park, the parking facilities may be quite flexible in their layout. Some of the required parking capacity can be obtained from unpaved grass fields that normally surround the park. Also, remote overflow parking lots are utilized in conjunction with shuttle bus service.

In the news articles and telephone interviews from which the data on amusement parks were compiled, there were only a few references to parking lot overflows during peak periods. In contrast, there were many reports of incremental expansions of parking capacity in anticipation of increased attendance.

Parking is generally supervised at large amusement parks, which should result in higher densities of parked vehicles than with unsupervised parking. Aisles must be maintained in the lots so that all vehicles are free to depart at any time. Therefore, the average space per vehicle in parking areas is usually limited to the range of 190 to 210 square feet per car.

The above discussion of parking requirements was for guest parking only. At most parks, a separate parking facility is provided for employees. Very little data was obtained on employee parking lots, but capacity analyses for these lots are not relevant, since the overflow vehicles can use the main parking lot.

SECTION VI
TRAFFIC PARAMETERS

The methodology for describing traffic movement around this complex source, as outlined in Section VII, requires estimates of the average running time for the vehicles in and around the amusement park and the volume of such traffic. Traffic parameters which should be used to develop these two values are discussed in this section.

PARAMETERS TO ESTABLISH TRAFFIC VOLUMES

The estimated number of persons entering and leaving the park by hour would be submitted by the developer. This data is converted to hourly traffic volume by dividing by average vehicle occupancy. Although this procedure for estimating traffic patterns places much emphasis on a traffic parameter which is not very precise, it parallels a procedure used by developers to estimate expected traffic volume for parking lot design purposes. Also, no more accurate method of projecting traffic volumes for a proposed park could be determined. As an example of the effect of the average vehicle occupancy (A.V.O.) on traffic estimates, a change in the assumed A.V.O. from 4.0 to 3.5 results in a 14.3 percent increase in estimated traffic volume.

No published data citing A.V.O. values were found. Economics Research Associates reported that large theme parks such as those listed in Table 2 have average vehicle occupancies in the order of 3.6, with a range in this parameter of 3.2 to 4.0 for different parks.[6] These data are based on actual surveys by park personnel and on design values used by ERA. An attempt should certainly be made to obtain an A.V.O. value specifically for each park reviewed, and possibly even different values for particular times of the day or week.

This method of estimating traffic volume assumes that everyone arrives at the park by automobile. If this assumption is incorrect, the number of persons using other modes of transportation should be subtracted from the total attendance before calculating the estimated traffic volumes.

The above procedure does not consider traffic volume generated by peak employees. In most cases, employees do not use the same entrances or parking facilities as the guests, nor is their pattern of arrival and departure the same. Therefore, the entire traffic analysis should be handled separately. The estimated number of employees entering and leaving each hour should be easier to establish than the pattern for the park guests. For employees, an average vehicle occupancy of 1.2 to 1.5 appears to be appropriate.

PARAMETERS TO ESTABLISH RUNNING TIMES

Concept of Emissions per Unit Time

In the immediate vicinity of amusement parks, maximum vehicle speeds rarely exceed 10 or 15mph, 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 mile with slight change in average operating speed.

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

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

2. Traffic movement in the vicinity of a park 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.

---

* Less than 10 percent increase in CO and hydrocarbon emissions per minute from idle to 15 mph.

Values for automotive pollutant emissions for 1972 in grams/minute at idle are available from A Study of Emissions from Light Duty Vehicles in Six Cities.[5] They are summarized in Table 5. These test data compare well with emission factors calculated from the current edition of AP-42,[7] when converted to grams/minute at various speeds and then extrapolated to zero speed.

Table 5. 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 from evaporation of gasoline at the end of a trip ("hot soak"). If subsequent investigation of the relative magnitude of these emissions, compared 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 amusement park at any time would be the product of the number of vehicles, times average vehicle running time, times the appropriate emission factor from Table 5.

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

V = Traffic volume during period of concern

RT = Average running time, minutes

EF = Emission factor, grams/minute.

Operational Modes at Amusement Parks

For purposes of analysis, traffic movement in the vicinity of an amusement park has been divided into the same eight operational modes that were specified for shopping centers, airports, and sports stadiums. These are summarized below and shown schematically in Figure 1. The two major types of access traffic have been distinguished from each other in the figure. The discussion which follows is primarily applicable to travel by park guests rather than employees.

Approach (A) - The time or distance along the immediate access road, usually on park property, during which traffic movement is strongly affected by vehicles entering or leaving the park.

Entrance (I) - Waiting and service time at the ticket gate or entranceway to the parking facility.

Movement in (MI) - Driving time or distance to the designated parking space (with supervised parking). This also includes waiting time in a queue within the parking area or driving time to an overflow parking facility.

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 preferred exitway.

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

Departure (D) - The time or distance along the immediate access road that movement continues to be influenced by traffic from the amusement park.

The average running time in each of these modes can be quantified for a specific park as a function of its physical dimensions, traffic control procedures, and traffic volume.

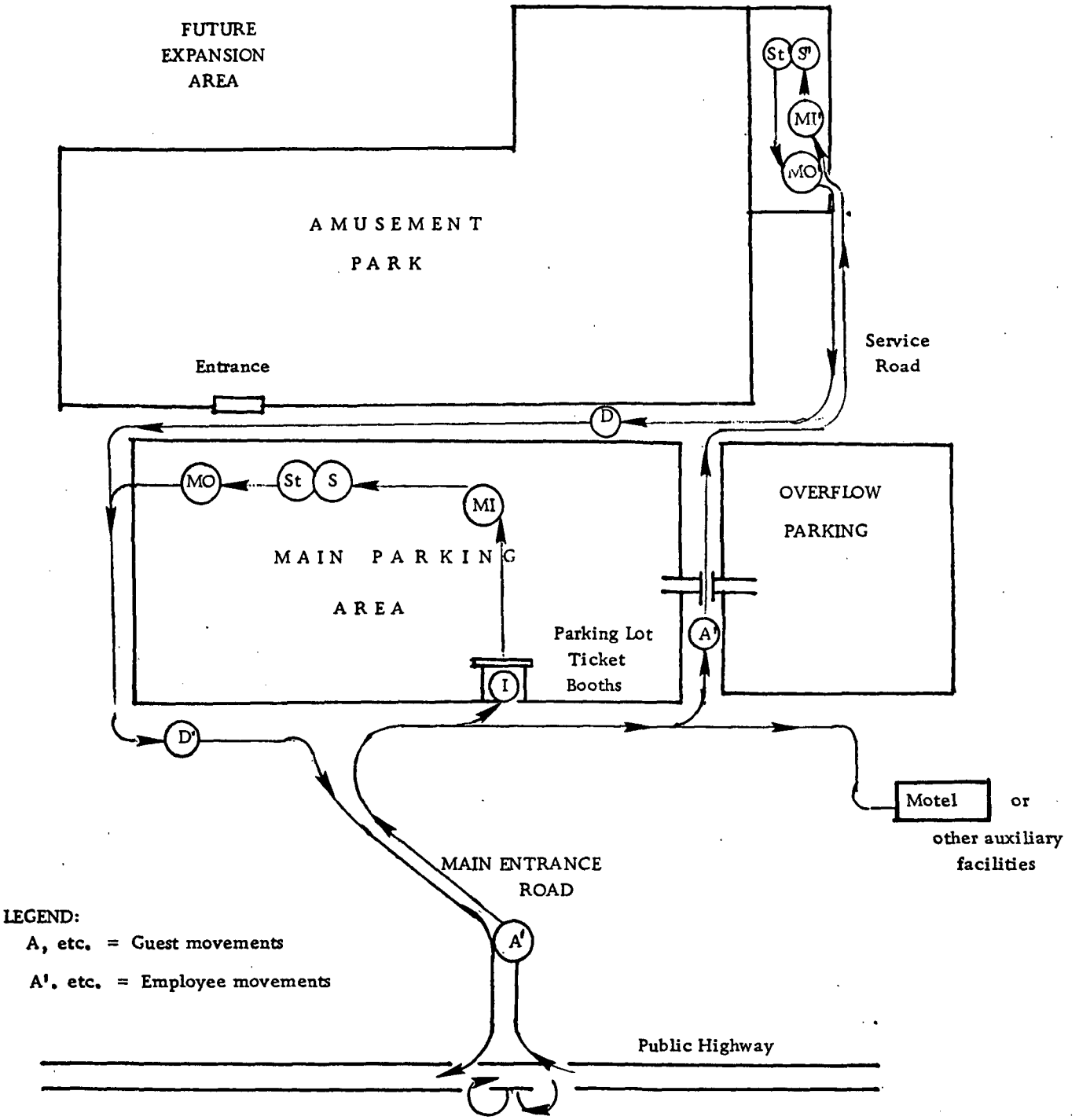

Figure 1. SCHEMATIC REPRESENTATION OF VEHICLE OPERATING MODES AT AMUSEMENT PARKS

Base Running Time

There is an average minimum vehicle running time for each amusement park 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 operating condition at the park and because at most parks it is expected to be exceeded only during periods of relatively high traffic volume. The base running time can be estimated from a plan of the amusement park with an additional knowledge of its traffic control procedures and probable driving patterns.

Due to the relatively low traffic volumes normally associated with employee travel and the separate employee parking facilities, it has been assumed for this analysis that employee traffic always moves with the same average, or base, running time. This assumption appears reasonable because: (1) employee peak travel times do not coincide with guest peak travel times; (2) there are no ticket gates or other constraints to employee parking lot ingress; and (3) the sizes of employee parking lots are small enough that driving times within the lot would not increase significantly with traffic volume.

Relationship Between Running Time and Traffic Volume

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

- Queues at parking ticket booths, in the active parking area as cars are directed into their assigned parking spaces, and at other temporary or permanent traffic control points.
- Queues created as vehicles attempt to exit onto uncontrolled access roads.
- Traffic intersections and merging traffic lanes within the parking area.
- Traffic aisles blocked by vehicles making dropoffs or pickups.
- Increased number of pedestrians in parking area.

Generally, running time is related to traffic volume as shown in Figure 2. The base running time (BRT) can be determined for a specific amusement park as described above. The magnitude of increase above the BRT with increased traffic can also be estimated from available traffic parameters, by the procedures developed in Section VII.

Identification of Critical Modes at Amusement Parks

Examination of the eight operational modes that were identified indicates that running times in some modes are relatively constant, but that times in others may increase sharply under peak attendance/traffic conditions. For amusement parks, the three modes whose times are greatly affected by traffic congestion, in order of decreasing impact, are:

1. Entrance
2. Movement in
3. Exit

Time in the entrance mode is affected by the collection of parking fees as the vehicles enter parking lots at most amusement parks.

Movement time into a parking space is a function of the maximum parking rate that can be accomplished by park employees as they direct traffic within the lot. If traffic flow into the lot is controlled by a ticket gate, running times in the parking lot should not increase much with increased traffic. However, sizeable queues form during these periods in free parking lots. Time in the "movement in" mode expands incrementally when the main parking lot is filled and incoming traffic must all drive an additional distance to an overflow lot.

Exit time for a vehicle in a parking lot is a function of the egress capacity of the lot. As this is approached or exceeded, running time increases. Waiting times in the resulting queues contribute significantly to total running times. Exit queue lengths are moderate compared to those for the entrance mode by the departure of vehicles over a longer period of time.

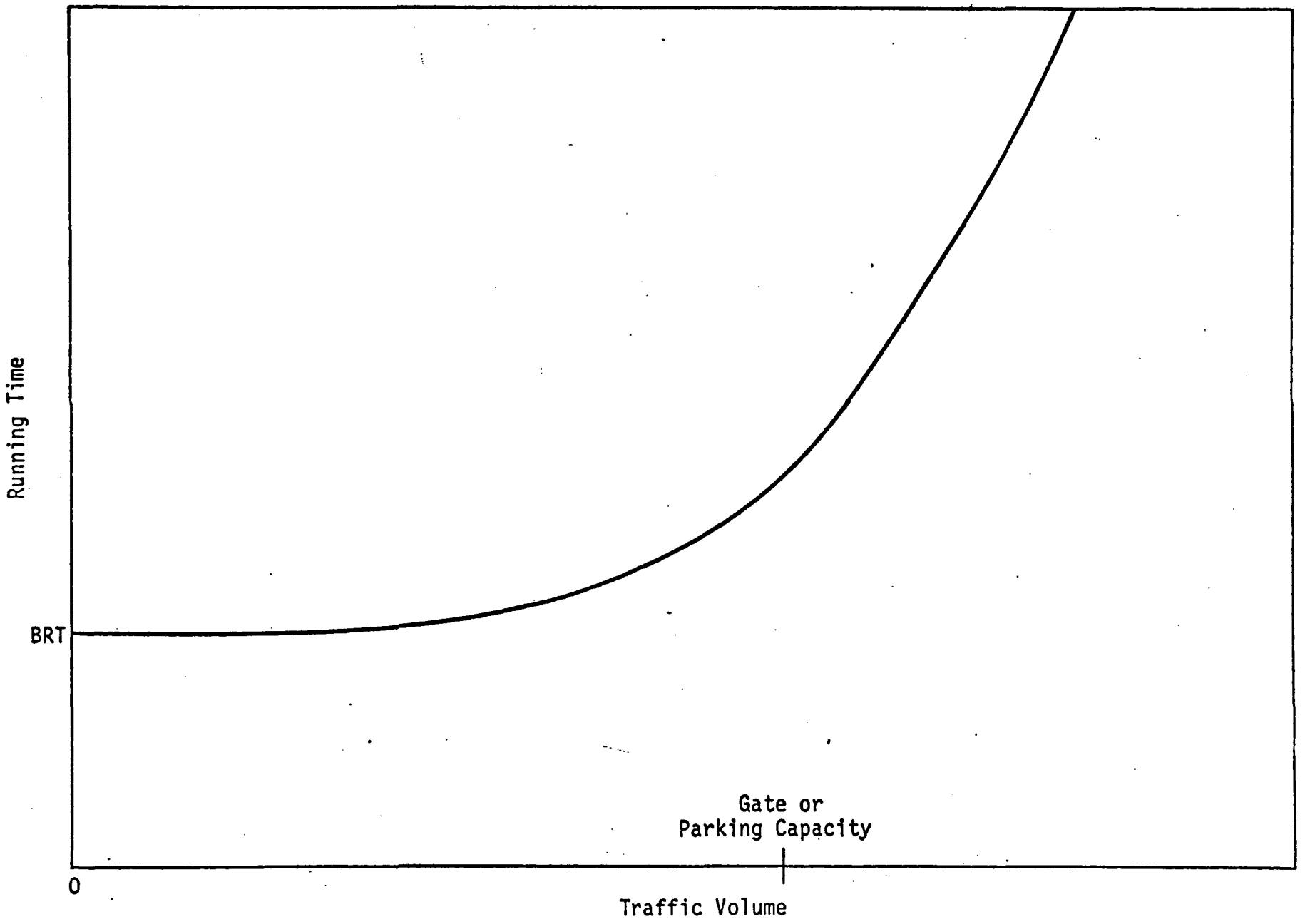

Figure 2. General Relationship Between Traffic Volume and Total Running Time

SECTION VII

ANALYSIS

In this section, three analyses are developed for converting available data into vehicle running times and numbers of vehicles running. The final step of combining all these intermediate results into a quantitative description of the amusement park traffic problem is then treated in Section VIII, Results.

ENTRANCE OR PARKING TIME

Time spent entering a parking lot or waiting to be directed to a parking space is a function of the rate at which vehicles are attempting to enter the lot, the number of entrance lines, and the average time required to collect the parking fee (service time). Running time can be quantified with data on these three parameters by use of a methodology employing queueing theory. The hourly inflow rate is obtained from the projected traffic distribution pattern for the park. Average service time per vehicle ranges from about 0.10 minute, where parking is free or the fee is collected after the vehicle has parked, to 0.25 minutes in cases where there are inadequate attendants or a poor entrance configuration. This value is difficult to predict from design data, since it is much more closely related to operational features of the parking facility.

Estimates of running times for the entrance mode cannot be precise, especially considering the available input data. The equations employed here for waiting time in queue result from assumptions that vehicles are reaching the gate randomly over the time increment of concern, and are passing through the gate randomly; hence, their distribution conforms to the negative exponential law, with the queue discipline the first-come-first-served rule (classic basic queueing theory). Errors in the estimates by use of these equations are thought to be relatively low.

For periods when traffic flow is less than gate capacity, the average running time (in minutes) in a queue is given by the equation:

$$RT = b \frac{a}{1-a} \text{ , where}$$

$$a = \text{utilization factor}$$

$$= \frac{\text{(vehicle inflow rate, veh/min) (b)}}{\text{(no. of entrance lines)}}$$

$$b = \text{average service time, min.}$$

For these periods when traffic flow <u>exceeds</u> gate capacity (a>1.0), the queue continues to build during each time increment by the amount that traffic volume exceeds capacity. Average running time for this situation can best be estimated by the tabular calculation procedure exemplified in Table 6. The procedure is illustrated with data for a two-hour peak traffic period (3:00p.m. - 5:00p.m.) with vehicles existing as shown in column 2, four entrance lanes, and an average service time of 0.1 minute.

EXIT TIME

Since guests leave the park over a period of several hours, as indicated by the data in Tables 3 and 4, it is unusual for congestion and excessive queueing to occur at the parking lot exits or on the access roads. However, if inadequate exit capacity for peak crowds is suspected, the queueing theory equation or tabular method presented above may also be used to estimate running times in the exit mode.

Generally, it is more direct to describe the exit constraint in terms of gate capacity rather than average service time. The "b" factor in the equation can still be easily quantified, since it is the average outflow time per vehicle or the number of exit gates divided by the total gate capacity in vehicles per minute.

Table 6. EXAMPLE QUEUE CALCULATION WHEN GATE CAPACITY IS EXCEEDED

1		2	3	4	5	6	7
Time Period		Entering Traffic Volume	Vehicles Serviced	ΔN	N at End of Period	$N_{AV.}$	RT, Min.
Starting	Ending						
				col. 3- col. 2	col. 4+ col. 5' (line above)	$\frac{\text{col. 5+col. 5'}}{2}$	(b) (col. 6) Divided by No. of gates
2:30	3:00	900	1200	-	-	-	(use equation)
3:00	3:30	1220	1200	+ 20	20	10	.25
3:30	4:00	1400	1200	+ 200	220	120	3.0
4:00	4:30	1600	1200	+ 400	620	420	10.5
4:30	5:00	1400	1200	+ 200	820	720	18.0
5:00	5:30	1100	1200	- 100	720	770	19.25
5:30	6:00	980	1200	- 220	500	610	15.25
6:00	6:30	750	1200	- 440	60	280	7.0

N = queue length, in cars

RT = average running time, in minutes

= (av. inflow time per vehicle, min.) (av. queue length)

MOVEMENT IN TIME

Running time spent in reaching a parking space increases as a function of the number of vehicles already in the parking area, since the late arrivals are directed to the more remote sections of the lot. The average running time in this mode for a day, then, should be proportional to the daily attendance. Actual values for a particular park are estimated from driving distances as determined from a plan of the parking area.

For parking lots with no ticket booth, a queue may form at the point of active parking during periods of high inflow rather than at the entranceway. However, the same queueing theory equation is still applicable.

The largest increase in running time for the "movement in" mode occurs when the capacity of the main parking lot is exceeded and incoming cars must be diverted to an auxiliary or overflow area. Therefore, some quantitative analysis of number of parked vehicles at any time of the day is desirable. Vehicle accumulation can be derived simply from the hourly data on arrival and departure of guests. After these data have been converted to equivalent inflow/outflow of traffic, the number of vehicles in parking at any time is the cumulative difference between these two hourly values. This is shown graphically in Figure 3 on a percentage basis for the attendance data in Table 4. At the time of day on a peak attendance day when the estimated number of vehicles in parking exceeds the primary parking capacity, running time is incrementally increased by an amount that accounts for driving time to the overflow lot, plus any additional days associated with this movement.

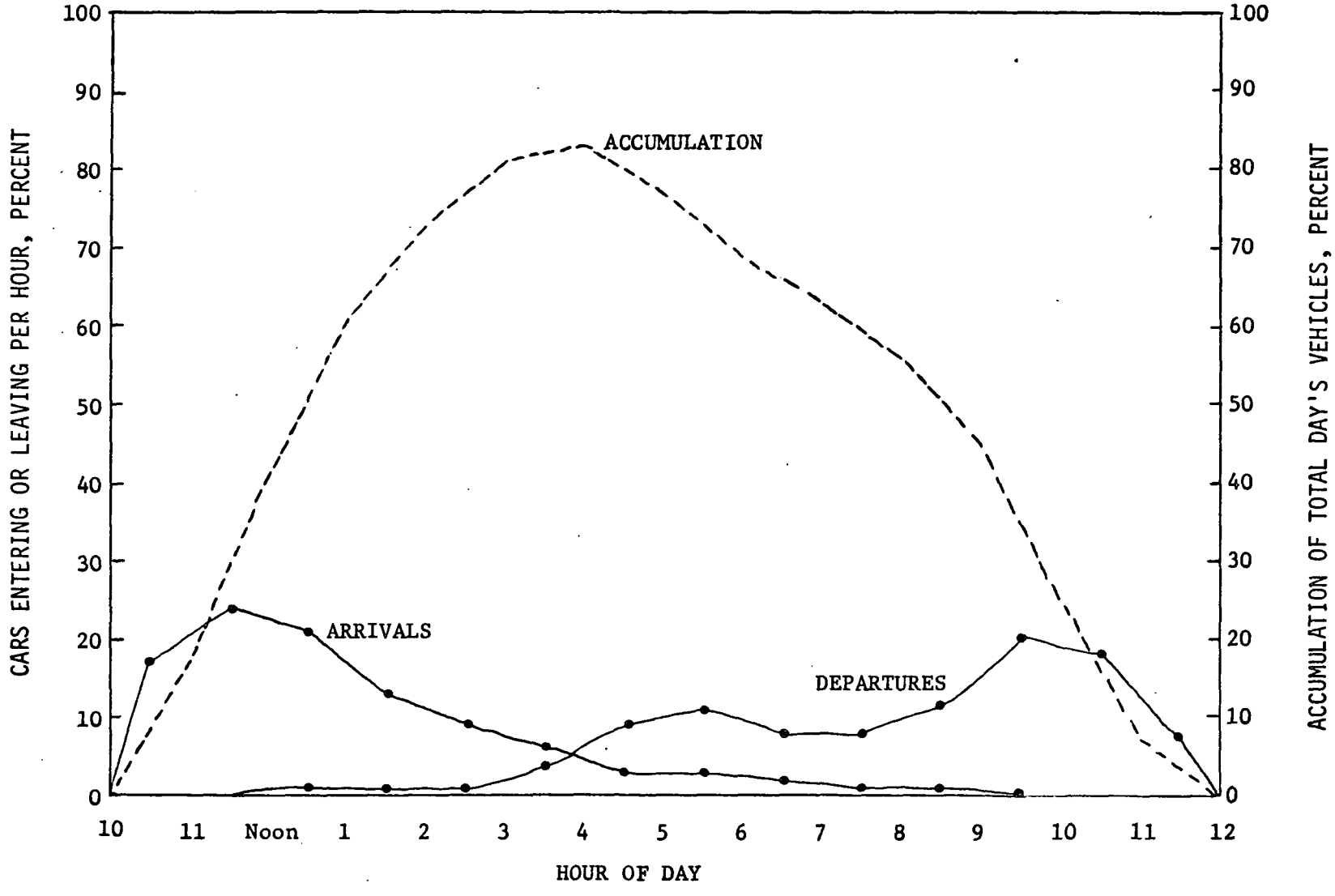

Figure 3. VEHICLE ACCUMULATION BY HOUR FOR PEAK ATTENDANCE DAYS AT MAJOR THEME PARKS

SECTION VIII

RESULTS

METHODOLOGY

In general terms, the methodology proceeds as described in the next two paragraphs which follow. It should be emphasized that this description is of the technique, shown schematically in Figure 4, in its most general form, which provides the starting for each of the seven types of complexes investigated. Significant differences in implementation from this general approach arose for each of the first three complexes, but the methodology for amusement parks follows the general approach closely with no peculiarities or exceptions.

Starting from the physical, geographic, and demographic characteristics of the complex, relationships are established for estimating typical and peak traffic volumes. The concept of operational traffic modes is used to generate best estimates of average running times for cars. The typical traffic volumes and base running times provide the description of typical conditions.

The parameters of the complex which significantly and adversely impact traffic behavior are also defined. Quantitative relationships are proposed or estimated for the controlling parameters of the complex with respect to excess running times in critical traffic operating modes. These, in turn, are superimposed on the base running times to generate peak running times. The peak running times are then associated with peak traffic volumes to create the required information on peak traffic conditions.

In the case of amusement parks, as shown in Figure 5, the methodology proceeds from basic information about a given park (see Section V), via traffic behavior data and traffic volume projections (see Section VI), to generate estimates of peak and typical numbers of vehicles and associated running times by hour of the day. Typical and peak one-hour and eight-hour periods, required end products, can then be extracted from this information.

The specifics of the procedure are presented below. First, the attendance patterns associated with typical and peak days at the park are delineated. These are converted into number of vehicles entering and leaving the park per hour by dividing numbers of patrons and employees by their respective average vehicle occupancies. Running times in the eight operating modes are then determined. A schematic diagram similar to Figure 1 may be helpful in analyzing the operating modes at the park under different traffic volume situations. If the schematic is approximately to scale for the parking area and access roads, it enables estimates of the base running times in each mode to be made.

The access roads to most large amusement parks are private roads on park property, so running times in the approach and departure modes are influenced only by traffic to and from the park and by the configuration of the access road. Running times in the stop and the start modes are probably always very low--the value of 0.1 minute used in the first task report is still appropriate here. Running times in the entrance and exit modes are estimated by the procedures presented in Section VII, as functions of the traffic volume and entrance and exit gate capacities. Because parking lots at amusement parks generally have supervised parking, movement into a parking space is primarily related to the size of the facility until the lot becomes filled. Therefore, the traffic volume estimates must be used in conjunction with parking lot capacity to determine whether capacity is exceeded during peak periods, and the number of vehicles that will have an additional running time to an overflow parking area. Time for movement out appears to be just a function of parking lot size, and relatively constant for all attendance rates.

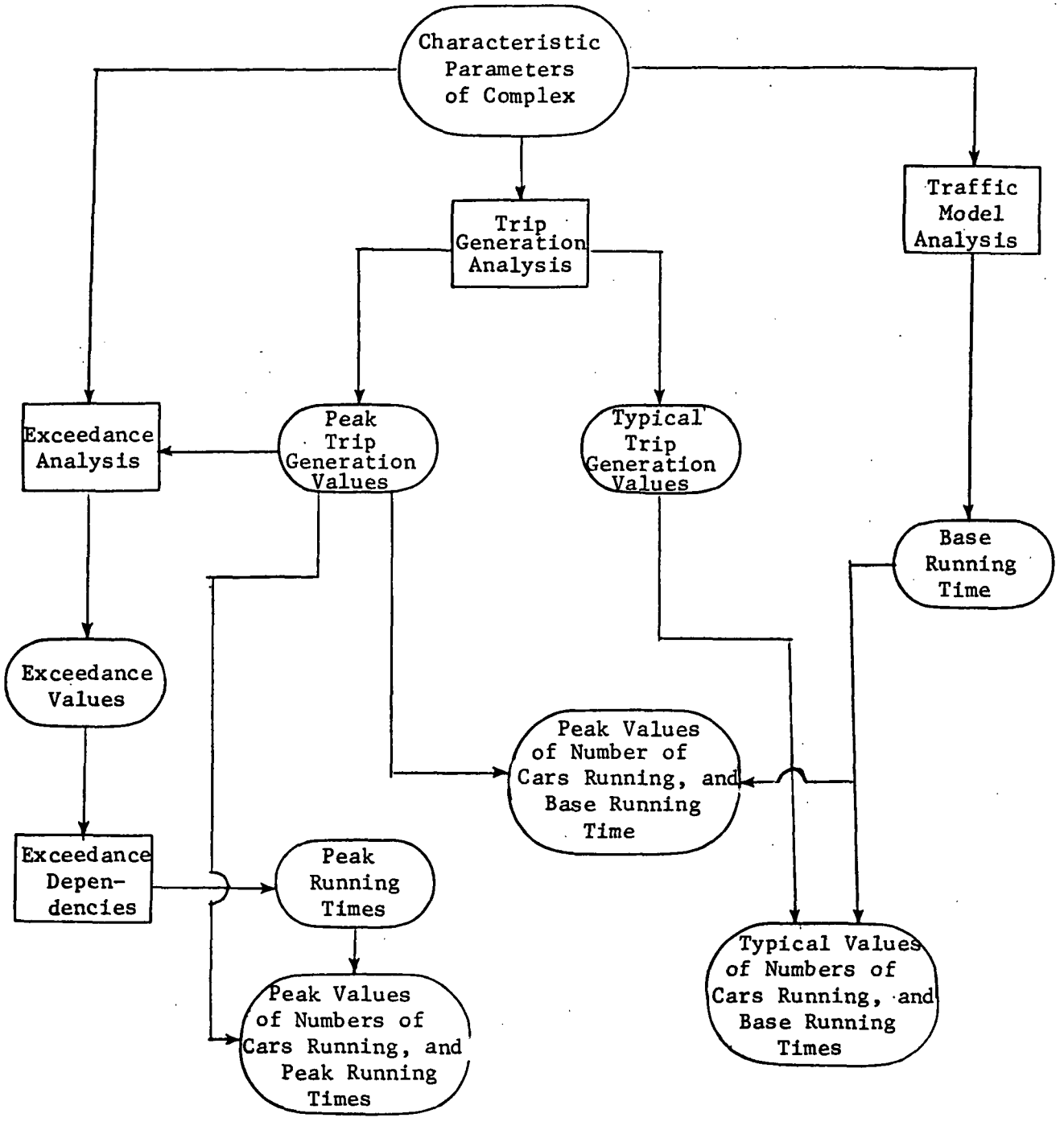

Figure 4. GENERALIZED METHODOLOGY

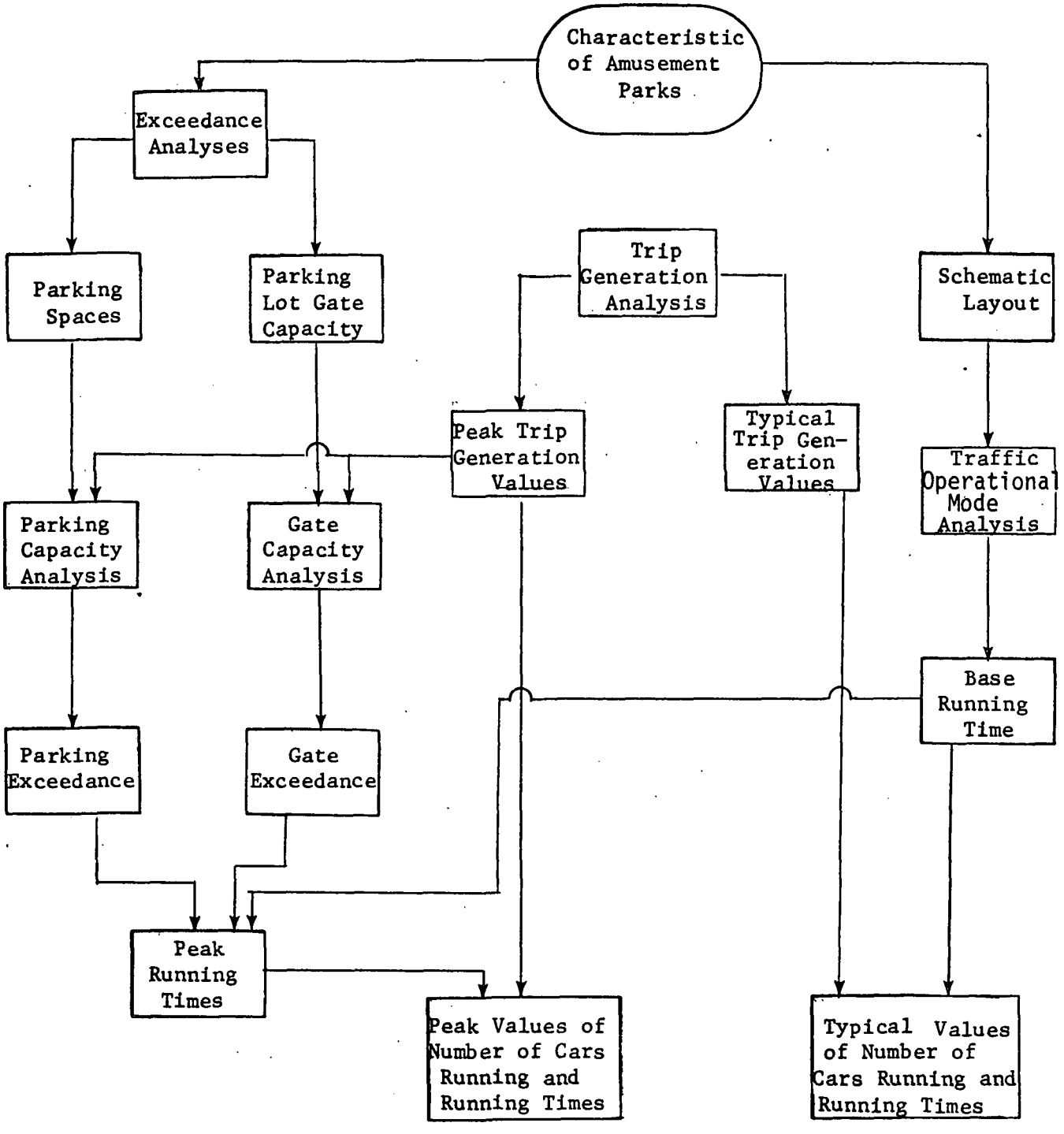

Figure 5. GENERALIZED METHODOLOGY APPLIED TO AMUSEMENT PARKS

The identity of each of the two traffic types (guest and employee) is preserved through the calculation procedure because of differences in the base running times and because of the differential impact of exceedances on their running times. The base running times for each traffic type are combined with typical traffic volumes for the same type to provide the required values of total vehicles running and base running times. For the peak case, diurnal variations of guest and employee traffic must be examined to select the composite peak hour and eight hours. Typically, the patrons' traffic will overshadow employee travel, and their trips will determine the peaking times.

In summary, the two main concerns for an amusement park are for adequate parking lot entrance capacity and adequate parking spaces, or an efficient means of directing and moving incoming traffic to an overflow parking area.

GEOGRAPHIC DISTRIBUTION

Running times, and hence emissions, from an amusement park complex can usually be considered as being distributed fairly uniformly over the parking areas during typical operating periods (base running times). Some concentration of vehicles may occur in the vicinity of the parking lot entrance line. The added emissions attributed to this particular line may be determined from the breakdown of running times by mode for a typical period. It may also be desirable to simulate access road traffic as a separate line source, depending on the orientation of the road (especially if straight away from the park) and the distance of expected effect.

Under peak traffic conditions, the running time in the entrance mode is greatly increased and the need to consider the entrance line as a special source is accentuated. The area over which the other running times are distributed may also increase, due to the utilization of secondary parking areas.

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 sources, such as automobiles at amusement parks, 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).

Peak use of amusement parks occurs during summer, with the highest days of the week usually being on the weekend. The peak hour use generally occurs during the mid-day (somewhere from 11a.m. to 1p.m.). The peak eight-hour period is generally 11a.m. to 7p.m. Holzworth (1972) has mixing height and wind speed figures which are directly applicable to summer afternoon conditions for locations in the contiguous United States, and these may be used directly (Figures 6 and 7). For the weekend mid-day peak, atmospheric stability classes B, C, and D may occur with classes C and D being the most prevalent.

The period when meteorological conditions are least favorable for diluting pollutants is the period when amusement parks are essentially not in use. This would be from very late in the 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.

QUALITATIVE GUIDELINES

In addition to the quantitative guidelines developed above, the review of amusement parks as complex emission sources should also include the following considerations which are not presently reducible to quantitative terms:

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 befor 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.

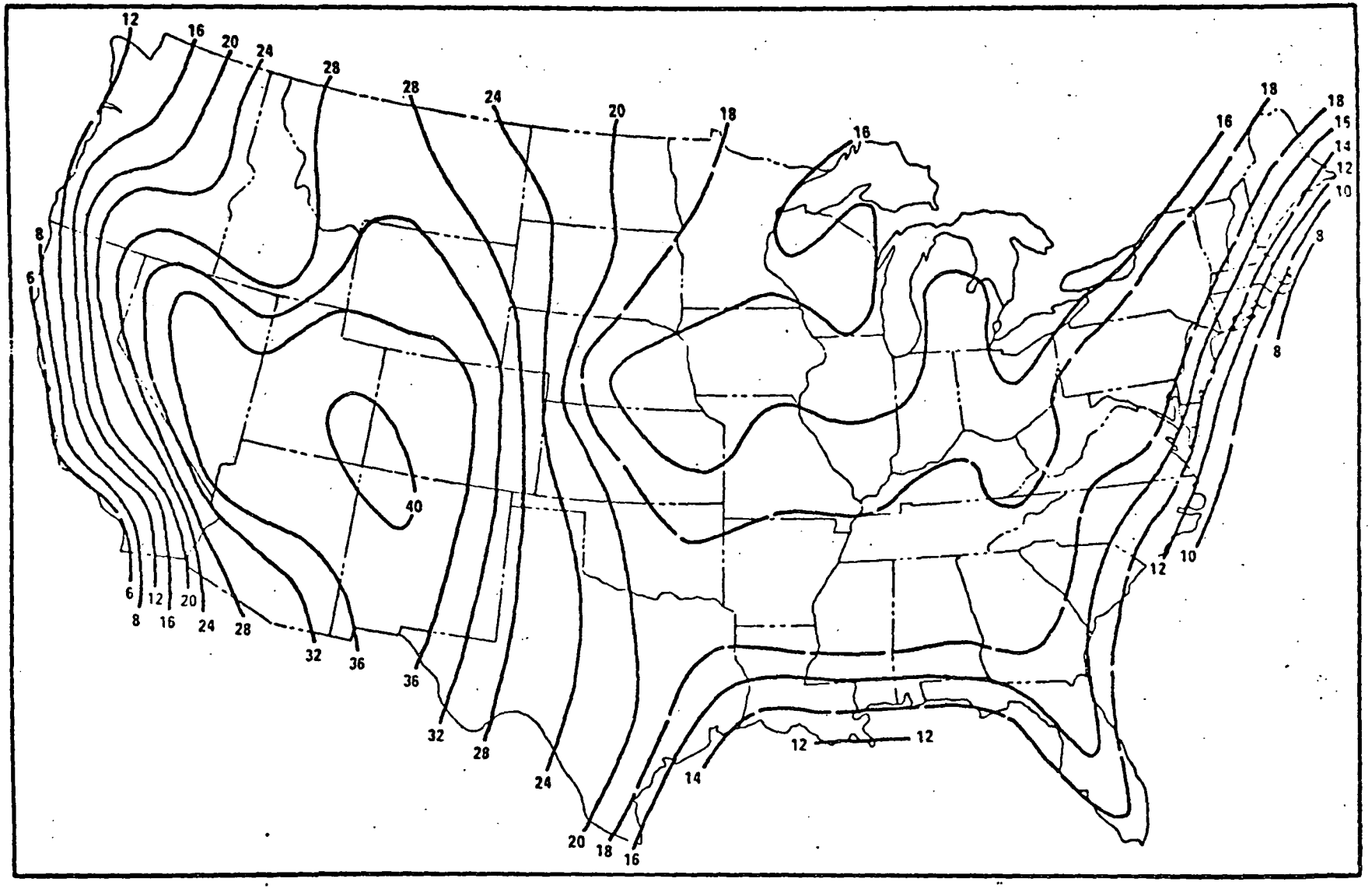

Figure 6. ISOPLETHS (mx10^2) OF MEAN SUMMER AFTERNOON MIXING HEIGHTS

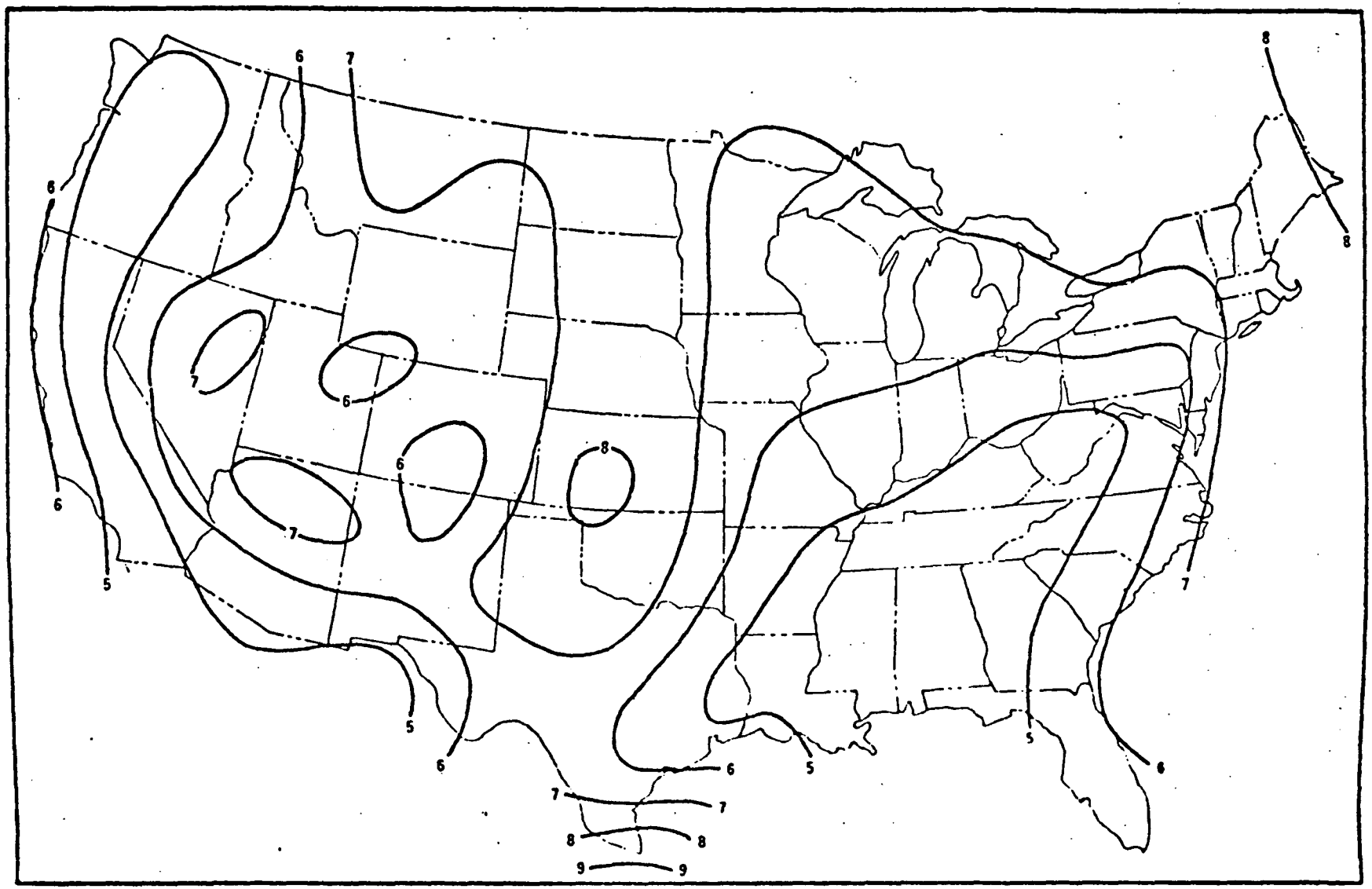

Figure 7. ISOPLETHS (m sec^{-1}) OF MEAN SUMMER WIND SPEED AVERAGED THROUGH AFTERNOON MIXING LAYER (Figure 5

1. Since the layouts of amusement parks can usually be modified comparatively easily to accommodate larger crowds or to alleviate traffic problems, the amount of space available for expansion or modifications should be checked. Specifically, the ease with which parking capacity and access roads could be expanded should be reviewed.

2. The appropriate and adequate use of signs and markers to direct motorists throughout the vehicular areas of the park is important, since many of the guests are tourists visiting the facility for the first time.

3. The developer should demonstrate an effort to optimize traffic circulation patterns in the park by such methods as:

- No left turn movements across the main access roads
- Maximum use of one-way and divided streets
- Markings that separate parking lot entrance lanes from through traffic lanes, where appropriate
- Prohibition of on-street parking within the park.

4. In addition to the employees normally assigned to parking and traffic control, the park's security personnel should be available to assist in these areas during peak periods.

THE NINE QUESTIONS

While the specific information called for by the task work statement has been provided in Sections V through VIII, the nine questions spelled out as part of the work statement warrant specific response. This is given here, with the questions abbreviated.

1. Area alloted to or occupied by a single vehicle? From 190 to 210 feet.

2. Percentage of land and parking spaces potentially occupied by vehicles? The usual percentage? For the few parks for which data could be obtained, the acreage for parking varied from about half up to almost the same amount of land that was used for the amusement area proper. However, acreage dedicated to such purposes as buffer areas, camping, gardens, lakes, and expansion exceeded that for either the amusement or parking areas at many of the parks.

3. Typical and peak values (absolute or fractional) of vehicles running for one- and eight-hour periods? The fractional values can be closely approximated by the tabular summaries of number of guests arriving and departing by hour, as shown in Tables 3 and 4.

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 subheading entitled Geographic Distribution in Section VIII.

6. Design parameters of the complex likely to be known beforehand? See Section V, Parameters for Amusement Parks.

7. Design parameters in question (6) which can be most successfully related to traffic, and hence emissions? See Sections V through VII.

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 Section V.

9. Meteorological conditions likely to occur during peak use? Use level during periods of worst meteorology? See the subheading entitled Meteorological Aspects in Section VIII.

SECTION IX

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16. ABSTRACT

A general methodology is presented for relating parameters of traffic behavior at amusement parks, including vehicle running time and traffic volume, to more readily available characteristics of the parks, including attendance rates, temporal variations in attendance, patrons' average length of stay and parking capacity. Such relationships are to be used to relate amusement park characteristics to air quality.

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