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VEHICLE BEHAVIOR IN AND AROUND COMPLEX SOURCES AND RELATED COMPLEX SOURCE CHARACTERISTICS VOLUME III - SPORTS STADIUMS

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 third of seven types of complex source, sports complexes; the information generated, relating sports complex parameters to the associated traffic behavior, will now be used by the sponsor to generate guidance for studying the impact of new sports complexes on air quality.

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SECTION I

CONCLUSIONS

1. A general methodology has been developed which relates parameters of traffic behavior associated with 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 third (sports complexes) of seven types of complexes, with quantitative results presented in this task report. The methodology is considerably simplified for sports complexes because they can be analyzed on a well-defined single-event basis.

SECTION II

RECOMMENDATIONS

It is recommended that, as planned, the project officer employ this methodology to develop guidance for relating the traffic characteristics of sports complexes 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 craracteristics 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
2. Sports complexes (stadiums)
3. Amusement parks
4. Major highways
5. Recreational areas (e.g., State and National Parks)
6. Parking lots (e.g., Municipal)
7. Airports

This, the third task report, describes the methodology developed, and the analysis and results of its application to sports complexes.

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 in this report consists of describing automobile operating modes in and around complexes and the emission significance of each mode. In our analysis, this leads to an important emphasis of 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 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.

This general methodology is simplified somewhat for sports complexes because the traffic generated by them is not continuous, but instead is related to well-defined (i.e., by attendance and starting and ending times), isolated events. For this reason, the usage patterns need not be determined as a function of time; usage and traffic patterns can both be related directly to the time frame of each individual event.

Total running times and number of vehicles running, the desired quantitative descriptions of traffic behavior, can then be determined for each event instead of for one- or eight-hour periods of maximum usage. Qualitative guidelines which should provide further insight into factors related to traffic congestion around sports complexes are also presented. 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" cases cited in the section 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 the report describes the implementation of this methodology for sports complexes, and the results obtained.

SECTION IV

CHARACTERISTICS OF SPORTS COMPLEXES

Major spectator sporting events are held in two widely different and easily distinguishable types of facilities -- outdoor stadiums and indoor auditoriums. Highest attendances at outdoor stadium events, in descending order, are for football, baseball, soccer, and field and track. The most popular indoor sporting events are basketball and hockey. Stadiums built in recent years generally have a seating capacity of about 70,000,[1] whereas new auditoriums designed primarily for sporting events seat 20,000 to 25,000.

In addition to stadiums and auditoriums, special facilities exist for spectator sports such as horse or dog racing, auto racing, tennis, and competition swimming. These facilities have characteristics which distinguish them from the two "standard" facilities. For example, they may be used much less frequently and therefore have more temporary provisions for parking, seating, and traffic control. Also, these events usually attract smaller numbers of spectators.

All sports facilities have one characteristic which separates them from other complex sources: single-event orientation. Because of this characteristic, the traffic analyses are simplified, to traffic per event rather than complex variations of traffic with time, i.e., daily, weekly, and seasonal.

Sports facilities are further distinguished by their location. New stadiums and auditoriums are about equally split between downtown and suburban sites. Location affects traffic levels by influencing the modal split of spectators.

OUTDOOR STADIUMS

Because of time constraints, only one type of sports complex, the outdoor stadium, has been selected for more detailed analysis in this report. Stadiums were choosen becasuse they are the sites of the most frequent and highest-attended sporting events, and hence are the facilities of greatest concern as complex sources. However, the methodologies developed herein for relating characteristics of the complex to vehicle behavior in and around the complex are equally applicable to auditoriums and other sports facilities. Sites that are used very infrequently for large events, such as the Indianapolis Motor Speedway, may show extreme capacity excesses and more traffic congestion, but they are isolated occurrences and should not form the basis for methodology development.

General information on most of the recently-built stadiums in the country is presented in Table 1. This information was complied from published data[1,2] and from telephone surveys of stadium managers. Physical characteristics and traffic parameters for these stadiums, obtained from the same sources, are included in subsequent sections.

FUTURE STADIUMS

All of these relatively new stadiums except for the one in Kansas City are termed "second generation" stadiums because they have been designed specifically to accommodate both football and baseball, rahter than being designed as baseball stadiums which later have been used for football events. Since seating capacities, attendance patterns, and other parameters vary for the two sports, a dual-purpose stadium should actuall be analyzed separately for the different sports.

The Kansas City sports complex marks the advent of what may become the third generation of stadiums -- single-purpose structures side-by-side, sharing common parking and other auxiliary facilities. These stadiums have the advantage of optimum configuration for each event and avoid problems of shifting from one sport to the other. This design is not as expensive as might initially be expected, since the single-purpose stadiums can be kept simpler in design.

Table 1. RECENTLY CONSTRUCTED MAJOR U.S. STADIUMS

Name	City	Area of Stadium Complex, Acres	Location	Metropolitan Pop. (SMSA), Millions
Atlanta Stadiums	Atlanta	60	1 mile from CBD	1.39
(not yet completed)	Baltimore	50	Downtown	2.07
Rich Stadium	Buffalo	154	15 miles from CBD	1.35
Riverfront Stadium	Cincinnati	48	Downtown	1.38
Schaefer Stadium	Foxboro, Mass.	69	22 mi. from Boston CBD	2.74
Astrodome	Houston	260	6 miles from CBD	1.99
Truman Sports Complex	Kansas City	370	10 miles from CBD	1.25
Louisiana Superdome	New Orleans	55	Near French Quarter	1.05
Veteran's Stadium	Philadelphia	n.d.	2 miles from CBD	4.82
3 Rivers Stadium	Pittsburgh	80	Downtown	2.40
Busch Stadium	St. Louis	85	Downtown	2.36
San Diego Stadium	San DIego	166	7 miles from CBD	1.36
Robt. F. Kennedy Stadium	Washington, D.C.	60	4 miles from CBD	2.83

n.d. = no data

CBD = Central Business District

SMSA = Standard Metropolitan Statistical Area

The side-by-side single-purpose stadium concept may be carried a step further by locating other sports facilities adjacent to the stadium nucleus, forming what is truly a sports "complex". Such a design is presently nearing completion in New Jersey, where a football stadium for the New York Giants, a baseball park, an indoor facility for basketball and hockey, a race track, a hotel, and an exposition hall are all located at one site. In Philadelphia, Veteran's Stadium, John F. Kennedy Stadium, and the Spectrum Sports Arena are on the same site.

While the stadium authority which manages a multiple-facility complex would certainly attempt to prevent scheduling conflicts, unavoidable overlapping is a possibility. The chances of a conflict between major events increases with the number of facilities at the complex. If two events coincide, the traffic analysis would use the combined traffic volumes for the two events.

SECTION V

PARAMETERS FOR OUTDOOR STADIUMS

There are only a few measures of size and activity level which have been widely used as descriptive parameters for stadiums. These measures are part of the design criteria for the stadium, so they are known to the developer as early as the planning stage.

Coincidently, these few available parameters, presented below, also are important in estimating traffic volume and behavior at stadium events. However, empirical traffic parameters discussed in Section VI are equally important in the proposed methodology for estimating traffic patterns at stadiums.

SIZE

The size of a stadium is almost always expressed in terms of seating capacity. A dual-purpose stadium usually has a lower seating capacity for baseball than for football, due to movable seats and the different field configurations. Capacities of the newer stadiums are shown in Table 2.

For an individual sporting event (the basic unit for traffic analyses), the size is measured in attendance, which is obviously limited at the upper end by seating capacity plus the standing-room crowd. Attendance is a function of the sporting event being held. For professional football, average attendance for all teams over the past two seasons has been greater than 95 percent of capacity,[2] indicating that there is no significant difference between typical and peak attendance. Both can be accurately estimated by seating capacity.

Table 2. SEATING CAPACITIES AND PARKING AT STADIUMS

Stadium	City	Baseball Seating Capacity	Football Seating Capacity	Parking			Off-Street Parking Spaces Per Seat
				At Stadium	Parking Lots	On-Street	
Atlanta Stadium	Atlanta	51,400	58,800	4,400	5,500	*	0.17
(not yet completed)	Baltimore	55,000	70,000	6,500	6,700	900	0.19
Rich Stadium	Buffalo	-	80,000	15,000	-	800	0.19
Riverfront Stadium	Cincinnati	52,000	56,200	4,600	20,000	*	0.44
Schaefer Stadium	Boston	-	61,000	16,200	-	-	0.27
Astrodome	Houston	45,000	50,000	30,000	-	-	0.60
Truman Sports Compex	Kansas City	42,000	78,000	16,000	-	-	0.21
Louisiana Superdome	New Orleans	56,500	78,000	5,100	7,500	-	0.16
Veteran's Stadium	Philadelphia	55,000	65,000	6,800	5,000	*	0.18
3 Rivers Stadium	Pittsburgh	50,300	50,300	4,400	24,000	*	0.57
Busch Stadium	St. Louis	50,100	51,200	5,200	10,000	500	0.30
San Diego Stadium	San Diego	48,000	55,000	16,200	-	-	0.29
Robt. F. Kennedy Stadium	Washington, D.C.	45,000	54,000	11,500	-	1,000	0.21

* Combined in value for parking lots

Source: Personal communications with Stadium Managers, September, 1973, and ref. 2.

In contrast, capacity crowds for baseball are rare and usually occur only when the home team has a winning record or during post-season playoff games. Since the long-range won-lost record of a team cannot be accurately predicted, peak attendance should be assumed as the seating capacity of the stadium for baseball. Average (typical) attendance values may be obtained from market surveys for a new team or from past attendance records for an established team moving to a new stadium.

PARKING SPACES

The number of available parking spaces is a critical parameter for any complex source, and sports facilities are no exception. For purposes of analysis, total parking spaces should be obtained from three subtotals: stadium parking, other public and private lots, and on-street parking. The developer should have these three subtotal values.

The area allotted per vehicle in stadium parking lots may be slightly lower than at lots serving other types of facilities, primarily because parking is usually supervised and there is no turnover in the lot, making three-, four-, or five-deep stall parking more common. The range of gross areas (parking spaces plus access lanes) per vehicle is 170 to 260 sq. ft., with 200 sq. ft. a mean value.

Parking capacity is commonly evaluated in spaces per seat. Many cities have regulatory requirements for the number of off-street parking spaces serving public buildings. These requirements for stadiums and arenas are summarized in Table 3.[4] Corresponding values of off-street parking per seat for the stadiums surveyed are shown in Table 2.

The maximum distance that parking spaces may be located from the stadium is also a consideration. Observations by stadium officials have indicated that spectators are willing to walk as far as 2400 feet to a baseball game and 3000 feet to a football game.[2] These radiuses should be used in determining the parking available for each event.

Table 3. OFF-STREET PARKING REQUIREMENTS FOR STADIUMS AND ARENAS

Spaces per Seat	Value Specified in Regulation
Minimum	0.05
Maximum	0.33
Modal	0.25
Mean	0.20

Number of cities with

This basis = 91

With other basis = 53

With no requirement = 63

Ref.[4] : Zoning, Parking, and Traffic
David K. Witheford, Eno Foundation for Transportation, Saugatuck, Conn. 1972.

The distribution of parking spaces is also important. If all of the spaces are concentrated in a single stadium lot or a few parking garages, heavy congestion at entrance/exits and on the streets within a few blocks of the lot is inevitable. Even traffic distribution throughout the stadium area can best be achieved by more dispersed parking.

TEMPORAL PARAMETERS

Two parameters that are related to the stadium or the sporting event which are used in the traffic analysis are the stadium emptying time and the time periods when events are scheduled. Stadium emptying time is the number of minutes required after the game for the spectator seating area exitways, and concourses to be vacated. It is a function of stadium size, attendance, and configuration of the pedestrian system. Emptying time normally varies from 10 minutes for a typical crowd to 20 or even 25 minutes for a capacity crowd at a large stadium. It should be possible for the developer to estimate emptying time from the stadium design.

The schedule of events at a new stadium should be relatively fixed by league policies. The important determination on game starting and ending times is to check that they do not coincide with peak-hour traffic conditions on the nearby arterial streets and highways. With this exception, neither the timing nor duration of sporting events are factors in traffic analyses.

SECTION VI

TRAFFIC PARAMETERS, VALUES AND DERIVATIONS

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 the vicinity of the stadium and the volume of such traffic. Traffic parameters which should be used to develop these two values for a specific sporting event at a stadium are discussed in this section.

PARAMETERS TO ESTABLISH RUNNING TIMES

Concept of Emissions per Unit Time

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

For sports complexes, 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 insignificant at the lowest speeds;* and

2. Traffic movement in the vicinity of a stadium 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.

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* 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 4. These test data compare well with emission factors calculated from the current edition of AP-42,[6] when converted to grams/minute at various speeds and then extrapolated to zero speed.

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 of to 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 sports complex for any event 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 at Stadiums

For purposes of analysis, traffic movement in the vicinity of a stadium has been divided into the same eight operational modes that were specified for shopping centers and for airports. These are summarized below and shown schematically in Figure 1. Because vehicles parking at each of the three types of parking facilities have distinctly different running times in the operational modes, the modal analysis actually evolves to an 8 x 3 factor analysis.

Approach (A) - The time or distance along streets leading to the stadium in which total traffic movement is strongly affected by vehicles moving toward stadium area parking. This area of influence has varied from 0.5 to 1.5 miles in previous traffic design studies for stadiums.[2,7]

Entrance (I) - Waiting time at the ticket gate to the parking facility. (Negligible for on-street parking).

Movement in (MI) - Driving and waiting time within the parking facility. (Negligible for on-street parking).

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

Start (ST) - Starting of the engine and egress from the parking space (No cold start because of short duration of parking).

Movement out (MO) - Driving time or distance from the parking space to the preferred exitway. (Negligible for on-street parking).

Exit (E) - Movement through the exitway, including waiting time in a queue. (Negligible for on-street parking).

Departure (D) - The time or distance along streets within the immediate area of influence of the stadium.

The concept of a base running time for the eight modes is not usually applicable in analyzing traffic for a sports complex, since it is characterized by very high volume over a short period of time, and thus is either a peak flow or nonexistent.

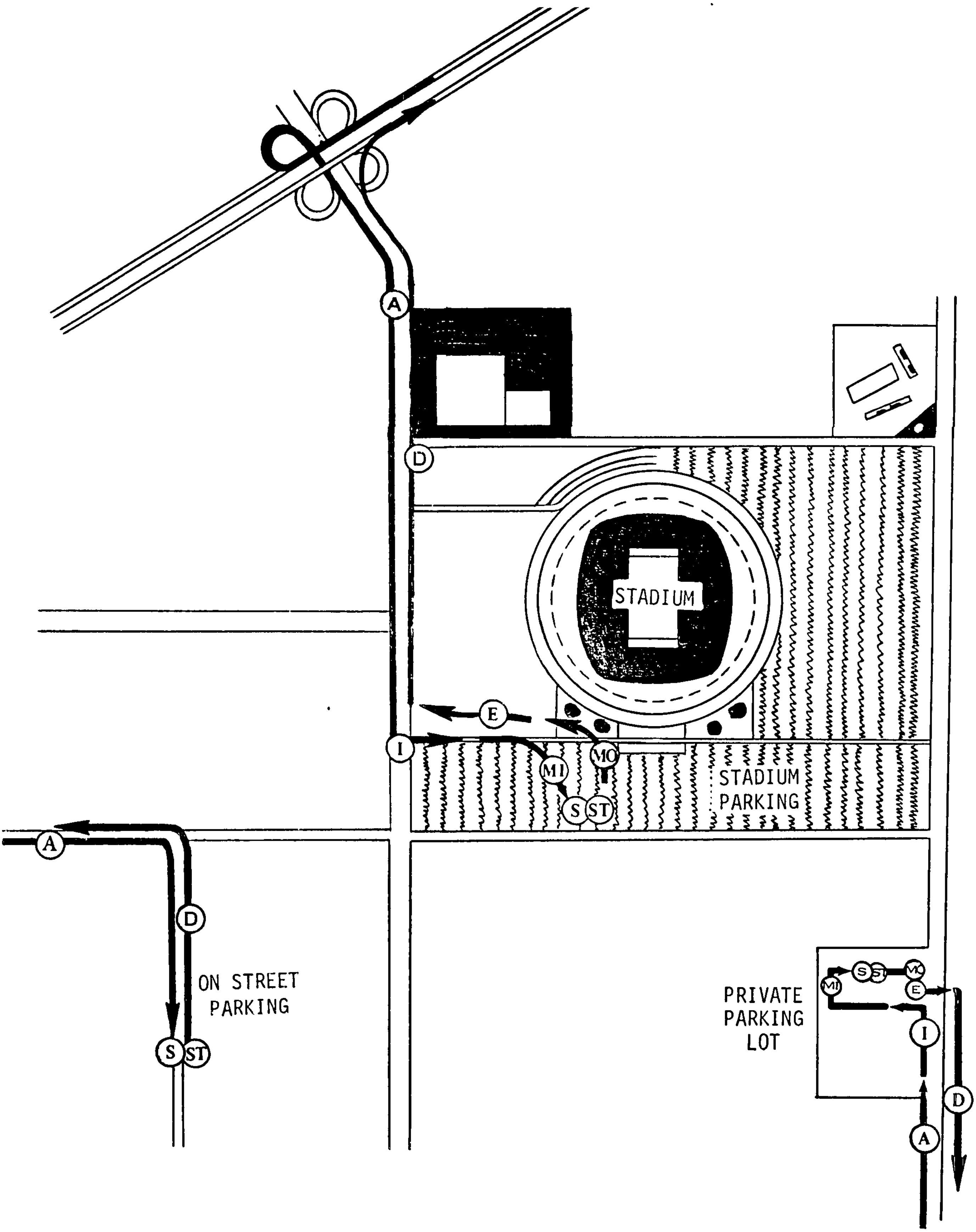


Figure 1. SCHEMATIC REPRESENTATION OF VEHICLE OPERATING MODES AT STADIUMS

Identification of Critical Modes at Stadiums

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

1. Exit
2. Departure
3. Entrance
4. Approach
5. Movement out

Exit time for a vehicle in a parking lot is a function of the egress capacity of the lot. Since all of the vehicles desire to leave the lot within a few minutes' time span after the game, exit gate capacities are almost immediately exceeded and the time in the exit mode becomes the average waiting time in the resulting queue.

Departure time is a function of the street capacities of those arterial streets and highways that carry the traffic away from the game. Again, as a result of the almost simultaneous departure of all vehicles from the stadium area, street carrying capacities may be exceeded with resulting increases in running times.

Time in the entrance mode is affected by the collection of parking fees as vehicles enter the parking lots. Queue lengths are moderated somewhat over those for the exit mode by the arrival of vehicles over a longer period of time.

Approach time, like departure time, is a function of the capacities of the surrounding streets.

Normally, movement out of a parking space and into the exit line requires such an insiginificant amount of time that it can be combined with the time for exit mode with no loss of accuracy. However, if the parking arrangement in the lot causes some of the vehicles to be blocked, long average waiting times in the movement-out mode may result as early returnees must wait for later ones to move their cars. Estimation of running times in this mode is further complicated by the observation that the waiting motorists do not necessarily start their engines while they are waiting.

Spectator Arrival and Departure Patterns

The spectators who travel by automobile arrive at the stadium area prior to the game with some distribution over time. However, this pattern either is not characteristic and set or it has not been investigated in detail, because previous transportation planning studies for stadiums have simply assumed that all the traffic for the game arrives at a uniform rate over the one-hour period immediately prior to the start of the game.[2,7] While further investigation would undoubtedly show that significant variations occur between different 10-minute intervals within this hour, the assumption that essentially all of the stadium traffic be assigned to the one-hour period appears to be valid. The few vehicles that arrive more than one-hour ahead of game time probably diminish the actual peak-hour traffic volume by about the same amount that private vehicles which drop off spectators within the peak hour but do not remain in the stadium area increase the actual volume over the estimate.

Spectator departure patterns can be predicted much more closely. The stadium emptying time, a value available from the developer, indicates the time after game end by which all motorists have reached stadium parking spaces. More remote private lots and on-street parking spaces would require an additional 5 to 15 minute walking time. With the assumptions that spectators leave the stadium at a constant rate over the period of the emptying time and start their autos immediately upon their return, the number of vehicles starting from each type of parking facility can be estimated for each minute following the end of the event. Design criteria call for a maximum of one-hour time for egress of all stadium traffic.

Traffic Assignments

Traffic volumes on surrounding streets during pre- and post-game periods are the sum of two components -- stadium and non-stadium traffic. Non-stadium traffic estimates should be requested from the developer for the specific pre- and past-game periods, since they are critical to the determination of adequate highway capacity for this particular complex source. They can usually be obtained from the local highway department.

Stadium traffic volume estimation is discussed later in this section. Its distribution is controlled by two primary factors, traffic origin and capacities of streets leading to the stadium. Traffic origin by direction may be approximated from the home addresses of season ticketholders, from market surveys, or by other estimating procedures.

These directional movements must be superimposed over the street system in the area of the stadium (0.5 to 1.5 mile radius) to determine the probable travel routes. The street capacities are used at this point. The assignment of traffic volume to the various approaching and departing routes, when added to the non-stadium traffic, should not exceed the peak-hour capacities of these streets.

PARAMETERS OF TRAFFIC AND PARKING

Spectator Transportation

The split of spectator transportation among autos, buses and other transit, and walking affects traffic volumes at the stadium. Charter buses and park-and-ride systems can account for significant portion of the total attendance. Walk-ins are usually a factor only when the stadium is in a downtown location.

The percent of spectators that normally arrive by auto at each of the stadiums surveyed is shown in Table 5. The range in these values is 66 to 96 percent and the mean is 83 percent. There does not appear to be any correlation between these percentages and the downtown vs. suburban location of the stadium. One reference states that designers usually assume 88 percent of the spectators will come by car.

Table 5. PARAMETERS FOR ESTIMATION OF TRAFFIC VOLUMES

Stadium	City	Percent Arriving by Auto	Av. Vehicle Occupancy	
			For Baseball	For Football
Atlanta Stadium	Atlanta	87/66	3.04	2.72
Rich Stadium	Buffalo	88	-	3.5
Riverfront Stadium	Cincinnati	90	n.a.	3.25
Schaefer Stadium	Boston	96	-	3.5
Truman Sports Complex	Kansas City	71	n.a.	3.52
Veteran's Stadium	Philadelphia	94	2.8	2.8
3 Rivers Stadium	Pittsburgh	70	3.47	n.a.
Busch Stadium	St. Louis	n.a.	n.a.	3.0
San Diego Stadium	San Diego	84	n.a.	3.1
Robt. F. Kennedy Stadium	Washington, D.C.	77	-	3.4
Average		83	3.1	3.2
Accepted Design Value		88	2.5	3.5

n.a. = data not available

Source = Personal communications with Stadium Managers, September, 1973, and ref. 2.

The number of spectators that arrive by bus can be estimated from the number of buses parked at the stadium. The developer should have a capacity value for this parameter available, since special provision must be made in design of the parking facility for bus parking. Occupancy for a park-and-ride bus is assumed to be 30 and for a charter bus, 40.[2]

Average Vehicle Occupancy

After the number of spectators traveling by auto is determined, this value can be converted to traffic volume for the event by dividing by average vehicle occupancy. This parameter purportedly varies from football to baseball and is directly proportional to crowd size,[2] although this variation is not shown in the surveyed values of average vehicle occupancy presented in Table 5. The accepted design values for vehicle occupancy are 2.5 for baseball and 3.5 for football.[2,7] The data in Table 5 does not reveal any significant change in car occupancy rates between a downtwon stadium location and a suburban one, either.

Parking Preferences

Parking capacity in the vicinity of a new stadium should very nearly approximate the maximum predicted traffic volume for a sporting event. The exception to this rule is a stadium located in a downtown area where more parking spaces are needed to handle workday parking requirements than for stadium events. If excess spaces are available, car occupancy and bus ridership may initially be low in response to anticipated ease of parking.

If parking capacity does exceed predicted traffic volume for a sell-out event, it should be assumed that the stadium lot and on-street parking spaces will be completely filled and that the remainder of the vehicles will use private lots.

For analysis of non-capacity events, the distribution of parking among the stadium lot, private lots, and on-street parking should also be known. Observations by stadium managers reveal that the stadium parking facility is often filled even for events with average attendance, indicating that this is the preferential parking area. These observations obviously are not for those stadiums where all or almost all of the parking spaces are at the stadium. On-street parking is apparently the second preference, although it does not provide a substantial percent of total parking even at non-capacity events. On-street parking is preferable for many spectators because of its lower cost and a walking distance comparable with that of a private lot.

A generalized procedure for the quantitative assignment of vehicles to the alternate parking facilities for a typical-attendance event would be quite complex. However, the developer should be able to provide a good estimate of the split of vehicles among the three types of parking facilities for a non-capacity event.

SECTION VII

ANALYSIS

In this section, the relationships are developed for converting the stadium parameters and traffic parameters into vehicle running times and numbers of vehicles running. The final step of combining all these intermediate results into a quantitative description of the stadium traffic problem is then treated in Section VIII, RESULTS.

STADIUM TRAFFIC VOLUME

The very straightforward procedure for estimating stadium traffice volume has been implied in the previous sections. In summary, the relationship is as follows:

$$V = \frac{(p)\ (A)}{avo} + B \text{ , where}$$

V = total stadium traffic volume, in vehicles

p = percent of spectators arriving by auto

A = attendance

avo = average vehicle occupancy, in persons

B = buses at game

Seating capacity is input for attendance (A) to estimate peak traffic, while average attendance is used to estimate typical traffic volume. This procedure is commonly used in planning and design calculations for stadiums.

The same number of vehicles, V, are moving in the stadium area in both the pre-game and post-game traffic periods. Note that this traffic flow is not tied to a specific time interval (i.e., vehicles/hour).

The number of buses either may be estimated by a calculation analogous to that for autos or may be requested by the developer. It is normally in the range of 100 to 400 buses because of equipment availability limitations. As a percentage of total traffic volume, this is quite small--less than four percent--and thus not critical to the accuracy of the traffic analyses. However, in the subsequent application of this data in estimating air pollutant emissions, the percent of total vehicles that are buses may be an important factor. Therefore, it is recommended that subtotals for automobile and bus traffic volumes be carried through the traffic analyses for later use in emission calculation.

APPROACH AND DEPARTURE TIMES

Running times for these two modes cannot be estimated by the methods used for the other modes because of the complex network of alternate routes involved and the interspersed traffic entry points. Other problems associated with the prediction of running times on the public access streets to the stadium are:

a. Determination of the distance from the stadium that is to be included in the calculation of running time in the two modes (stadium traffic may have some measurable effect on traffic conditions for many miles from the stadium);

b. The possible consideration of non-stadium traffic in the analysis, since it is slowed by the congestion and therefore produces more air pollutant emissions per vehicle-mile;

c. Difficulty in obtaining traffic volumes for periods of less than one hour's duration (traffic stalls of 5 or 10 minutes' length may go unnoticed when traffic volumes are averaged over an hour);

d. Inability to predict the degree of route-changing that drivers will undertake to minimize overloading of major access routes; and

e. Prediction and simulation of traffic controls, such as reverse-flow street operations and temporary parking bans on access routes, that will be employed to increase capacities and average speeds.

While running times cannot be determined, some analysis can be done to predict the potential for excessive congestion on the access routes during approach and departure periods. These are called capacity analyses, and are a comparison of estimated peak traffic flows to respective streets capacities. If this ratio is greater than one, severe traffic problems can be anticipated.

First, the origin and movement directions of the total stadium traffic volume must be determined, as briefly discussed in Section VI. A one-hour interval is proposed as the initial assumption for the duration of the pre-game traffic movement.

Post-game traffic occurs over a period of 5 to 10 minutes longer than the longest parking lot emptying time (see EXIT TIMES), provided that access route capacities are adequate to remove the traffic from the stadium area. If this time is longer than one hour, the post-game traffic flow rate should be estimated by dividing the traffic volumes by the period over which they occur.

These traffic flow rates are then assigned to specific access routes by constructing an imaginary "screen line" enclosing the stadium at a distance of 0.5 to 1.5 miles and placing the initial traffic flow estimates at the intersections of the access roads and the screen line, based on percent traffic movement in each direction to and from the stadium. The total stadium traffic should be accounted for with these assignments.

Next, non-stadium traffic volumes for the hour periods of approach and departure should be obtained for the streets with stadium traffic. The two partial traffic flow rates should then be added to get total hourly traffic flows at the several points around the screen line.

These initial flow estimates should be compared with street capacities for the same points and, ideally, the ratio should be less than about 0.9 in all cases. If the ratio for one arterial exceeds 1.0, while another in almost the same direction does not even approach capacity, the initial stadium traffic assignments may be modified so that both are providing the same level of service.

Traffic controls that will be used to alleviate stadium traffic congestion should be considered in specifying the street capacities.

The capacity analyses for the approach and departure modes for an event should be almost identical when using a one-hour traffic averaging time, since volumes and directions of origin would be the same. Potential differences are in incoming/departure street capacities and pre- and post-game non-stadium traffic flows.

This procedure for a capacity analysis is explained by use of example data in "Transportation Planning Considerations for New Stadia".[2]

ENTRANCE TIMES

Time spent entering a parking lot 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). The average vehicle inflow rate is determined by the capacity of the parking facility or the number of vehicles assigned to it divided by the one-hour pre-game ingress period previously discussed. The number of entrance lanes or gates to the lot should be determined by the developer or from design drawings (if the facility is a parking garage).

Average service time per vehicle ranges from about 0.10 minutes, 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. If no estimate can be obtained from available data, an average service time of 0.18 minutes should be used for parking lots and 0.20 minutes for parking garages.

The above input data are then used to calculate running time in the entrance mode by use of a modified version of the equation for queue waiting time that was used for shopping center entrance and exit gates:

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

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

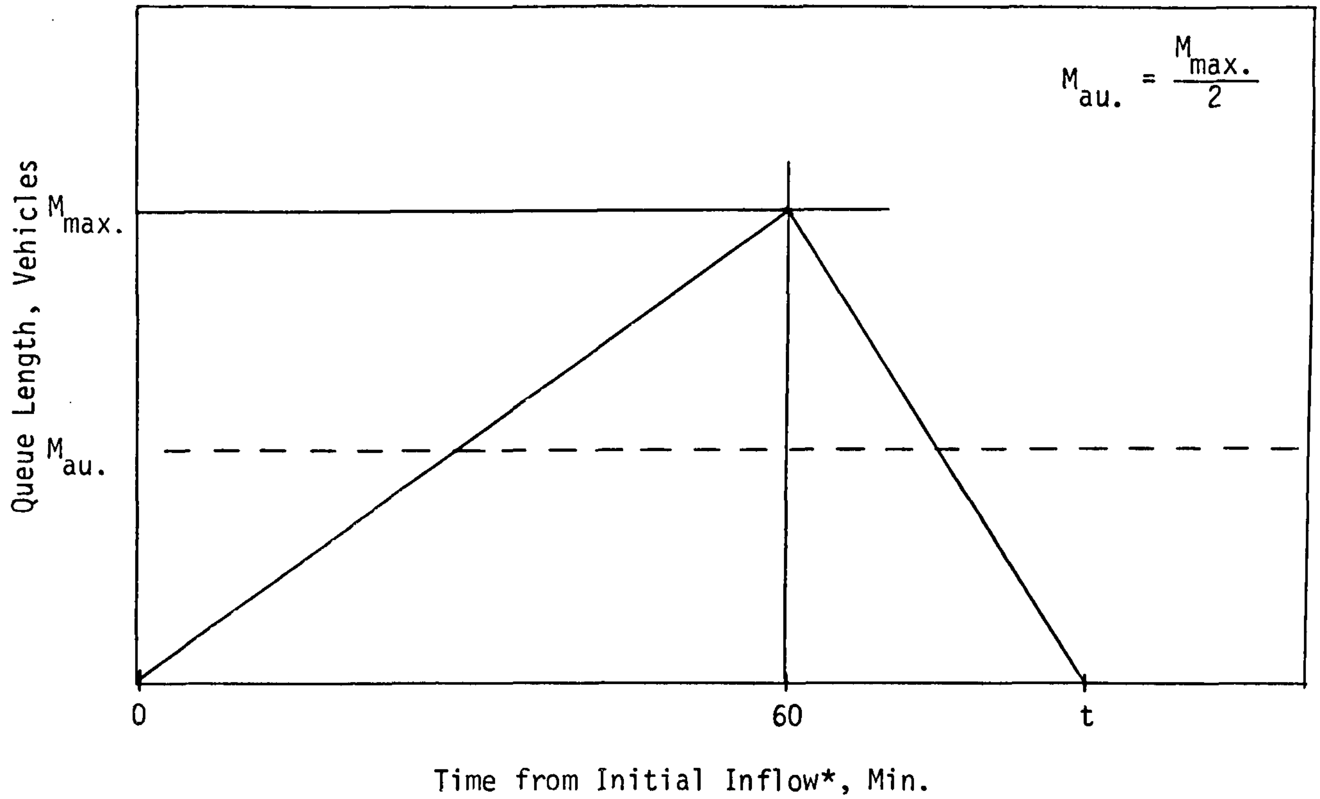
$$b = \text{average service time, min.}$$

The utilization factor, a, in this equation cannot equal or exceed 1.0. If the first calculation of "a" shows a value of one or greater, this indicates that the entrances are operating at capacity for the entire pregame hour and still have a remaining queue at the end of the hour. Under this condition, "a" should be set equal to one (complete gate utilization) and the same equation should be used to solve for the time needed to completly fill the lot. This time is the denominator of the vehicle inflow rate in vehicles per minute. Carrying the calculation further, the number of cars in each queue at the end of the first hour can be determined by dividing the inflow time greater than one hour by the average service time, b. This step follows because no more cars are entering the queue after the first hour in the proposed simulation, so the queue dissipates to zero at the constant rate of the service time over the extra time period. Finally, since the queue length builds and dissipates at approximately constant rates with time before and after the end of the hour as shown in Figure 2, the average queue length over the entire period can be estimated as one-half the previously calculated maximum queue length. Running time for $a \geq 1$ is then:

$$RT = (\text{average queue length})\ (\text{av. service time})$$

$$= \left(\frac{M \text{ max.}}{2}\right)(b) \text{ , where}$$

$$M = \text{queue length, in vehicles}$$



* A one-hour pre-game period for inflow of all stadium traffic is stipulated.

Figure 2. QUEUE LENGTH AS A FUNCTION OF TIME WHEN GATE CAPACITY IS EXCEEDED

Use of the queueing equation is illustrated in the following example. The stadium lot at RFK Stadium in Washington, D.C. is filled to its capacity of 11,500 cars. There are 28 entrance lanes, and an average service time of 0.18 minute is assumed. Average running time for the entrance mode would be:

$$a = \frac{\left(\frac{11500}{60}\right)(0.18)}{28}$$

$$= 1.23$$

Since $a > 1$, solve for total ingress time;

$$1 = \frac{\left(\frac{11500}{t}\right)(0.18)}{28}$$

$$t = 74 \text{ minutes}$$

$$M_{max.} = \frac{74-60}{b}$$

$$= 78 \text{ autos}$$

$$M_{au.} = \frac{78}{2}$$

$$= 39 \text{ autos}$$

$$RT = (39)\ (.18)$$

$$= 7.0 \text{ minutes}$$

The basic queueing theory equation employed here assumes that vehicles reach the entrances randomly over the specified time interval and distribute themselves optimally among the alternate entrances. Errors resulting from these assumptions are thought to be much lower than those involved in quantifying the input data (vehicle inflow rate and service time).

This procedure should only be used for off-street parking areas. The portion of the vehicles that utilize on-street parking have no entrance, movement in, movement out, or exit modes. The stadium parking facility and private lots should be analyzed separately, because of demonstrated differences in spectator parking preferences between these two types of facilities. However, the private lots may be grouped together for a single analysis under the following conditions:

a. Very small lots (less than 50 cars) are excluded from the analysis;

b. The total number of entrances lanes can be accurately determined;

c. No strong driver preferences are indicated among the private lots; and

d. A single lot does not account for more than 30 percent of the vehicles using private lots.

MOVEMENT OUT TIMES

In conventional parking facilities, all parking spaces have free access to traffic aisles and vehicles can therefore depart at the driver's convenience. Some stadium lots, because of their relative infrequent usage, have been modified for more compact parking arrangements in which cars are parked 2 to 5 deep and cannot leave until all cars blocking their access to the nearest aisle have moved. Typical space savings from "stall" parking are shown in Table 6.

Table 6. AREA CONSUMPTION PER PARKING SPACE[3]

No. of Cars in Stall	Area per Parking Space, sq. ft.
1	262
2	209
3	191
4	182
5	176
6	173
7	170

While the running time in the movement-out mode from the parking space to the end of the exit queue is negligible for the conventional parking lot, it can be significant if the car is running but unable to move from the space. This situation has been investigated by Hauer and Templeton,[3] who have developed a probability function to estimate the average waiting times associated with stall parking, based on the average cars-per-stall and the stadium emptying time. This function has been solved for cars-per-stall values of 2 through 7, and the resulting average waiting times have been summarized in Table 7.

Table 7. WAITING TIMES FOR EXIT FROM PARKING STALLS

Average Cars Per Stall	Average Waiting Time, Minutes
2	.083 (s.e.t.)*
3	.138 (s.e.t.)
4	.179 (s.e.t.)
5	.210 (s.e.t.)
6	.235 (s.e.t.)
7	.255 (s.e.t.)

* s.e.t. = stadium emptying time in minutes

The above derivation was primarily for application to a stadium event or other large public gathering characterized by a single termination time, so it should be appropriate for use. Important assumptions in the derivation are:

a. All passengers of each car are considered as a single spectator with a single arrival time at the car;

b. The spectators reach their vehicles randomly over a total period of time which may be approximated by the emptying time of the stadium; and

c. The order of arrival of the spectators is completely independent of their vehicles order in the parking stalls.

As previously mentioned, waiting time is not necessarily equal to running time in the movement out mode, because the motorists may not start their engines until their exit path is cleared. Returning spectators are more likely to start their engines immediately in very warm or very cold outside temperatures. No quantitative relationship has been determined for estimating running time as a function of waiting time and temperature.

EXIT TIMES

A simple model is proposed for estimating average running times in the exit mode. First, the model hypothesizes that vehicles begin leaving the parking lot almost immediately following the end of the event and that the rate of exiting from the time of this initial outflow until the lot is emptied is determined by exit gate capacities for the lot. While this assumption may not be valid for the first few cars and last exiting cars, it does not appear to alter the final predicted value of running time substantially because it is correct for almost all of the vehicles. Based on this assumption, the total emptying time for a lot is calculated as the number of parked vehicles divided by the gate capacity (in vehicles per minute).

Observed values of capacity exiting rates show them to be of the same magnitude as average service times upon entry--0.13 to 0.22 minutes per vehicle, or 8 to 13 vehicles per minute per exit lane. Values are held within this range by required merging and turning movements in the exit areas.

The estimated total emptying time for a parking lot is a parameter that is easily checked by observation. Calculated values are compared with observations of stadium managers in Table 8. The good correlation partially verifies the applicability of the proposed model.

Table 8. CALCULATED AND OBSERVED PARKING LOT EMPTYING TIMES

Stadium Lot	Parking, Vehicles	Exit Lanes	Calculated Emptying Time, Minutes	Observed Emptying Time, Minutes
RFK	11,500*	36	32	40 to 45
Busch	5,200*	13	40	35 to 40
	3,500	13	27	20
Rich	15,000*	30	50	75
	13,500	30	45	40
San Diego	16,200*	32	51	60

* Capacity

If all the vehicles were started at the time of initial outflow, the average running time per vehicle would be one-half of the lot's emptying time. However, the returning spectators actually start their cars and enter the exit queues randomly over a time period equal to the stadium emptying time (this same hypothesis was used for the movement-out made). Therefore, the average running time is reduced by a time equal to one-half the stadium emptying time, and is estimated as follows:

$$RT = \frac{\text{Parking lot emptying time - stadium emptying time}}{2}$$

This simple relationship appears to be quite adequate as an estimating tool for capacity (peak) events and, in most cases, also for typical attendances. As the stadium emptying time (s.e.t.) approaches the parking lot emptying time (p.l.e.t.) for low-attendance events, the equation obviously becomes unsatisfactory. When the p.l.e.t. minus the s.e.t. is less than one or negative, the condition of random arrival at the queue is met and the queueing theory equation can be employed to estimate the average running time in the exit queue:

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

a = utilization factor

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

b = average service time, min.

The procedure is illustrated in the following example. Stadium parking garages at Busch Stadium in St. Louis have a capacity 5,200 vehicles and 13 exit lanes. For one event, 4,400 spaces are filled. Exit running time is:

Estimated max. rate/lane = 10 vehicles/minute

Total exiting rate = 10 (13 exit lanes)

= 130 vehicles/minute

$$\text{p.l.e.t.} = \frac{4400}{130}$$

s.e.t. = 15 minutes

$$RT = \frac{\text{p.l.e.t. - s.e.t.}}{2}$$

= 9.4 minutes

Exit analyses become more complex if parking lot egress is impeded by street congestion immediately at the exit. If this condition exists or is anticipated, the longer resulting exit times should be attributed to the departure mode and the vehicles considered to be displaced from the exit for purposes of analysis.

SECTION VIII

RESULTS

METHODOLOGY

In general terms, the methodology proceeds as described in the first paragraph which follows. It should be emphasized that this description is of the technique, shown schematically in Figure 3, 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, and particularly for sports complexes.

Starting from the physical, geographic, and demographic characteristics of the complex, relationships are established for estimating typical and peak traffic volumes. The concepts of operational traffic modes are used to generate best estimates of associated running times for cars. The parameters of the center which significantly and adversely impact traffic behavior are also defined. 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 center parameters and 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. This generality is modified somewhat for application to each type of complex.

In the case of sports complexes, as shown in Figure 4, the methodology proceeds from basic information about a given sports complex (see Section V), via traffic behavior data (see Section VI) and traffic volume projections (see Section VII) to generate estimates of peak and typical numbers of vehicles and associated running times per event. The same procedure for

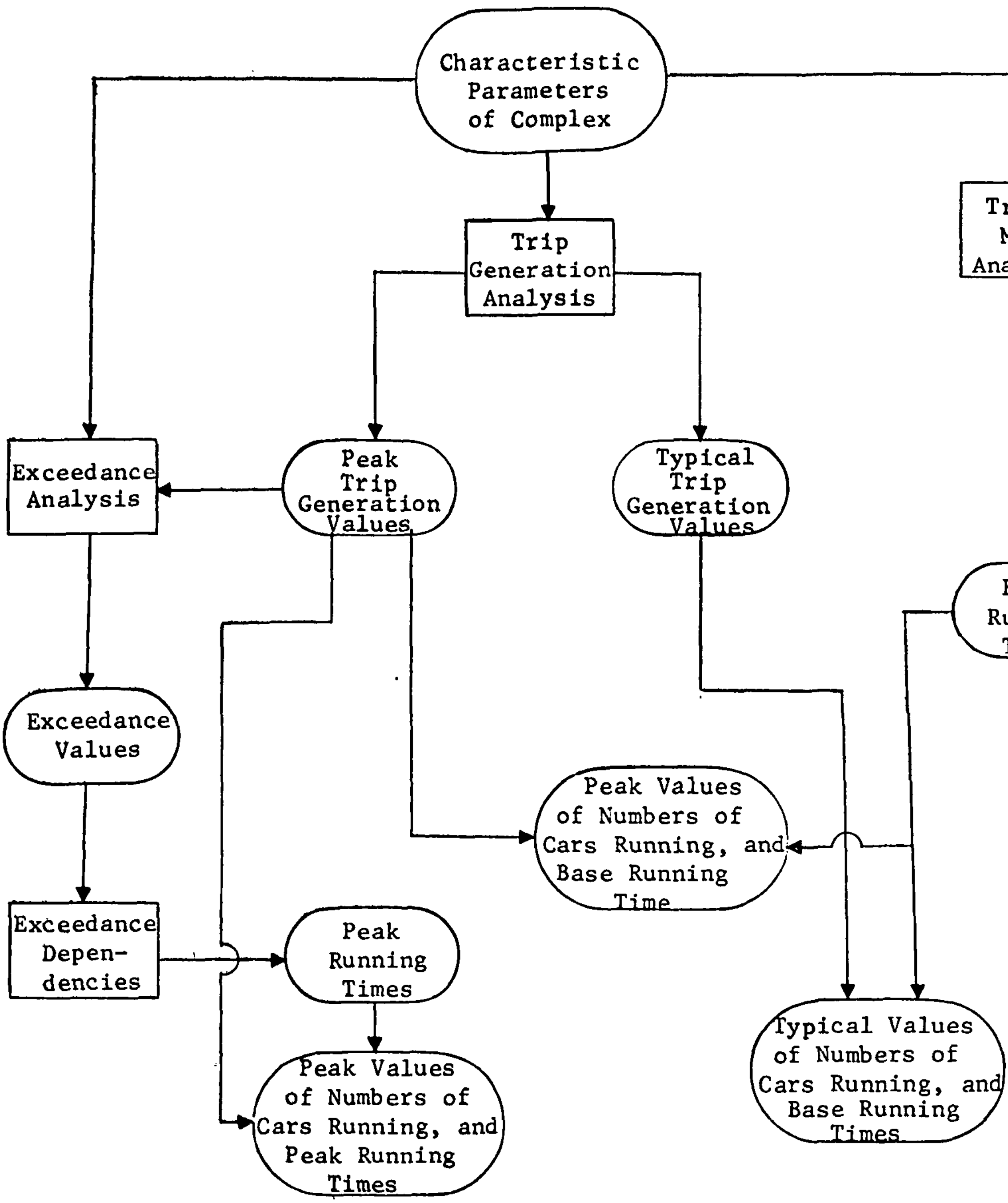


Figure 3. GENERALIZED METHODOLOGY

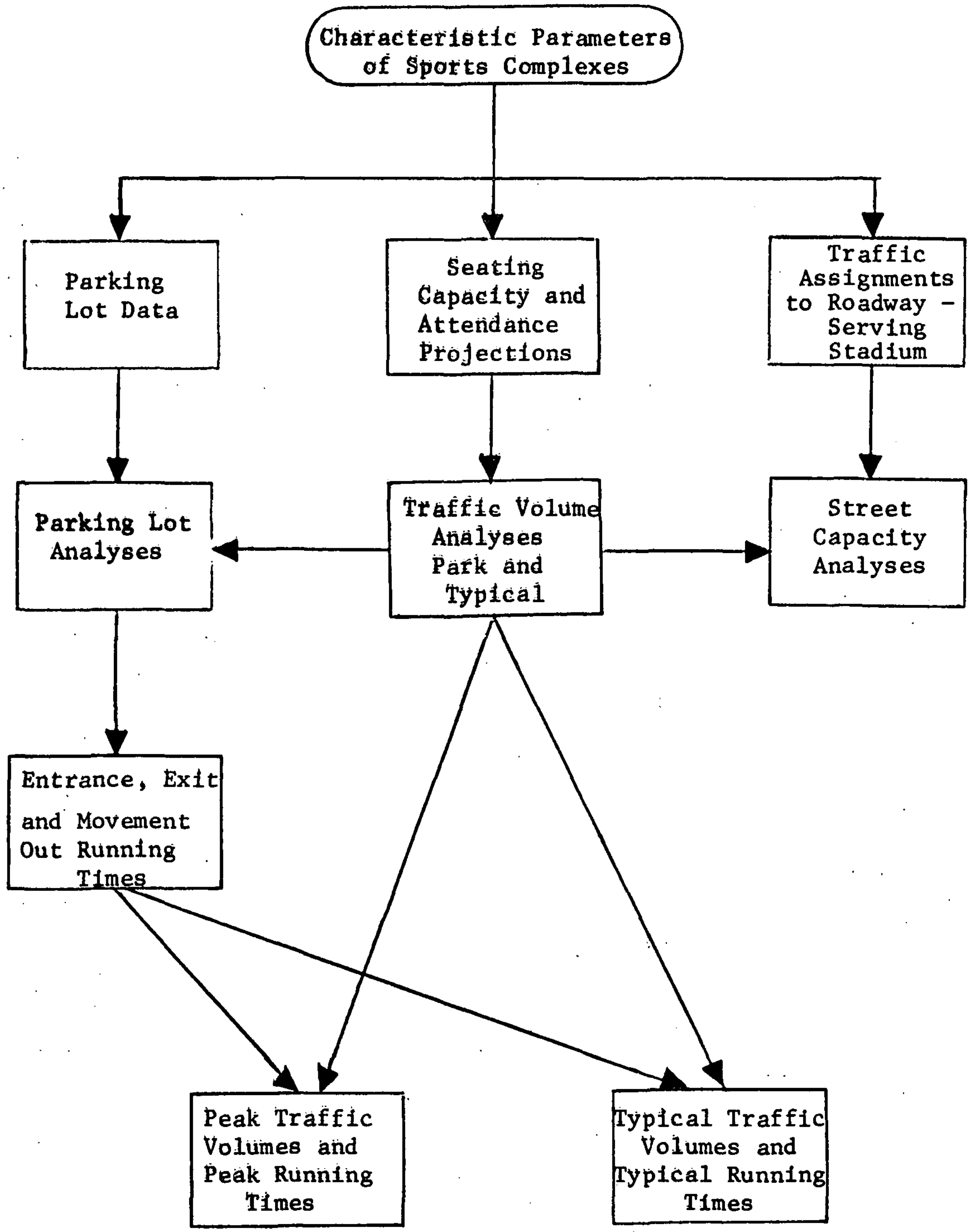


Figure 4. METHODOLOGY APPLIED TO SPORTS COMPLEXES

calculating running times is employed for both peak and typical traffic conditions.

Two significant one-hour periods can be analyzed individually for each event--the hour immediately preceding the event and the hour immediately following the event. Post-game running times are generally longer than pre-game times. Any eight-hour period of interest would include both of these hours, plus any runovers of traffic movement into adjacent hours. The quantitative descriptions of traffic volumes and running times for the one- and eight-hour periods are the required end products of the task.

The specifics of the procedure are presented below. First, the attnedance associated with peak and typical events at the stadium are delineated. These are converted into number of vehicles coming to the event by determining the percent of spectators traveling by car and the average occupancy per vehicle. After the total number of vehicles has been estimated, this number is divided among the three available types of parking facilities according to capacities and parking preferences.

Running times in six of the operating modes are then determined. Because of reasons outlined in Section VII, it is not possible to develop accurate estimates for running times in the approach and departure modes. 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. Because the parking lots at stadiums generally have supervised parking, movement into a parking space becomes primarily a function of the type and size of parking facility. The average running time for this mode, which should be relatively independent of traffic volume, can probably best be estimated from a diagram of the stadium parking areas. Running times in the entrance, movement out, and exit modes are estimated by the procedures presented in Section VII as functions of the number of vehicles parked and physical characteristics of parking lots.

A schematic diagram similar to Figure 1 may be helpful in analyzing the operating modes at the different parking areas around the stadium under investigation. The average running times for the total stadium traffic are simply the weighted averages of running times for all the segments that are analyzed separately. On-street parking, for instance, does not generate running times other than small times for movement in, stop, start, and movement out. However, it does contribute to the traffic volume considered in the street capacity analysis.

Finally, the street capacity analysis is performed to test the adequacy of the access routes to and from the stadium (see Section VII). The results of this analysis are not additive with those from the other modes; rather, they indicate a potential problem and the need for further traffic studies.

In summary, the main concerns for a sports complex are for adequate parking capacity, adequate parking lot gate capacity, and adequate street capacity.

GEOGRAPHIC DISTRIBUTION

The sports complex is characterized by infrequent but extremely high volume traffic and therefore is prone to capacity excesses and queueing problems. Running times, and hence emissions, at a sports complex are usually concentrated around entrances, exits, and points of constriction and merging along the access routes.

Running times within the lots are relatively low because of supervised parking, except in the case of exit queues extending throughout the parking facility. A less common circumstance leading to high running times in the parking area is the blocking of vehicles attempting to exit from stall parking (cars parked two or more deep).

Other isolated points of traffic congestion are passenger discharge/pickup areas and pedestrian street crossings.

The procedure of estimating running time for each mode individually allows some of these areas of high emission density to be evaluated quantitatively. Emissions from a queue or an access street carrying its capacity can be simulated as a continuously emitting line source.

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 9. For ground level sources, such as automobiles in stadium parking lots, 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 stadiums is cited as late fall-early winter in Section V titled "Parameters for Outdoor Stadiums", with the highest day usually being a late fall Saturday or Sunday. The peak hour of use on any given weekend is generally during departure, say, 5 to 6p.m. The peak eight-hour period would encompass the entrance period (1 to 2p.m.) as well as the exit period, and thus would run about, say, noon to 8p.m.

Since the period of concern occurs during the transition from autumn to winter, the meteorological conditions which characterize the period of use of stadiums 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 5 through 8, taken from Holzworth, 1972. An occasional evening secondary peak is discussed later. 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 rare 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 any evening peak use period. For the weekend afternoon peak,

* This section was prepared by Mr. Robert C. Koch, Senior Research Scientist of GEOMET, Incorporated.

Table 9. KEY TO STABILITY CATEGORIES (after Turner 1970)

Surface Wind Speed (at 10 m), m sec^{-1}	Day: Incoming Solar Radiation			Night	
	Strong	Moderate	Slight	Thinly Overcast or ≥ 4/8 Low Cloud	≤3/8 Cloud
<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.

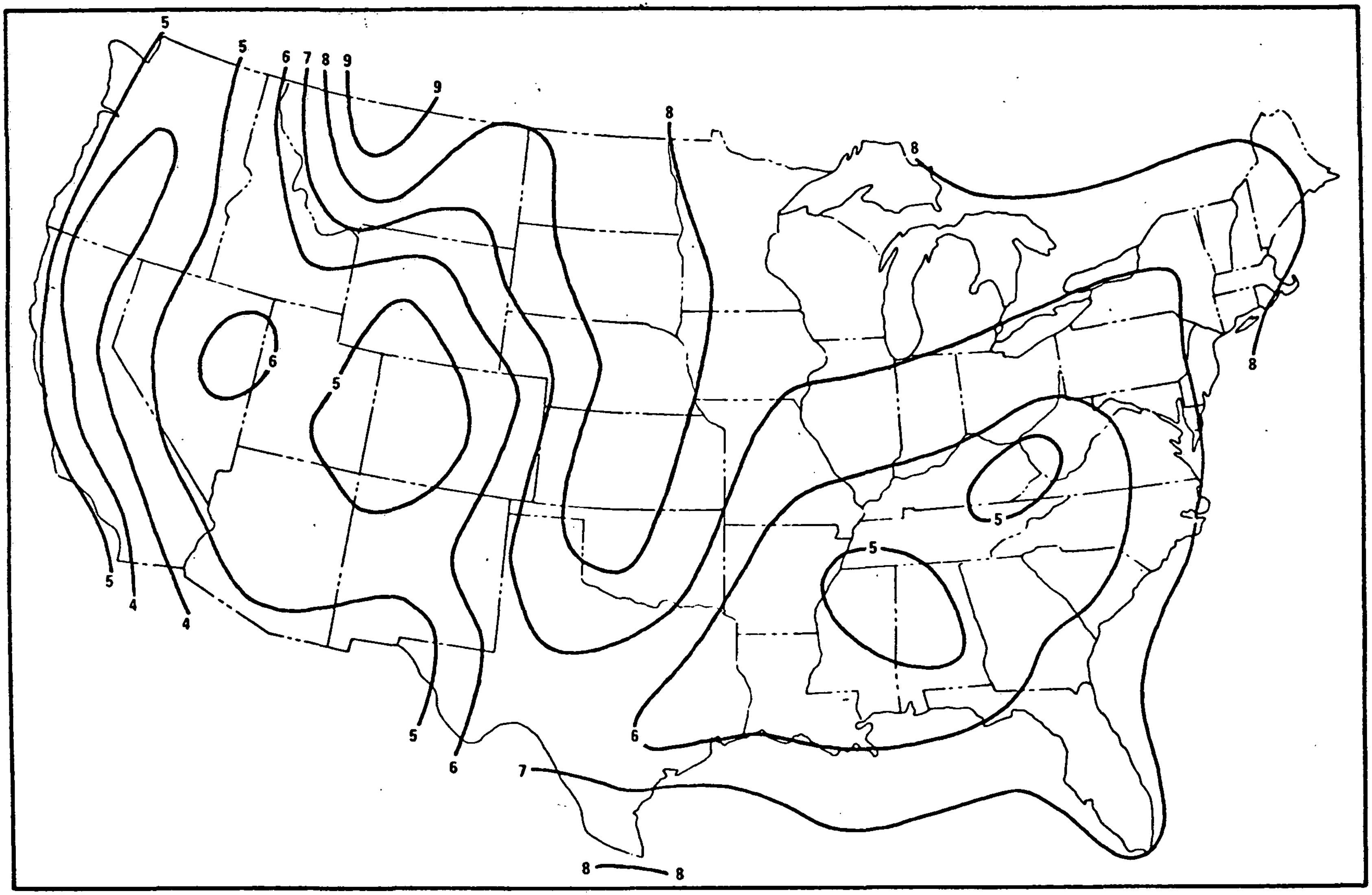


Figure 5. ISOPLETHS (m sec^{-1}) OF MEAN AUTUMN WIND SPEED AVERAGED THROUGH THE AFTERNOON MIXING LAYER

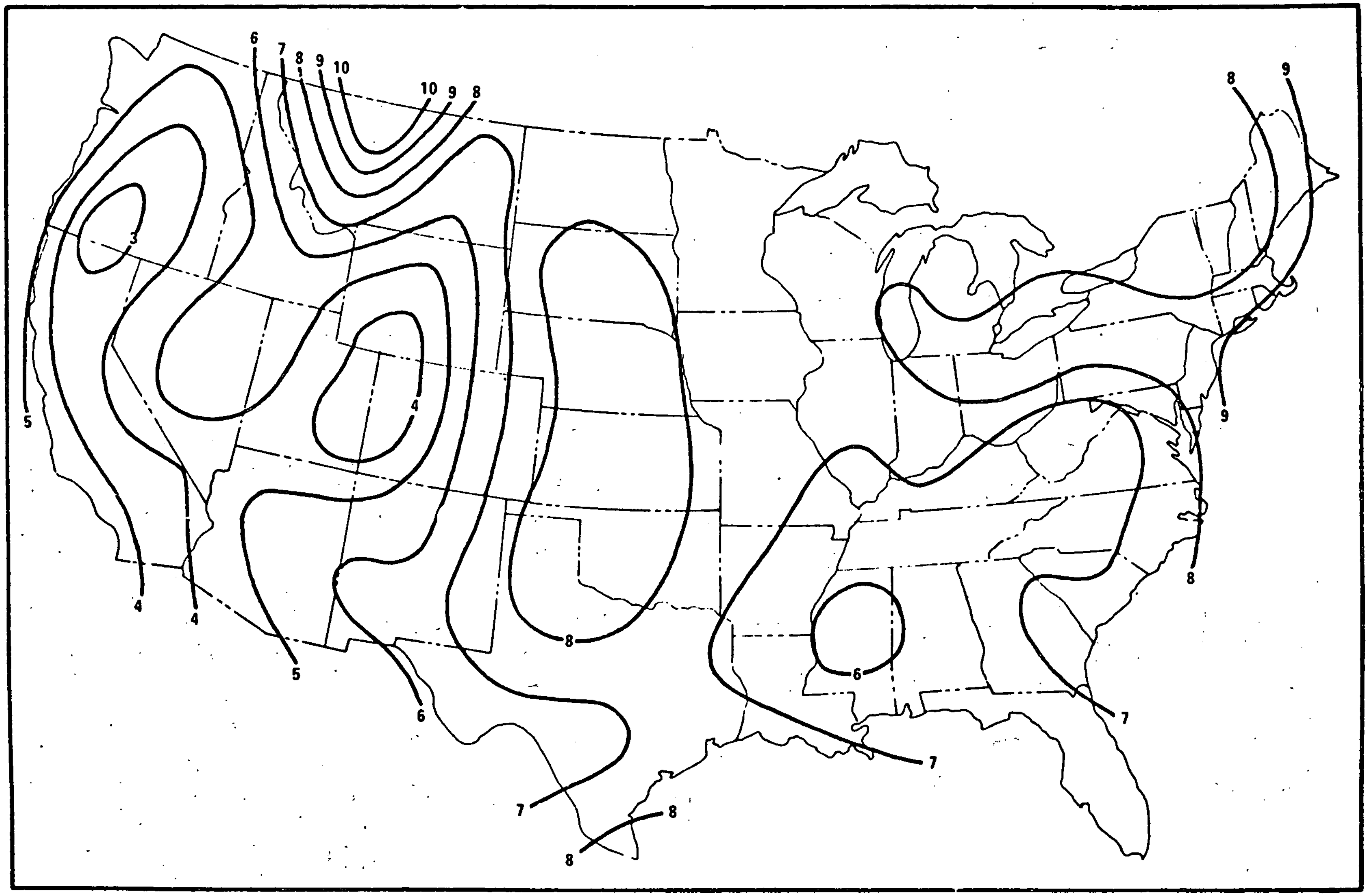


Figure 6. ISOPLETHS (m sec^{-1}) OF MEAN WINTER WIND SPEED AVERAGED THROUGH THE AFTERNOON MIXING LAYER

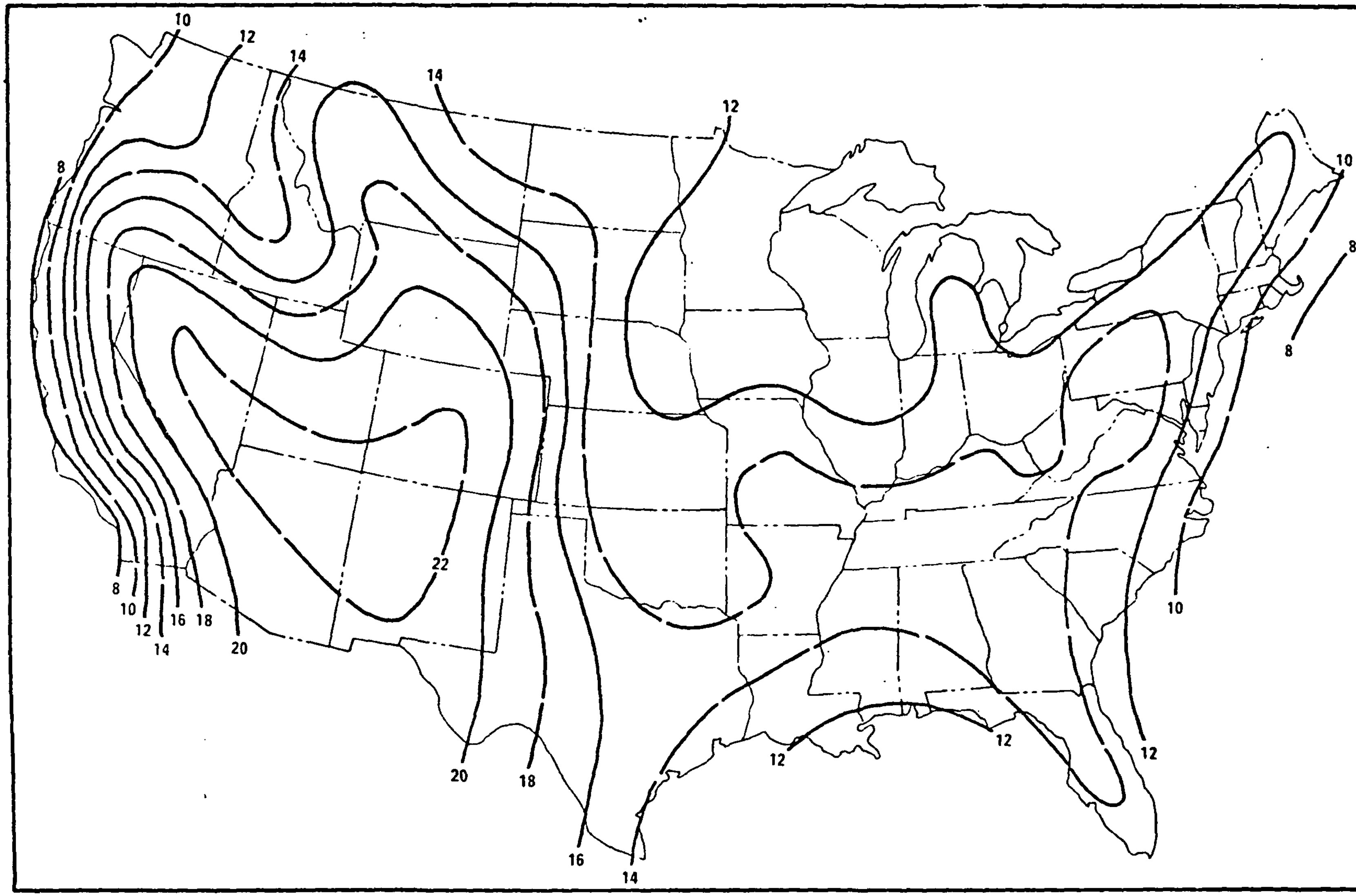


Figure 7. ISOPLETHS (m x 10^2) OF MEAN AUTUMN AFTERNOON MIXING HEIGHTS

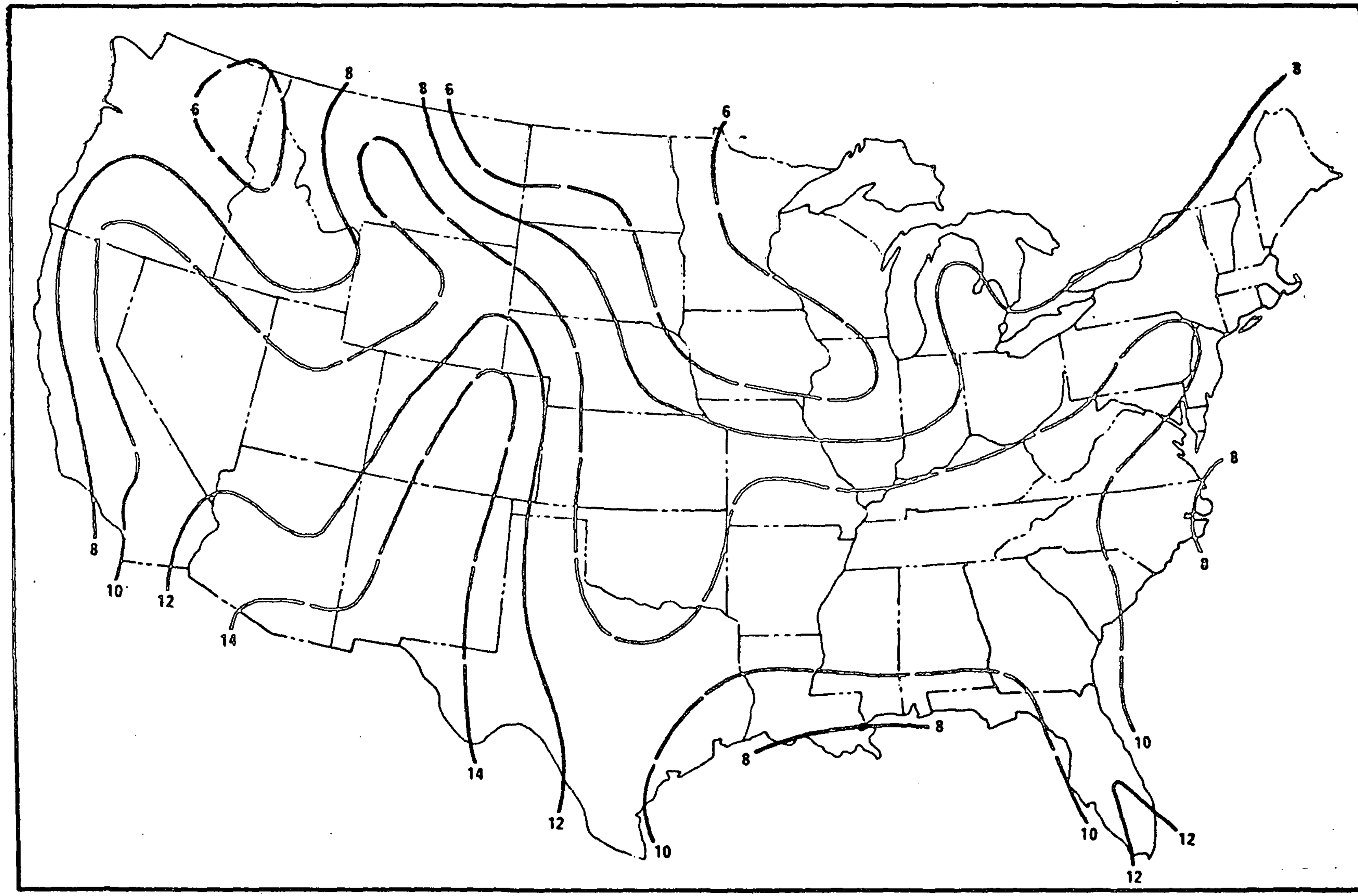


Figure 8. ISOPLETHS (m x 10^2) OF MEAN WINTER AFTERNOON MIXING HEIGHTS

atmospheric stability classes B, C, and D may occur with classes C and D being the most prevalent. During any 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, if an evening peak use period occurs, it will probably be associated with more stable conditions, and may be the more critical period for air quality considerations from the viewpoint of joint consideration of peak use and adverse meteorology.

The period when meteorological conditions are least favorable for diluting pollutants is the period when stadiums 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 there may be a fall or early winter evening game occasionally, then, from a meteorological point of view, the single hour least favorable for dispersing pollutants during that period would be during departure, from say, from 11p.m. to midnight, during the autumn season. The least favorable eight-hour period would be from 4 to midnight.

QUALITATIVE GUIDELINES

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

1. Conflicts between large numbers of pedestrians and traffic, both concentrated in the same time frame and in the area of the stadium, can cause substantial increases in running times. The interruption of traffic flow can be minimized by extensive use of grade separations--bridges, ramps, and underpasses--and by close-in curb frontage for high-volume discharge and pickup of passengers.

2. Temporary traffic controls, particularly reverse-flow one-way streets, can be very effective for increasing access route capacities in the vicinity of the stadium. These traffic controls are particularly important for stadiums that are located in built-up downtown areas where lanes cannot be added to existing streets.

3. The developer should provide plans for expected traffic circulation patterns around the stadium. These should be checked for:

- no left turn movements across traffic
- right turns in and out for garage traffic
- maximum use of one-way and divided streets
- two-lane exits from parking lots onto streets.

4. Traffic information signs should be promimently displayed to improve traffic movement.

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 allotted to or occupied by a single vehicle? See Table 6 and accompanying text.

2. Percentage of land and parking spaces potentially occupied by vehicles? The usual percentage? The stadium proper occupies about 15 acres. If streets are internal to the complex, they may account for 3 to 5 acres. The remainders of the gross stadium areas shown in Table 1 are devoted to parking. This averaged about 85 percent.

3. Typical and peak values (absolute or fractional) of vehicles running for one- and eight-hour periods? All of the vehicles are running during the typical and peak one-hour periods. All of the vehicles complete one cycle of operating modes during the typical and peak eight-hour periods.

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 Outdoor Stadiums.

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

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

REFERENCES

(1) The Stadium: All American Monument. Progressive Architecture. November 1971.

(2) Ashwood, J.E. Transportation Planning Considerations for New Stadia. Traffic Engineering, Vol. 143, No. 10. July, 1973.

(3) Hauer, E. and J.G.C. Templeton. Queuing in Lanes. Traffic Quarterly.

(4) Witherford, D.K. and G.E. Kanaan. Zoning, Parking and Traffic. The Eno Foundation, Saugatuck, Corr. 1972.

(5) A Study of Emissions from Light Duty Vehicles in Six Cities. Automotive Environmental Systems, Inc. Environmental Protection Agency Publication No. APTD-1497. March, 1973.

(6) Compilation of Air Pollutant Emission Factors. Environmental Protection Agency Publication No. AP-42, Second Edition. April, 1973.

(7) Proposed Roadway Improvements, Jackson County Sports Complex Area. Howard, Needles, Tammen and Bergendoff, Kansas City, Missouri. February, 1969.

(8) Holzworth, G.C. 1972. Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States. U.S. Environmental Protection Agency, Office of Air Programs, Research Triangle Park, N.C. AP-101.

(9) Turner, D.B. 1970. Workbook of Atmospheric Dispersion Estimates. U.S. Department of Health, Education, and Welfare, National Air Pollution Control Administration, Cincinnati, Ohio. AP-26.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

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A general methodology is presented for relating parameters of traffic behavior at sports stadiums, including vehicle running time, traffic volume and vehicle occupancy, to more readily available characteristics of stadiums, including seating capacity, parking capacity and stadium emptying time. Such relationships are to be used to relate staduim characteristics to air quality.

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