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VEHICLE BEHAVIOR IN AND AROUND COMPLEX SOURCES AND RELATED COMPLEX SOURCE CHARACTERISTICS VOLUME II - AIRPORTS

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Water Programs
Office of Air Quality Planning and Standards
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VEHICLE BEHAVIOR IN AND AROUND COMPLEX SOURCES AND RELATED COMPLEX SOURCE CHARACTERISTICS

VOLUME II - AIRPORTS

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ABSTRACT

The report presents an application of 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 a broad quantitative fashion for the second of seven types of complex sources, airports; the information generated, relating airport parameters to the associated traffic behavior, will now be used by the sponsor to generate guidance for studying the impact of new airports on air quality. The point is made, however, that the development of a major new airport, or of a major addition to an existing airport, represents an event of sufficient rarity and magnitude, that it will inevitably require an extensive and intensive environmental impact study of its own, including major concepts in land development. A significant part of this must be a detailed study of all emission sources associated with the airport, including vehicles. Such a technique for vehicular sources is cited as part of a complete methodology being developed separately as part of the ongoing work of another EPA contractor, Argonne National Laboratory.

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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 second (airports) 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 (sports complexes), and apply the methodology appropriately.

SECTION II

RECOMMENDATIONS

It is recommended that, as planned, the project officer employ this methodology to develop broad guidance for relating the traffic characteristics of airports to typical and peak air pollution concentrations; however each new major airport or addition to an existing airport will require special additional detailed analysis in its own right.

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 (15 Aug. - Report submitted)
2. Sports complexes (stadiums) (next sub-task)
3. Amusement parks
4. Major highways
5. Recreational areas (e.g., State and National Parks)
6. Parking lots (e.g., Municipal)
7. Airports (the present sub-task report)

This, the second task report, describes the methodology developed, and the analysis and results of its application to airports.

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 seeding 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.

Basic parameteric 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 the report covers special considerations required in the case of airports, and describes the implementation of this methodology for airports, and the results obtained.

SPECIAL CONSIDERATIONS FOR AIRPORTS

The construction of a major new airport, or the construction of a major addition to an existing airport, is of sufficient significance and rarity that it customarily receives extensive preparatory study in its own right, including complete environmental impact analysis. This is required because such a development involves not only extensive aircraft activity and non-aircraft airport activity which are sources of pollutant emissions, but will frequently generate associate land development which will in turn involve additional emission sources.

Reflecting the import and impact of such a development, the Environmental Protection Agency is presently sponsoring the development, under contract to the Argonne National Laboratory, of a complete methodology to enable airport, transportation and comprehensive planners to incorporate environmental considerations into the site selection and design of airport facilities, and into planning for the development of the land in the airport environs. The portion of the Phase I report (air pollution) which deals with access traffic is called to the reader's special attention, in order to demonstrate the magnitude and complexity of a complete and proper assessment of emissions from access traffic alone.

This is not to say, however that there is not a need for a general set of guidelines which comprise a simpler version of the methodology, and which treats, in simplified form, those aspects of traffic behavior which form the major portion of the pollutant emissions. Accordingly, the generalized methodology developed in the first of this series of reports has been implemented here to provide broad guidelines which can be used to define the range of emissions to be expected from a given airport development.

SECTION IV

CHARACTERISTICS OF AIRPORTS

Broadly speaking, the most fundamental parameter which governs the characteristics of an airport in determining its total emissions is that of aircraft activity, or aircraft operations (also an indicator of passenger and hence traffic numbers). This is not to say that aircraft are the prime emitters, but rather that their number and type largely determine all the other activity which involves emissions, including passenger access traffic.

Other characteristics, such as the distribution of aircraft between air carrier and general aviation, are of secondary importance, but on occasion may be significant, as for example when most of the activity is general aviation, with considerably less passenger access traffic.

FAA data, focussed on aircraft operations recorded at airports which have FAA-operated airport traffic control towers, provide a broad base of operational data for our purposes.

As of 1972 there were 12,070 civil airports of all kinds existing in the United States; of these the National Airport System identified 3,240 in the National Airport System. FAA Air Traffic Control Towers operated at 346 principal airports, and reported a total of 53,702,396 aircraft operations, an operation being defined as either an aircraft arrival or departure. Of these, 33,371,852 were so-called itinerant operations, and thus of potential interest as regards ground traffic. The other type, called local, involves operations within the local traffic pattern or in sight of the tower, flights to or from local practice areas, or simulated instrument approaches, or low passes at the airport; thus the local operations will generate relatively little associated ground traffic.

The 33,371,852 itinerant operations were largely general aviation (22,093,762), next air carrier (9,791,525) and last military (1,486,565).

The top ten airports in each of the four categories of total operations, itinerant operations, air carrier operations, and general aviation itinerant operations, are given in Tables 1 through 4, along with some statistics related to the total sample of 346 control tower airports.

These tables demonstrate for us some order of magnitude ideas about aircraft operations as indicators of the magnitude of activity at the principal airports in the United States. In our subsequent treatment we will emphasize the category of air carrier operations (Table 3) because these generate by far the largest amount of associated ground traffic, from all points of view (passengers, visitors, employees, ground service vehicles, and cargo vehicles). The same principles to be developed may be applied in instances where general aviation is of special interest, but we will not do so here.

Other characteristics of airports which are of potential relevance include public traffic generated by air passenger activity and employee traffic. Each airport may be expected to have distinctive traffic generated characteristics for each traffic type. Public traffic generation varies with the relative amount of through and plane-to-plane transfer passengers (compared to originating and terminating passengers), and with the various ground transportation modes employed. THese, in turn, are functions of such complex variables as geographic location, city size, type of population served, and available transportation systems. Employee traffic generation is partially related to air passenger travel, but also is strongly dependent on the amount of aircraft maintenance, air cargo activity, and other airport services provided. Further information on these and other parameters is provided in Section V titled Airport Parameters.

Table 1. AIRPORTS WITH FAA-OPERATED AIRPORT TRAFFIC CONTROL TOWERS BY RANK ORDER OF TOTAL AIRCRAFT OPERATIONS - CALENDAR 1971

Tower	Rank	Total Number of Operations
Chicago O'Hare, Ill.	1	641,429
Long Beach, Cal.	2	587,845
Van Nuys, Cal.	3	562,030
Santa Ana, Cal.	4	555,897
Los Angeles, Cal.	5	493,234
Atlanta Mun., Ga.	6	438,704
San Jose Mun., Cal.	7	408,252
Dallas Love Field, Tex.	8	387,092
JFK International, N.Y.	9	380,000
San Francisco, Cal.	10	366,766

Sum of Top Ten: 4,821,249(% of total: 9.0)

Total Airports: 346 Total Operations 53,702,396

Minimum Operations: 13,721

Maximum: 641,429

Median: 132,523

Mean: 155,209

Table 2. AIRPORTS WITH FAA-OPERATED AIRPORT TRAFFIC CONTROL TOWERS BY RANK ORDER OF ITINERANT AIRCRAFT OPERATIONS - CALENDAR 1971

Tower	Rank	Number of Itinerant Operations
Chicago O'Hare, Ill.	1	640,964
Los Angeles, Cal.	2	487,947
Atlanta Mun., Ga.	3	428,708
Dallas Love Field, Tex.	4	385,697
JFK International, N.Y.	5	380,000
San Francisco, Cal.	6	366,744
LaGuardia, N.Y.	7	363,469
Miami, Fla.	8	337,125
Washington National, D.C.	9	327,992
Denver, Colo.	10	312,673
	Sum of Top Ten:	4,031,319 (%of total: 12.1)

Total Airports: 346 Total Itinerant Operations: 33,371,852

Minimum Itinerant Operations: 5,307

Maximum: 640,964

Median: 72,993

Mean: 96,450

Table 3. AIRPORTS WITH FAA-OPERATED AIRPORT TRAFFIC CONTROL TOWERS BY RANK ORDER OF AIR CARRIER OPERATIONS - CALENDAR 1971

Tower	Rank	Number of Air Carrier Operations
Chicago O'Hare, Ill.	1	565,826
Atlanta Mun., Ga.	2	387,775
Los Angeles, Cal.	3	373,870
JFK International, N.Y.	4	333,558
LaGuardia, N.Y.	5	287,192
San Francisco, Cal.	6	286,339
Dallas Love Field, Tex.	7	270,573
Miami, Fla.	8	233,958
Washington National, D.C.	9	222,739
Boston, Mass.	10	213,594
	Sum of Top Ten	3,175,424 (% of total: 32.4)

Total Airports with <u>any</u> air carrier operations: 296

Minimum Air Carrier Operations: 1 Total Air Carrier Operations: 9,791,525

Maximum: 565,826

Median: 10,798

Mean: 33,079

Table 4. AIRPORTS WITH FAA-OPERATED AIRPORT TRAFFIC CONTROL TOWERS BY RANK ORDER OF GENERAL AVIATION ITINERANT OPERATIONS - CALENDAR 1971

Tower	Rank	Number of General Aviation Itinerant Operations
Van Nuys, Cal.	1	306,257
Long Beach, Cal.	2	270,322
Santa Ana, Cal.	3	247,107
Phoenix, Ariz.	4	194,188
Fort Lauderdale, Fla.	5	194,060
Houston, Tex.	6	189,683
Opa Locka, Fla.	7	181,970
Seattle Boeing, Wash.	8	172,482
Teterboro, N.J.	9	163,835
San Jose Mun., Cal.	10	159,123

Sum of Top Ten: 2,079,027 (% of total: 9.4)

Total Airports: 346 Total Gen. Av. Itinerant Operations: 22,093,762

Minimum Gen. Av. Itinerant Oprs: 244

Maximum: 306,257

Median: 54,200

Mean: 63,855

FUTURE EXPECTATIONS

An EPA-sponsored study by the Argonne National Laboratory reports that, according to the FAA, in the next ten years there will be a need for 1,410 new airports, of which 112 will accomodate both air carrier and general aviation activity; the remaining 1,298 will be exclusively oriented toward general aviation.

This indicates some 112 new airports which will have varying ratios between air carrier and general aviation activity, and a wide range of total activity. The key point to be made here is that significant new airports will be increasingly rare events, and each, in its own right, will warrant and receive extensive and intensive environmental analysis.

Accordingly, the analysis and methodology development reported here focusses on broad guidelines for assessing environmental traffic impact, and does not attempt to explore the refinements which may well be essential in a detailed environmental impact analyses.

Further future expectations for large airports and/or airport modifications are reflected both in the predictions from the FAA projection, and in reports presented in forecasting architectural literature which attempts to anticipate future airport requirements.

These respectively indicate both an increasing recognition of the potential impact of airports on the environment, and an acknowledgement of the need to perform detailed environmental impact analyses in order to both account for the environmental impact and respond to the increasingly restrictive legal requirements.

In broad terms, the specific major developments which are expected in the foreseeable future are fairly readily identifiable. Reviews given in recent architechtural publications highlight key new construction and expansion, such as Dallas-Fort Worth, Tampa, Orlando, San Francisco, Boston, John F. Kennedy, Jacksonville, Cleveland, St. Louis, Chicago O'Hare, Kansas City International and Greater Pittsburgh. In addition many of these point out special attention which must be given to, and some solutions for, unusual problems in highway traffic, congestion and parking. In the Architechtural Record, Simon V. Waitzman, Vice President of Airport Systems Planning and Design at John Carl Warnecke & Associates is quoted, in part, as follows: "The airport planning team, including the architect, cannot propose parochial solutions, but must be cognizant of the needs of commercial and general aviation, of the severity of the noise problem, of the demographic, ecological and pollution problems, of the airspace/airport aircraft congestion problem, of the highway access problem, and of the overriding problems associated with the premature obsolescence of facilities."

SECTION V

AIRPORT PARAMETERS

We now must convert what we know about airports into data which can be quantitatively related to the ground traffic characteristics of the airport. Ideally this would be the traffic parameters themselves (numbers, types and timewise distributions), but more often the information will be in less direct form, such as passenger numbers, or passenger/visitor/employee numbers; or even less direct, such as aircraft operations. Each of these elements is relatable to each other by various approximation techniques, and in addition there is seasonal, daily and diurnal data on certain parameters which is summarized in the following material.

SCHEMATIC LAYOUT

To facilitate analysis of certain aspects of the problem, we need a diagram of the airport, to include its access roads, parking areas, and curb frontage for enplaning and deplaning. Diagrams such as are found in the Airline Guide Travel Planner and Hotel/Motel Supplement are useful in this regard. The latest issue has diagrams which present general access road and parking layouts, and curb frontage access, as well as airline terminal and gate locations, for some thirty of the major airports in the contiguous United States. These provide a good picture of the tendency toward a similarity of structure of these facilities. Parking is generally centrally located, surrounded on three sides by the main terminal buildings (from which the concourses project outward), and with the access roads located on the fourth side. Characteristically, required new parking is added along the access roads, where space is usually available because of the normally remote location of the airport. Satellite lots with free shuttle buses are also used. Future plans for some of the larger airports call for the use of multi-storied parking garages (up to six levels) handling some 3,000 to 10,000 parking spaces; such structures generally do not exist at present, and the size is of course constrained by height restrictions on near-airport construction.

Another tendency which is on the increase is the construction of commercially oriented buildings (offices, hotel/motel structures, restaurants, and similar structures) in the vicinity of airports; these have their own associated traffic characteristics. We will focus, however, on the airport-oriented passenger and employee traffic.

Section IV has given some broad indications of airport activity. Other broad indicators can be cited from various sources: for example, the rate of increase in numbers of passengers served at major city airports is beginning to flatten, although the rates at some medium-sized airports continue to grow undiminished as they absorb some of the congestion from the major airports. The rate of increase is slower on a national basis. In spite of this, O'Hare reports a three-year passenger increase through 1972 of from 18 million to 30 million annual passengers. Tampa International has 3 million annually and is projecting 18 million by 1980. Another indicator is in terms of present and projected gates. Dallas-Fort Worth expects to eventually be three times the size of Kennedy, going from 105 gates to almost 200. Orlando has 32 and forecasts 75 to 88, and San Francisco projects an increase from 54 to 94. As shown by these examples, growth is definitely projected at many locations.

Characteristic parking lot sizes are in the range of 2,000-3,000 spaces for airports such as Kansas City, San Francisco, Friendship, Dulles and Washington National. Except for airports which are severely constrained for space, of which the best (or worst) example is centrally located Washington National, additional space as needed is not a problem; the problem is the provision of parking which is handy to the terminal by one means or another, including shuttle. The only impact this has on the present analysis is the tendency of drivers to preferentially seek the close-in spaces.

With regard to transportation access, private auto and taxi appear to be the preferred mode; public transportation systems are in the study (Dulles), planning (O'Hare), and initial (Washington National) stages in a few places, but will have little impact on general requirements for auto transport for some time to come.

Data on auto transport, passenger distributions, and aircraft activity, all from a variety of sources listed in Section IX, are presented next. The Technical Council on Urban Transportation reports the following, from a survey of the following thirteen airports:

Atlanta Airport
Chicago-O'Hare International Airport
Denver-Stapleton International Airport
Kansas City Municipal Airport
Los Angeles International Airport
Miami International Airport
New York-Kennedy International Airport
New York-LaGuardia Airport
New York-Newark Airport
Phoenix-Sky Harbor Airport
San Diego International Airport
Seattle-Tacoma International Airport
Washington, D. C.-National Airport

The 13 airports that are included in this study include many of the nation's major airports. Using total enplaned passengers during fiscal year 1966 as the basis of measurement, the list included the 4 largest airports, 7 of the top 10 and 9 of the top 15. The airports are well balanced geographically, covering 12 states and the District of Columbia, and ranging the nation from Seattle to San Diego and New York to Miami. All types of urban environments are represented, from densely populated, highly complex areas, such as New York and Chicago, to relatively less complicated areas like Phoenix and San Diego.

Ten airports provided complete data on airline passenger, employee, and visitor population for both average and peak days in 1966-67. Population collectively totalled 475,000 people on an average day, and increased by 35% to about 650,000 people on a peak day. In approximate terms, airline passengers accounted for nearly one-half of the airport population, employees about one-fifth, and visitors better than one-third.

The number of daily access trips made to and from the airport is different than the reported airport population. Airline transfer passengers are usually not involved in access to and from the airport. Further, each airline passenger accounts for a trip either to or from the airport whereas each employee and visitor accounts for a trip both to and from the airport. On these bases, it is estimated that the total number of daily ground access trips to and from the 10 airports referenced is nearly 50% greater than the populations cited. Viewed in this context, airline passengers account for only one-quarter of the access trips, as do employees. Visitors account for one-half of them.

The thrust of this report is central business district-to-airport access, however. Central business districts can generate substantial, but usually not majority proportions of total airport populations. Their influence varies from city to city, but for six airports supplying complete information on this matter, air passenger generation in central business districts averages 29% of total airport airline passenger population; corresponding employee generation is 11%; and visitor generation is 14%. For all types of airport trips, central business districts generate an average of 24% of the total airport populations.

Of the 13 airports participating in the survey, 3, Denver-Stapleton, Kansas City Municipal, and San Diego, reported no access problems at present. At Phoenix-Sky Harbor, congestion was only reported at the airport entrance, and this is presently being corrected. The nine other airports reported enroute congestion during peak hours, although only moderate in two cases. Four of the airports do not have direct connections to freeways and this was generally cited as a problem, as was congestion in front of airline terminal buildings at the airports, and inadequate parking facilities.

Seven airports look to some sort of highway improvement to meet their access problems. Improvements cited include new links to freeways, reconstructed enroute freeway interchanges for more efficient traffic flow, and simply, additional highway capacity in terms of new or expanded facilities. Many planners concur with the belief expressed by the Los Angeles International Airport management that most airport travellers will continue to use their private automobiles or other roadway vehicles for the foreseeable future, and the practical answer to serve this demand is to improve the capacity and quality of the highway network.

Table 5 shows the estimated total airport populations on an average day in 1966-67. The data are presented in three categories: passengers, employees, and visitors. Passengers include arrivals, departures, and intra-airport transferees, i.e., arrivals who connect with departing flights. Since they do not leave the airport, these transfer passengers generally do not figure into the airport access problem. The number of transfer passengers have not been identified in all cases, but they account for 10% to 30% of all airline passenger trips at the five airports reporting this information.

Employees usually include airline operations and maintenance personnel, Federal Aviation Administration flight controllers, airport staff, and representatives of consumer services such as restaurants, gift shops, rental car agencies, etc. Visitors are primarily relatives and friends accompanying passengers, but in this report the term "visitors" also includes sightseers and thos on airport business, such as salesmen, service and repair personnel, etc.

For the 11 airports that have provided complete data for all 3 categories of users on both average and peak days, the data reported show that approximately 475,000 people have been included in this survey of airport population on an average day. Airline passengers account for 45% of the daily airport population, employees 22%, and visitors 33%.

Table 6 shows the estimated total airport populations on a typical peak day in 1966-67. These data are indicative of the average peak rather than absolute peak conditions. Peak days can be seasonal in nature, but

Table 5. ESTIMATED TOTAL AIRPORT POPULATIONS AVERAGE DAY (1966-67)

Airports (1)	Passengers[a] (2)	Employees[b] (3)	Visitors (4)	Total[c] (5)
Atlanta	29,600	12,000	36,700	78,300
Chicago-O'Hare	50,000	16,000	25,000	91,000
Denver-Stapleton	5,500	5,500	8,500	19,500
Kansas City Municipal	6,700	1,100	1,500	10,300
Los Angeles	42,000	33,000	43,700	118,700
Miami	22,000	5,000	3,000[d]	30,000
New York-Kennedy	46,800	23,000	22,800	92,600
New York-La Guardia	17,200	3,300	4,000	24,500
New York-Newark	14,000	3,300	4,200	21,500
Phoenix-Sky Harbor	6,000	300	8,400	14,700
San Diego	3,000	1,600	3,200	7,800
Seattle-Tacoma	10,000	4,000	4,700	18,700
Washington, D.C.-National	26,000	13,100	26,000	65,100

[a]Total arrivals, departures, and intra-airport transferees.
[b]Data indicate employee counts on typical day. Total airport employee population may be considerably higher due to flight crew rotations, shifts, etc.
[c]Data indicate total number of people at airports on typical day. Total number of airport access trips are different however: each passenger, with the exception of intra-airport transfers, accounts for one single direction airport access trip per day. Each employee and visitor accounts for two single direction airport access trips per day.
[d]Visitor traffic at Miami estimated to be low because of tourist-trade nature of the airline passenger traffic.

Table 6. ESTIMATED TOTAL AIRPORT POPULATIONS PEAK DAY (1966-67)

Airports (1)	Passengers[a] (2)	Employees (3)	Visitors (4)	Total (5)
Atlanta	59,200	14,400	91,500	165,100
Chicago-O'Hare	60,000	16,500	50,000	126,500
Denver-Stapleton	6,900	5,500	10,700	23,100
Kansas City Municipal	9,000	1,200	2,000	12,200
Los Angeles	52,500	33,000	54,300	139,800
Miami	31,900	5,500	4,000	41,400
New York-Kennedy	58,500	23,000	30,800	112,300
New York-La Guardia	18,400	3,300	4,300	26,000
New York-Newark	15,500	3,300	4,700	23,500
Phoenix-Sky Harbor	6,500	3,700	4,800	15,000
San Diego	3,900	1,600	3,300	8,800
Seattle-Tacoma	12,000	4,000	5,600	21,600
Washington, D.C.-National	33,000	13,100	33,000	79,100

[a]See notes on Table 5

regardless of their exact distribution they further accentuate peaking during certain hours of the day as a general rule.

For the 10 airports that have provided complete airport population data for both average and peak days, the average daily population of 475,000 grows to nearly 650,000 on peak days, an increase of 35%. The airline passenger increase is 35% itself; the employee and visitor increases are 2% and 55% respectively.

In the individial categories, the 45% airline passenger share of airport population on an average day increases slightly to 46% on peak days. The employee share of population drops from 22% on an average day to 16% on a peak day, while the visitor share increases from 33% of total airport population on an average day to 38% on a peak day.

Note that the number of passengers and visitors is approximately the same at many airports, and in fact, for all 10 airports referenced, passenger population is 1.38 times visitor population on an average day. This factor is 1.20 on peak days. Business travellers are usually unaccompanied to and from the airport while many nonbusiness travellers are escorted by one or more relatives or friends, at least, at their home airports.

Daily airport population differs from the number of daily airport access trips, however. Excluding intra-airport transferees, each airline passenger accounts for one daily airport access trip - either into or out of the airport. Employees and visitors each account for two daily trips - both into and out of the airport. With this distinction in mind, and assuming that intra-airport transferees amount to 15% of the total airline passenger traffic for the purpose of illustration, approximately 700,000 ground access trips are made to and from the 10 airports on an average day (1966-67). On peak days this volume grows to about 950,000 reflecting the 35% increase that characterizes airport population on peak days as opposed to average days.

Because each employee and visitor accounts for two access trips as cited, their importance in access flow is more pronounced than would be indicated from a study of airport population alone. Whereas on an average day visitor traffic constitutes 33% of airport population, it accounts for 45% of the access trips to and from the airport. Employees constitute 22% of the population, but 29% of the access trips. And correspondingly, airline passengers who constitute 45% of the airport population only account for 26% of the ground access trips to and from the airport.

Thus, visitors constitute the largest element in airport access traffic on an average day - nearly one-half of the total flow - and this position is reinforced on peak days. Airline passengers and employees account for the remaining one-half of the access traffic flow about equally.

Although this survey has not attempted to gage the magnitude of peak period airport traffic flow, airport operators have been requested to identify the timing of peak periods for central business district-airport traffic. The responses, provided as a matter of record on Table 7, generally coincide with business hours on a normal work day.

The extent to which airline passengers (the following excludes employees and visitors) travelling between the airport and central business district use the various transportation services available shows that choices are made on the bases of travel time, service frequency and connections, location convenience, fare, comfort, and other amenities, some of which are described in subsequent sections of this report. The data clearly show that a great majority of the passengers use one of three means of transportation: private automobile, taxi, or franchised airport bus or limousine. At the 10 airports providing complete information on modal choices, the percentage of central business district passengers using these three types of services ranges from 80% to 99%. Each of these specific services carries at least 10% of the traffic at any one airport, with only two exceptions among the survey respondents. The only other services which accommodate 10% or more of central business district passengers at any airport are Newark, where frequent, nonstop public bus service is available in competition with the franchised bus, and at San Diego, where there is no franchised bus service. Airports at Los Angeles and San Diego

Table 7. PEAK TRAVEL HOURS BETWEEN AIRPORTS AND CENTRAL BUSINESS

Airports (1)	From (2)	To (3)
Atlanta	11:00 A.M.	5:00 P.M.
Chicago-O'Hare	6:00 A.M.	9:00 P.M.
Denver-Stapleton	7:00 A.M.	7:00 P.M.
Kansas City Municipal	6:30 A.M.	9:00 P.M.
Los Angeles	8:00 A.M.	4:30 P.M.
New York-Kennedy	4:00 A.M.	8:00 P.M.
New York-La Guardia	4:00 A.M.	8:00 P.M.
New York-Newark	4:00 A.M.	8:00 P.M.
Phoenix-Sky Harbor	7:50 A.M.	4:40 P.M.
San Diego	7:00 A.M.	9:00 P.M.
Seattle-Tacoma	7:00 A.M.	4:00 P.M.
Washington, D. C. - National	9:00 A.M.	4:00 P.M.

specifically report that more than 10% of central business district passengers use rental cars. It is assumed that at most airports, rental care data is apparently included in with private car data. The remaining services, helicopter and subway-bus transfer, account for an insignificant share of total passengers.

Frequency of service is important to the extent that any scheduled transportation operates often enough to assure ease of making plane connections (Table 8). The public bus and subway-bus services are frequent urban transit operations, yet they control but a small part of the CBD-airport market.

Now, from a Traffic Quarterly paper by Louis E. Bender, we have extracted the following information:

The amount of through air passengers and plane-to-plane transfer of air passengers varies greatly. The New York airports are typical of predominantly originating and terminating air travel, and have negligible through passengers (those who do not change planes). La Guardia and Newark Airport have only 11-12 percent transfer air passengers, and Kennedy has 23 percent transfers. In contrast, Atlanta has 10 percent through traffic and 70 percent transfers,* as its location fosters through passengers and transfers for air travel in many directions.

Airport visitors have been counted here as a portion of public-generated traffic. The bulk of these trips are occasioned by air passengers who use private auto transportation but who do not leave an auto at the airport. Passengers were accompanied by airport visitors with the following frequency: La Guardia, 47 percent, Newark, 53 percent, and Kennedy, 67 percent of the time. Thus, from one-half to two-thirds of auto users generated travel-related visitors. The two-way nature of these trips, as compared to the one-way trip of a departing passenger leaving an auto at the airport, must be recognized in planning.

*"Atlanta Airport Transportation Studies," Alan M. Voorhees Associates, Inc., November 1968.

Table 8. NUMBER OF TRIPS PER HOUR FOR TRANSPORTATION SERVICES BETWEEN AIRPORTS AND CENTRAL BUSINESS DISTRICTS DURING PEAK HOURS/OFF-PEAK HOURS[a]

Airports (1)	Airport bus or limo. (2)	Heli-copter (3)	Public bus (4)	Subway-bus transfer (5)	Taxi (6)	Private autos (7)	Rental cars (8)
Atlanta	5/2	-	2/1	-	30/5	NA	NA
Chicago-O'Hare	40/36	-	-	-	400/200	3000/100	270/50
Denver-Stapleton	NA/20	-	3/3	-	NA	NA	-
Kansas City-Municipal	NA	-	-	-	NA	NA	NA
Los Angeles	4/2	-	2/2	-	NA	NA	NA
Miami	1/1	-	NA	-	NA	NA	NA
New York-Kennedy	-b	2/1	-	15/6	NA	NA	-
New York-La Guardia	6/6	1/1	-	15/6	NA	NA	-
New York-Newark	6/4	2/1	10/6	-	NA	NA	-
Phoenix-Sky Harbor	2/1	-	3/1-1/2	-	NA	NA	-
San Diego	-	-	3/3	-	100/50	NA	15/6
Seattle-Tacoma	4/3	NA	1/1	-	20/10	200/75	-
Washington, D. C.-National	NA	-	6/NA	-	NA	NA	NA

[a]Hours as designated on Table 7.
[b]Typically 20 to 40 trips per hour, scheduled to connect with specific flights.
Note: Data on taxis, private autos, and rental cars apparently reflect the typical number of these vehicular movements into or out of the airports so referenced.

Usually, a minor portion of airport visitors' trips are not transporting air passengers. At Kennedy, a study found that 15 percent of access trips could not be accounted for by assignment to air passenger travel. This was a measure of visitor trips for a host of reasons, such as: ticket purchase, baggage movement, seeing off or greeting air passengers but not transporting them, and purely casual sightseeing and dining. Obviously, the amount of purely casual visitors will vary greatly among airports; at a particular airport, it will be dependent on the airport's relative and current attractiveness.

In summary, Table 9 has been developed to compare the vehicles generated per 1,000 domestic departures at La Guardia Airport with the same rates at O'Hare, Atlanta, and Los Angeles International airports. Vehicle occupancies similar to New York experience have been assumed. From this table can be seen the great difference in generation of air passenger vehicles, as much as 3 to 1, because of differing characteristics.

Table 9. VEHICLE TRIPS RELATED TO PASSENGER DEPARTURE

Airport	Percent Passenger Transfer to Other Plane	Percent Passenger Usage of Car or Taxi	Vehicles Per 1,000 Departing Air Passengers
La Guardia	11	83	530
O'Hare	70	81	180
Atlanta	70	93	200
Los Angeles	15	93	630

Employee traffic is the second principal component of surface traffic at airports. It varies sharply depending on the concentration of air transportation services such as plane maintenance, air cargo activity, and food and other consumer services. The national airport survey found for 10 reporting airports that employees comprised 22 percent of the average daily population. The ratio in Table 10 of employee totals at the three New York airports to air passengers shows how employee trip generation can vary due to different levels of airport operating services.

Employee travel mode appears to differ little from that of the typical office or industrial plant similarly located in the metropolitan area. At Kennedy Airport, 90 percent of the employees use cars with a 1.1 occupancy (persons per car) and the remainder use buses. Because of the large volume of employee-generated traffic, this segment of airport traffic should not be underestimated. The employee traffic volume will often exceed the traffic generated by air passengers.

Table 10. AIRPORT EMPLOYMENT RELATED TO PASSENGER DEPARTURES

Airport	1968 Total Employees	1968 Air Passengers	Employees Per 1,000 Annual Air Passengers
La Guardia	6.589	10,481,999	0.63
Newark	6,870	6,716,504	1.03
Kennedy	42,522	19,573,628	2.17

The total traffic peak that will be experienced at airports will result from the combination of public and employee-generated traffic. Automatically recording traffic stations on the Van Wyck Expressway, the main access route into Kennedy Airport, provide a 24-hour profile of inbound traffic, recorded at two locations: the Central Terminal Area (CTA) boundary and the boundary of the airport. This permits a comparison of the CTA-generated public air passenger traffic with the total airport-generated traffic, the difference approximating employee-generated traffic. Inbound data obtained on Friday, May 9, 1969, recorded a total of 43,943 vehicles, of which 57 percent were destined for the CTA and 43 percent for the employee areas. In contrast to this predominance of air passenger traffic over 24 hours, during the 6 to 9 a.m. peak period employee traffic outnumbered air passenger traffic nearly two to one and in the 3 to 6 p.m. peak, employee traffic predominated 54 percent to 46 percent. The inbound peak hour from 7 to 8 a.m. totaled 3,829 vehicles, of which 2,390 were employee vehicles.

The severest airport surface traffic volumes occur during the outbound p.m. peak period. At this time, CTA traffic is at its daily high level for a period of several hours, usually from 3 to 10 p.m. Within this same period, from 3 to 6 p.m., the homeward employee peak produces composite peaks from 3 to 6 p.m., approximately matching the time of the off-airport peak. For example, on Friday, May 2, 1969, the Van Wyck Expressway outbound flow was 10,901 vehicles between 3 to 6 p.m. with the CTA generating slightly over half (5,766 vehicles). The outbound peak hour, from 3 to 4 p.m., totaled 4,259 vehicles of which 2,158 were employee vehicles.

The 1968 survey data show that 72 percent of air-passenger-generated autos using Kennedy Airport desire to park, and the remaining 28 percent enter and leave the airport without parking. Thirty-nine percent are short-term parkers and one-third are "duration" parkers, leaving their cars at the airport during their air travel.

In a study of airport pollution, Northern Research and Engineering corporation generated data on airport operations, which have been converted by us into the following summaries: Table 11, annual and monthly air carrier activity; Table 12, activity by day of the week; Table 13, diurnal variations in activity; Table 14, NREC aircraft classes and seating capacity; and Table 15, distribution of air carrier activity by class, and estimated number of autos traveling per aircraft seat.

Finally, we have taken one table from the Argonne National Laboratory Study cited in the section on Special Considerations for Airports, and show it as our Table 16, on the diurnal distribution of employee traffic.

These data are subsequently employed in the Analysis Section (VII).

Table 11. AIR CARRIER ACTIVITY AT SELECTED AIRPORTS - CALENDAR YEAR 1970 - ANNUAL AND MONTHLY DATA

Airport		Washington National	Los Angeles	John F. Kennedy	Chicago O'Hare
Total Passengers		10,124,423	20,780,718	18,953,500	28,936,000
Total Operations (Landings and Takeoffs)		333,548	544,073	438,250	679,750
Air Carrier Operations (Landings and Takeoffs)		219,550	407,866	377,500	628,500
Percent of Operations by Month:	Jan	8.2	8.8	9.0	9.1
	Feb	7.7	7.8	7.3	8.2
	Mar	8.9	8.5	7.9	8.5
	Apr	7.9	8.1	7.1	7.2
	May	8.6	8.6	7.9	8.8
	June	9.1	8.9	8.5	9.1
	July	8.6	9.1	9.7	8.8
	Aug	8.4	6.7	9.6	8.8
	Sept	8.1	8.7	8.9	8.0
	Oct	8.4	8.6	8.5	7.9
	Nov	8.0	7.9	7.6	7.5
	Dec	8.2	8.2	8.0	7.8
Average Number of LTO cycles per month		9,148	16,994	15,729	26,186
Average Number of Passengers per LTO cycle		92	102	100	92

Table 12. DAY-OF-WEEK VARIATION OF AIR CARRIER ACTIVITY AS PERCENT OF DAILY MEAN - AVERAGE OF MAJOR U.S. AIRPORTS

Day of Week	Sun	Mon	Tue	Wed	Thur	Fri	Sat
Percent of Daily Mean	90	104	104	104	104	105	87

Table 13. HOUR-OF-THE-DAY VARIATION OF AIR CARRIER ACTIVITY AS PERCENT OF THE TOTAL FOR AN AVERAGE DAY

	Percent of Daily Total for Four Airports			
Hour	Washington National	Los Angeles	John F. Kennedy	Chicago O'Hare
1	0.15	4.0	0	0
2	0.2	2.0	0	0
3	0.1	1.0	0	0
4	0.15	0.3	0	0
5	0.1	0.5	0	0
6	0.1	0.3	2.2	1.5
7	0.65	0.9	3.6	3.9
8	3.9	2.0	4.7	5.1
9	6.5	5.0	5.3	6.0
10	7.1	6.0	5.7	6.2
11	6.5	6.0	4.4	5.9
12	6.4	6.0	4.8	5.7
13	6.5	7.0	4.7	6.4
14	6.0	6.0	4.9	6.7
15	6.3	6.0	6.4	6.9
16	6.9	5.0	7.3	6.6
17	7.2	5.0	7.4	7.5
18	7.2	5.0	7.7	7.2
19	7.1	5.0	6.6	7.2
20	6.0	6.0	7.7	6.2
21	5.2	5.0	6.6	5.0
22	5.5	7.0	5.9	3.5
23	3.3	5.0	4.1	2.5
24	0.9	4.0	0	0

Table 14. NREC AIRCRAFT CLASSES, TYPES, AND AVERAGE NUMBER OF PASSENGER SEATS

Aircraft Class	1	2	3	4	5	6	7
Passenger Seats	136	490	129	116	61	10	1
Aircraft Type	SST	Jumbo Jet Transport	Long-range Jet Transport	Medium Range Jet Transport	Turbo-Prop Transport	Business Jet	Piston Engine Utility

Table 15. DISTRIBUTION OF AIR CARRIER ACTIVITY BY NREC AIRCRAFT CLASS (CALENDAR 1969) AND ESTIMATED NUMBERS OF AUTOMOBILE TRIPS PER PASSENGER SEAT

	Percent of Each Class by Airport			
Aircraft Class	Los Angeles International	Washington National	John F. Kennedy	Chicago O'Hare
3	69	0	55	29
4	25	70	40	60
5	6	30	5	11
Estimated Automobiles per Aircraft Passenger Seat	1.2	1.0	1.1	1.1

Table 16. AIRPORT EMPLOYEE DIURNAL ARRIVAL AND DEPARTURE PATTERN

Hour	Percentage of Employees Arriving	Percentage of Employees Departing
1	0.1	3.0
2	0.1	0.5
3	0.3	0.7
4	0.3	0.3
5	1.3	0.2
6	5.3	0.4
7	27.3	1.0
8	19.1	3.5
9	4.5	1.3
10	2.8	2.0
11	3.0	2.2
12	1.7	3.5
13	4.0	1.2
14	5.6	3.0
15	8.8	6.1
16	4.0	25.0
17	1.9	14.9
18	0.5	6.0
19	1.3	3.6
20	1.0	3.0
21	0.9	3.0
22	0.3	2.8
23	5.0	5.0
24	0.9	7.8
	100.0%	100.0%

SECTION VI

TRAFFIC PARAMETERS

CONCEPT OF EMISSIONS PER UNIT TIME

In parking areas of airports, 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. Extreme variation in observed emission rates per unit distance traveled with slight change in average operating speed.

For airports, 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 and near the vicinity of an airport can be described more accurately and more easily in terms of minutes of running time, than in terms of average speed, particularly when engine idling can predominate during congested periods.

Values for automotive pollutant emissions in grams/minute at idle are available from A Study of Emission from Light Duty Vehicles in Six Cities.** They are summarized in Table 17. These test data compare well with emission factors calculated from the current edition of AP-42,*** when converted to grams/minute at various speeds and then extrapolated to zero speed.

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

** Reference: Automotive Environmental Systems, Inc., March 1973. Environmental Protection Agency Publication No. APTD-1497.

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

Table 17. VEHICLE EXHAUST EMISSIONS AT IDLE IN GRAMS PER MINUTE*

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

* These values do not include emissions due to the cold start of engines or to evaporation of gasoline at the end of a trip ("hot soak"). If subsequent investigation of the relative magnitude of these emissions, 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 vehicular emissions from the airport complex at any time would be the product of the number of vehicles, times average vehicle running time, times the appropriate emission factor from Table 7:

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

V = Traffic volume during period of concern

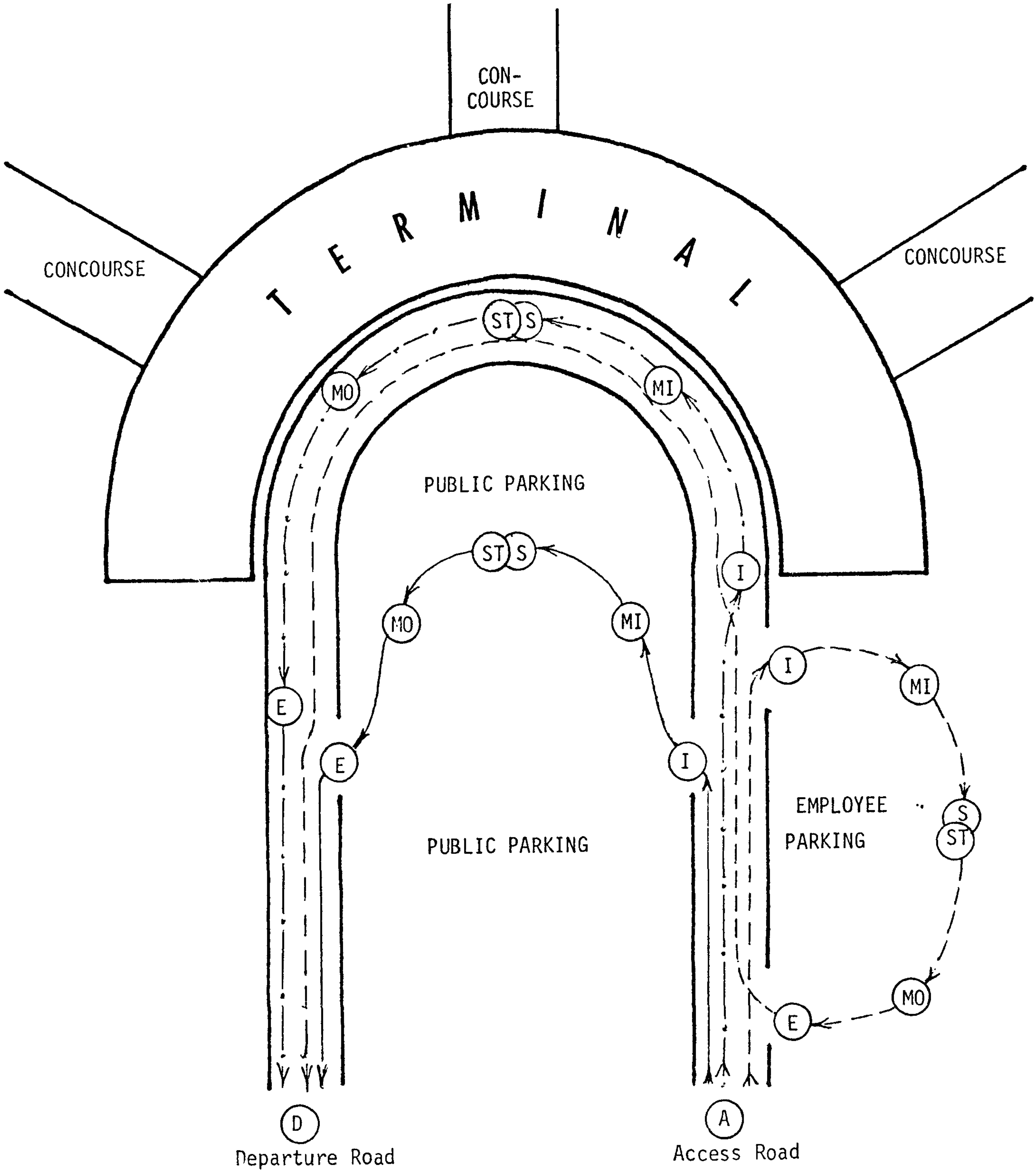
RT = Average running time, minutes

EF = Emission factor, grams/minute.

Operational Traffic Modes for Airports

For purposes of analysis, traffic movement in the vicinity of an airport has been divided into eight characteristic operational modes. Emphasis here is on private auto use. Comments are made later regarding other transport. The modes are summarized below and shown schematically in Figure 1.

We have distinguished the three major types of access traffic from each other in the figure, and discuss this distinction later in this section. The discussion which follows treats principally visitors/passengers who park, and employees (who also park, but most often in a separate lot).



Key: Visitors/Passengers who park ————————

Visitors/Passengers not parking; also Taxi/limousine/bus ·——·——

Employees — — — — — — — — — — — —

Figure 1. Schematic representation of vehicle operating modes at an airport.

Approach (A) - The time or distance along the immediate access road that total traffic movement is strongly affected by the vehicles entering and exiting the airport.

Entrance (I) - Movement through the entranceway, including waiting time at a traffic control light or in a queue.

Movement in (MI) - Driving time or distance from the entranceway to the preferred parking spaces, usually the nearest available areas to the terminal entrances. Time spent searching for an open space is also included in this mode.

Stop (S) - Parking of the vehicle and shutoff of 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 at a traffic control light or in a queue.

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

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

The third category of access traffic, distinguished from the two covered above (visitors/passengers, and employees, who park in lots), is that of some of the visitors/passengers, and all of the taxis, limousines and busses, all of which come to the main terminal entrances, stop and idle, or stop and shut off engines, for varying periods of time, and then depart. Differences from the modal descriptions above are in the absence of the entrance and exit modes, and the importance of the stop/start mode, which may involve extended periods at idle, without shutoff and start of the engine.

Base Running Time

There is an average minimum vehicle running time for each airport that is associated with periods of low or zero traffic congestion. This concept of a minimum or base running time is important because it usually is the most common (typical) operating condition for the airport and because at most airports it is expected to be exceeded only during periods of relatively high traffic volume. The base running time can be determined from a plan of the airport, with an additional knowledge of its traffic control devices and probable driving patterns.

Base running times for three example airports, Washington National, Baltimore Friendship, and Dulles International, have been constructed both by time measurement during simulated driving cycles and by estimates based on dimensions of the airports, entrance/exit configurations, and expected driving patterns. Total base running times and average times in each operational mode are shown in Table 18.

Table 18. BASE RUNNING TIMES BY OPERATING MODE AT THREE SUBURBAN WASHINGTON, D.C. AIRPORTS

Operational Mode	Base Running Time, Minutes		
	Dulles International	Washington National	Friendship International
Approach	1.0	1.5	2.0
Entrance	0.25	0.25	0.25
Movement in	2.0	1.5	0.75
Stop	0.1	0.1	0.10
Start	0.1	0.1	0.10
Movement out	0.75	0.75	0.75
Exit	0.75	0.75	0.50
Departure	1.0	1.5	2.0
Total BRT	5.95	6.45	6.45

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, traffic control lights and signs at entrance/exits
- Queues created as vehicles attmept 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, or waiting for parking spaces
- Increased number of pedestrians in parking area.

Generally, total running time is qualitatively related to traffic volume as shown in Figure 2. The base running time (BRT) can be determined for a specific airport as described above. The magnitude of increase above the BRT with increased traffic can be approximated from airport and trip generation parameters, by the procedure developed in the section titled Analysis.

Identification of Critical Modes for Airports

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

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

Exit and entrance times are functions of the egress and ingress capacities, respectively, of the individual entrance/exit ways. As these capacities are approached or exceeded, running times in the two modes increase.

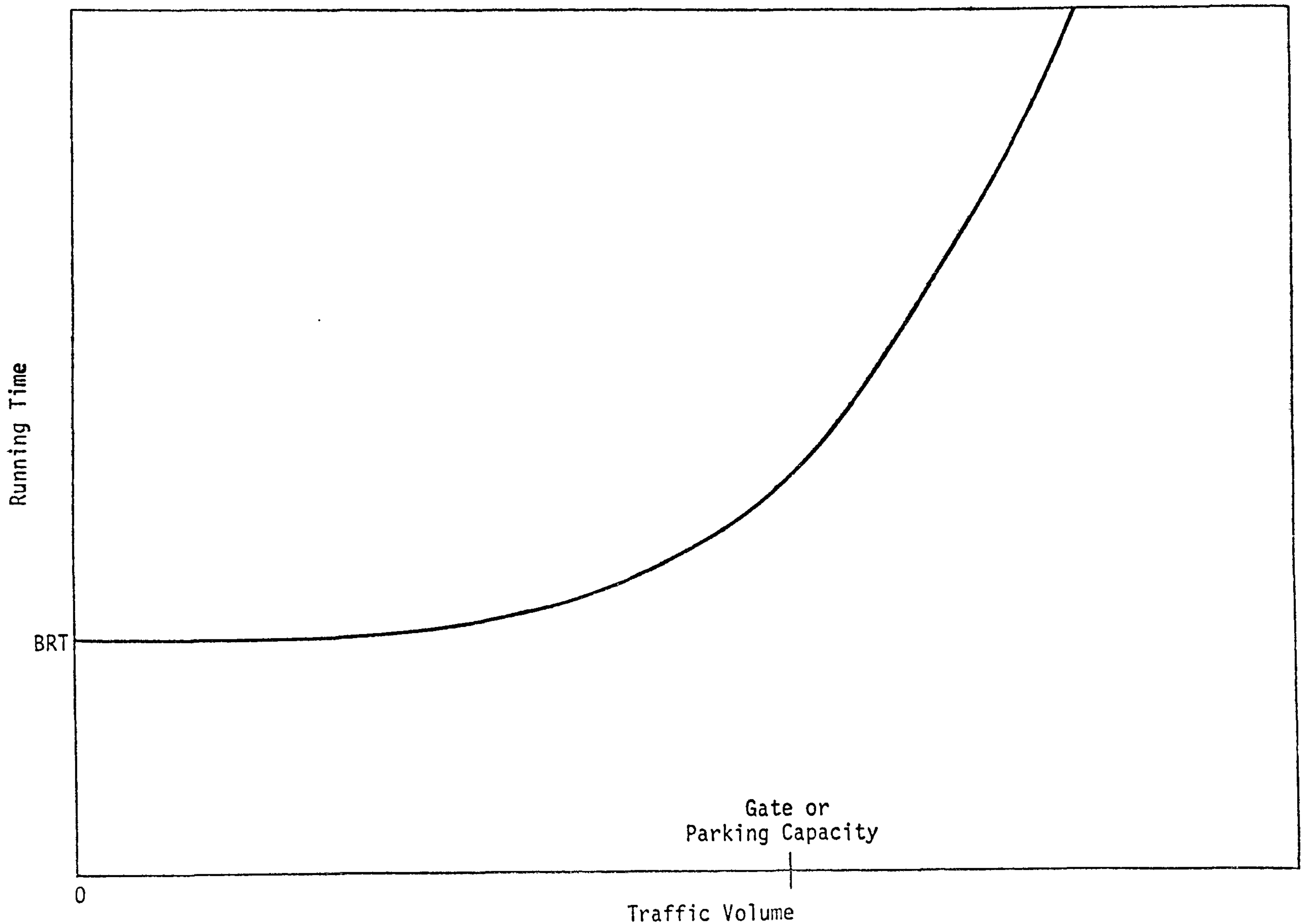


Figure 2. General Relationship Between Traffic Volume and Total Running Time

Waiting times in the resulting queues become the primary factors in determining total running times. However, because of variations in the number of vehicles entering and leaving airport parking facilities egress and ingress capacities generally are not exceeded simultaneously.

Movement time into a parking space, the remaining critical mode, is a function of the number of free parking spaces. The time in this mode increases only slightly with parking facility usage until the number of parked cars approaches the capacity of the lot. As parking capacity is exceeded, movement time and number of cars moving increases, due to incoming vehicles searching for open spaces or waiting for a space to be vacated.

For non-users of parking lots, the stop/start mode may become critical during periods of congestion, especially if extensive idling times develop at main terminal entrances. This can happen in the case of visitors/passengers who do not use the lots, and public transportation (taxis, limousines and buses).

The parameters developed above are analyzed further with the airport parameters in the Analysis section, and the findings employed in the Methodology section. Also, in the Analysis section, distinction is made where appropriate between the traffic characteristics of airports and those of their parking facilities.

SECTION VII

ANALYSIS

In this section we make the necessary interpretations and inferences for converting the data of the section titled Airport Parameters into the relationships needed for input to the methodology of the section titled Results. In the section titled Traffic Parameters, we discussed the entrance/exit and parking capacities, and the terminal curb frontage, as the airport parameters which could, under conditions of exceedance, increass either, or both, the vehicle running times and the number of vehicles running.

Typical and Maximum Trip Generation

There are two routes we can follow in getting to the necessary typical and peak trip generation rate data. The first we use in cases where direct data or estimates are available on frequencies of passengers, employees and visitors for typical and peak conditions; these data are directly convertible to estimates of vehicle numbers. In the absence of such population numbers, then the alternate method proceeds from data on aircraft operations to numbers of people, and thence to numbers of vehicles.

First, if the data are people-oriented: it will probably be necessary to convert aggregate data into smaller increments. Annual data may, for example, be reduced to monthly, daily and hourly figures (in order to obtain typical and peak one-hour and eight-hour values) using the characteristic monthly, daily and diurnal data of Section V on Airport Parameters.

Of course, if the available data are already in the necessary time-period forms, then the conversion to vehicle numbers may be done directly, again using the factors of Section V on people-vehicle relationships.

The passenger estimates are divided between through and transfer passengers on the one hand, and originating or terminating on the other. This distinction, as well as identification of the numbers of employees and visitors, provides the basic input. Conversion to vehicle numbers, and combination with base running times, provides the data sought for this subtask.

As an example, let us take an average and a peak day at JFK, from the Transportation Engineering Journal (TEJ) data, Table 5; for the average day there are 46,800 passengers arriving, departing and transfering; 23,000 employees; and 22,800 visitors. The corresponding peak numbers are 58,500 (indicated as average peak, rather than absolute peak); 23,000; and 30,800. From Table 11, the peak hour for visitors/passengers is from 5 to 6 p.m. (hour 18) and reflects 7.7 percent of the total (the peak eight hour period is from 2 to 10 p.m. and contains 55.6 percent. For employees (Table 16) the peak hour is hour 16. This is discussed further. TEJ assigns a complete trip cycle to each employee and visitor, and a half cycle for each originating or terminating passenger, for long-term (daily) considerations. For the employees, the diurnal pattern (Table 16) indicates that the departing hourly peak has passed (3-4 p.m.) when the passenger/visitor hourly peak occurs. We must now determine the composite peak, since the employee and visitor/passenger hourly peaks do not coincide, and the employee traffic is large in amount in this case; it is always characteristically more peaked than the visitor/passenger case.

We should now be concerned, however, about the half-cycle/full cycle assignment of trips for short (one-hour) terms, and must also be concerned about through and transferring passengers (who do not involve ground vehicles), and the potential overlap of counts for visitors and passengers, as regards vehicles. For employees, of course, we have from Table 16 the distinction between arriving and departing, so we determine the numbers corresponding to the hourly percents, and assign arriving and departing half-cycle counts, respectively. For the visitors/passengers this is more complex, since some passengers are through or transfering, some visitors do not transport passengers, and some passengers "park and fly," or ride public transport. We have made some rather involved sample calculations using data from Bender's Traffic Quarterly article and the TEJ article, and find that, as a reasonable first approximation, the assignment of half-cycles to passengers and full cycles to visitors, as done in the TEJ article, accounts for the interactions adequately.

Table 18.a shows the result, giving us an interesting impression of the interplay between employee and passenger/visitor traffic. (Table 18.a for typical hours has also been calculated.) The employee peak hour controls the time of the composite peak hour, and the invariance of employee traffic prevents the relative increase in traffic under peak travel conditions from soaring. Parallel treatment will give us the corresponding data for the typical and peak eight-hour periods.

The somewhat complex approach described above for passenger/visitor vehicle estimates, using passenger data, can be approximated by the use of air carrier activity as promulgated by NREC.

We go to Table 11 and find that a typical month has 8-1/3 percent (1/12) of 188,750, or 15,729 air carrier LTO cycles per day, and the peak month (July) has 18,309 (9.7 percent). Our peak hour is again the 18th (5-6 p.m.) with 7.7 percent (Table 13). From Tables 14 and 15, we find the distribution of aircraft classes and associated passenger seats, with the following results; 55 percent with class 3 (129 seats), 40 percent class 4 (116 seats) and 5 percent class 5 (61 seats). This estimates that the average 100 LTO cycles implies (55x129 + 40x116 + 5x61) or 12,040 passenger seats, and for 15,729 LTO's we have 1,893,722 passenger seats. Applying the factor of 1.1 from Table 15 implies passenger related 2,083,149 vehicle trips during the month, or 67,198 per day. A typical hour has 1/18th of these, or 3,733. Peak hours of the peak month (hours 16, 17, and 18) each have over 7 percent of the peak month's values (78,220 vehicle trips), or 5,710 (hour 16)

5,788 (hour 17) and 6,023 (hour 18), respectively. We must now break these out into half-cycles, as was done before, accounting for the fact the visitors trips are full cycles and passengers only, half-cycles.

Table 18. Traffic Model Half-Cycle Counts for Example Hours Assuming Employees and Passengers are Single Half-Cycles, and Visitors are Full-Cycles, or Two Half-Cycles Each

Hour of the Day	a. Typical Counts			
	Passengers	Visitors	Employees	Totals
Typical (Total Divided by 18 Hours of Operation	2,600	2,533	1,278	6,411
	b. Peak Counts			
15	3,744	3,942	3,427	11,113
16	4,271	4,496	6,670*	15,437**
17	4,329	4,558	3,864	12,751
18	4,504*	4,744*	1,495	10,743

* Individual Peak
** Composite Peak

We do it first for the typical hour (3,733): Analysis of the data of Section V (Airport Parameters) indicates that about half of the total (1867 out of 3733) is half-cycle oriented, passenger-only, and the other half are full-cycle passenger and visitor-oriented trips. Thus, we have (1,867 plus 1,867x2), or 5,601 half-cycle trips for passengers and visitors, approximating the first two columns of Table 18.a, which total 5,133. We suggest use of this relationship consistently.

Employees must be treated separately, and will, with necessary input from the developer, using comparable data as was obtained before from Tables 5, column b and Table 16, generate the same results as before in Table 18.a and Table 18.b in the "Employees" column.

The peaks for Passengers/Visitors are calculated in similar fashion to those for typical hours. We get, for example, for hour 18, (3012 plus 3012x2), or 9035, again comparable to the total of 9248 from the first two columns of Table 17.b, hour 18. The remainder of the treatment is as before. We must take special note of the dependence of this scheme (using air carrier operations) on the aircraft class/passenger seat distribution. With the advent of the larger capacity aircraft (L-1011 and DC-10) the passenger seats per aircraft will increase significantly; this must be accounted for in projections.

AIRPORT PARKING LOT GATE CAPACITY EXCEEDANCE AS A FUNCTION OF TRIP GENERATION AND GATE CAPACITY - RESULTING RUNNING TIME INCREASE (E)

Average running times for entrance to and exit from an airport's public parking lot are primarily functions of three parameters: traffic trips in and out of the lot, entrance and exit capacities, and the time sequences of the traffic control devices at the entrance/exit (gates). Running time can be quantified with data on these three parameters for an airport lot, by use of a methodology employing queueing theory.

The entrance and exit capacities for an airport lot are each considered to be constant over the time frame (one-hour) of this analysis. The estimated gate capacities should be submitted by the developer, but they may also be approximated from such information as the number of gates, lanes at each gate, and time sequences on parking fee collection at gates.

The total traffic entering or leaving the parking lot during any incremental period (trip generation) can be determined from the data on hourly, daily, and seasonal variations that were previously presented in the section titled Airport Parameters, and from the section titled Analysis. These data should, if possible, be adjusted to match the expected traffic for each specific airport lot and may need to be further adjusted to account for atypical variations at the lot, either anticipated or observed.

Estimates of running times for the entrance and exist modes 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:

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

a = utilization factor

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

b = average outflow time per vehicle (inverse of gate capacity), min.

For these periods when traffic flow exceeds gate capacity, 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 19. 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 and an exit capacity of 1200 vehicles per half-hour.

AIRPORT PARKING LOT PARKING CAPACITY EXCEEDANCE

This factor, which could be analyzed fairly effectively in the preceding study (Shopping Centers - GEOMET Report No. EF-263) because of an Urban Land Institute study on that specific element, did not lend itself to quantification in the present study at all. Accordingly, only the following general guidelines can be given.

First, the information available indicates that, except in special cases like Washington National Airport, which is limited in space and cannot

Table 19. EXAMPLE QUEUE CALCULATION WHEN GATE CAPACITY IS EXCEEDED

1		2	3	4	5	6	7
Time Period		Traffic Volume (in or out)	Gate Capacity (in or out)	ΔN	N at End of Period	$N_{AV.}$	RT
Starting	Ending						
				col. 3- col. 2	col. 4+ col. 5' (line above)	col. $\frac{5+\text{col. }5'}{2}$	(b) (col. 6)
2:30	3:00	900	1200	-	-	-	(use equation)
3:00	3:30	1220	1200	+ 20	20	20	.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. outflow time per vehicle, min.) (av. queue length) readily generate new parking areas, most airports should not suffer from this problem. Developers of new airports, and expanders of existing ones, can anticipate future parking requirements and allow for such expansion by advance lot construction before the problem develops.

Second, the problem should be calculable, for those cases when the calculations show that required spaces approach the parking capacity, by simply increasing the "Movement In (MI)" time by an amount approximating a slow movement, say, half-way around the lot, to reflect the search for a space.

AIRPORT TERMINAL AREA CAPACITY EXCEEDANCE

We recognize that one problem which exists and should be quantified is the situation when, during extreme peak periods, traffic congestion builds up as vehicles attempt to get to the terminal's curb frontage access areas for pickup and discharge of passengers. We have found no data on this, and again can only suggest an approximate technique. The end result of this phenomenon will be an increase in the idle or stopped time between the "stop" and "start" modes for vehicles trying to perform this maneuver, plus an increase in the time required for those vehicles to pass which are simply trying to depart the terminal; in Figure 1, for example, this would include employees who have left their lot and are departing past the terminal curb frontage. Allowance for a stopped-idle time for the first category, and for an increased departure time for the second, would have to be estimated by the analyst for a specific case in point, based on the configuration, curb frontage, road capacity and number of vehicles involved per unit time in the two categories.

SECTION VIII

RESULTS

THE METHODOLOGY

In general terms, the methodology proceeds as described in the first paragraph which follows. We wish to emphasize that this description is of the technique, shown 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.

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

In the case of airports, as shown in Figure 4, the methodology proceeds from basic information about a given airport (see "Airport Parameters"), via traffic behavior data (see "Traffic Parameters"), and typical trip generation data (see "Typical and Maximum Trip Generation"), to generate

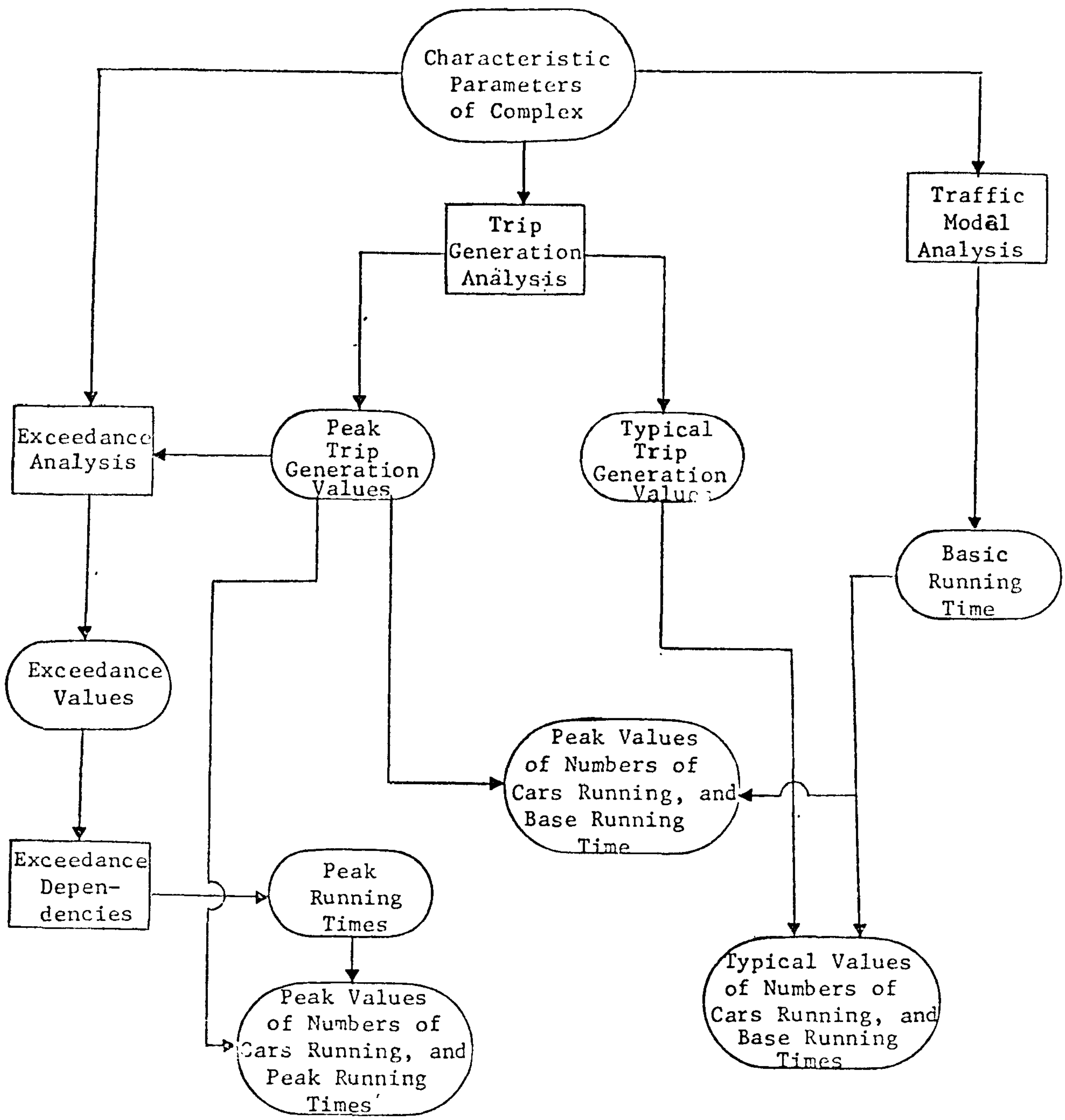


Figure 3. Generalized Methodology

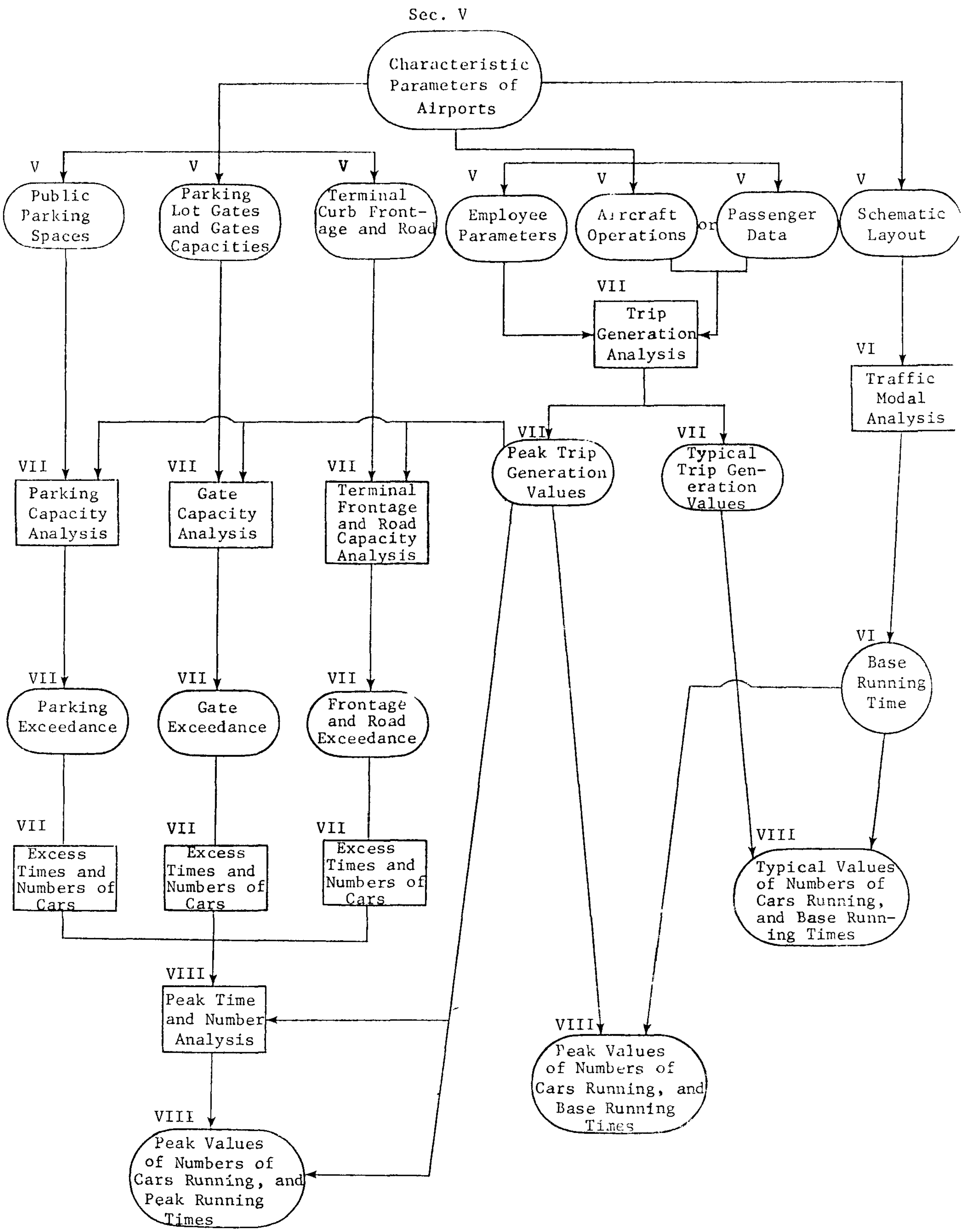


Figure 4. Generalized Methodology Applied to Airports

estimates of typical numbers of vehicles and associated base running times for one-hour and eight-hour periods; these are two of the required end products of the task. For the peak case, peak trip generation rates are estimated (see "Typical and Maximum Trip Generation") and then used to obtain exceedance estimates for parking lot gate and parking capacities, and for terminal curb frontage and road capacities (see the Analysis Section). That section describes general ways to estimate the associated increases in both numbers of vehicles running, and vehicle running times. These increases are combined with the base numbers described above, to provide the other two major products, the peak running times and vehicle numbers for one-hour and eight-hour periods. The third possible combination is of course the case where peak vehicles do not create exceedances, and thus are combined with base running times. The specifics of the procedure, with examples, are presented in the following paragraphs. It is easiest done with the occasional use of examples, but the general applicability will be evident.

First, we define our existing or proposed airport, or expansion, by means of a schematic diagram (Figure 1), and available or estimated data on: public and employee parking spaces, parking lot gates and gate capacities, and terminal curb frontage and road capacity; also numbers of employees and expected arrival and departure rates; also aircraft operation and/or passenger data, in as much detail as is feasible. If any of these parameter values are uncertain, then the estimated range should be provided (with an assist from some of the general data in the section on Airport Parameters), and the analysis carried out as a sensitivity study in order to determine the importance of the parameter value.

The schematic enables estimates to be made of the base running times (Figure 1 and Table 17). Possible differences among base running times should be delineated for the three major traffic types, which use the public parking lot, use the employees' lot, or go to the terminal curb front (Figure 1 and the section on Traffic Parameters). Table 17 shows base running times of about six minutes for each of the three Washington area airports.

The trip generation data may be obtained by the procedures of the analysis section, using employee data or estimates for the employee trips, and starting from aircraft operations, or passenger data, or both, for estimating the passenger/visitor-related traffic. If both aircraft and passenger data are available, it might be well to calculate both ways, for increased confidence in the result. If the results conflict, then either more analysis is called for, or the passenger technique should be accepted.

The identity of each of the three traffic types (employee, public parking, and terminal) is preserved through the calculation because of the potential differences in the modal elements of the base running times, and because of the differential impact of exceedances on different modal times (Analysis Section). Also, from the Analysis Section, if the time of concern is short enough we include only half the cycle (entrance or exit, not both) in the calculation of the employees and some of the passengers ("park and fly" types).

The base running times for each traffic type are combined with the typical trip generation rates for the same type, to provide the required typical values of vehicles running and base running times.

For the peak case, the diurnal variations of passenger/visitors and employee vehicles must be examined to select the composite peak hour. Typically the employees' trips show more exaggerated peaks than passengers/visitors, so that in cases where there are relatively large numbers of employees, their trips will determine the peaking time. Having defined the peak time, we first combine its vehicle numbers with the base running times to characterize that case where no capacity exceedances might exist.

We now proceed, for the peak case, to determine whether the peak vehicle numbers represent exceedances of any of the critical elements of public parking lot gate and parking capacity, or terminal curb frontage and road capacity. The methods of the analysis section give general approaches as to how to treat each of these potential exceedance areas, but the specifics of each case will require interpretation and judgement on the part of the analyst. An example of gate capacity exceedance is given in the Analysis Section.

The resulting increases in times are added to the appropriate base running times to give the peak running times, the peak trip generation rates will, as for the typical case, give the base peak numbers of vehicles running, to which we add any additional vehicles running because of exceedances.

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

GEOGRAPHIC DISTRIBUTION

Running times, and hence emissions, from an airport complex can usually be considered as being distributed fairly uniformly over the area of the airport roads and parking areas during typical operating periods (base running times), as indicated by the schematic in Figure 1, and the example data in Table 17 (see the section titled "Traffic Parameters"). For most analyses, an assumption of a geographically uniform emission density is thus sufficiently accurate. It may be necessary to distribute the access road traffic (and hence the Approach and Departure Model Emissions) along the access roads, depending on their orientation (especially if straight away from the airport) and distance of expected effect. Peak traffic conditions can result in either the gate or the parking capacities being exceeded, or both. If only the parking capacity is exceeded, emissions still tend to be distributed evenly over the entire parking area, as drivers search for empty parking spaces. However, if gate capacity is exceeded, a substantial part of the total running time and emissions become concentrated at the entrance/exit ways.

The procedure of estimating running time for each mode individually allows this uneven distribution to be evaluated quantitatively. Emissions from the ensuing traffic queue can be simulated as a continuously emitting line source(s) oriented from the gate along the main queue line, while emissions from the other seven modes are still considered to be uniformly distributed over the shopping center area, as above.

If the terminal area capacity is exceeded, than the excess vehicles may be simulated as a line lying along the terminal curb frontage, and treated comparably to the parking lot queues described above.

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 20. For ground level sources, such as automobiles at airports, 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 airports occurs during major holiday periods, especially in midsummer, with the highest day of the week usually being on Friday. The peak hour use generally occurs during the mid- to late afternoon. The peak eight-hour period is generally 2 p.m. to 10 p.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 5 and 6). For the Friday afternoon 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 airports are essentially not in use (Tables 13 and 16). 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.

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

Table 20. KEY TO STABILITY CATEGORIES (after Turner 1970)

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

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

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

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

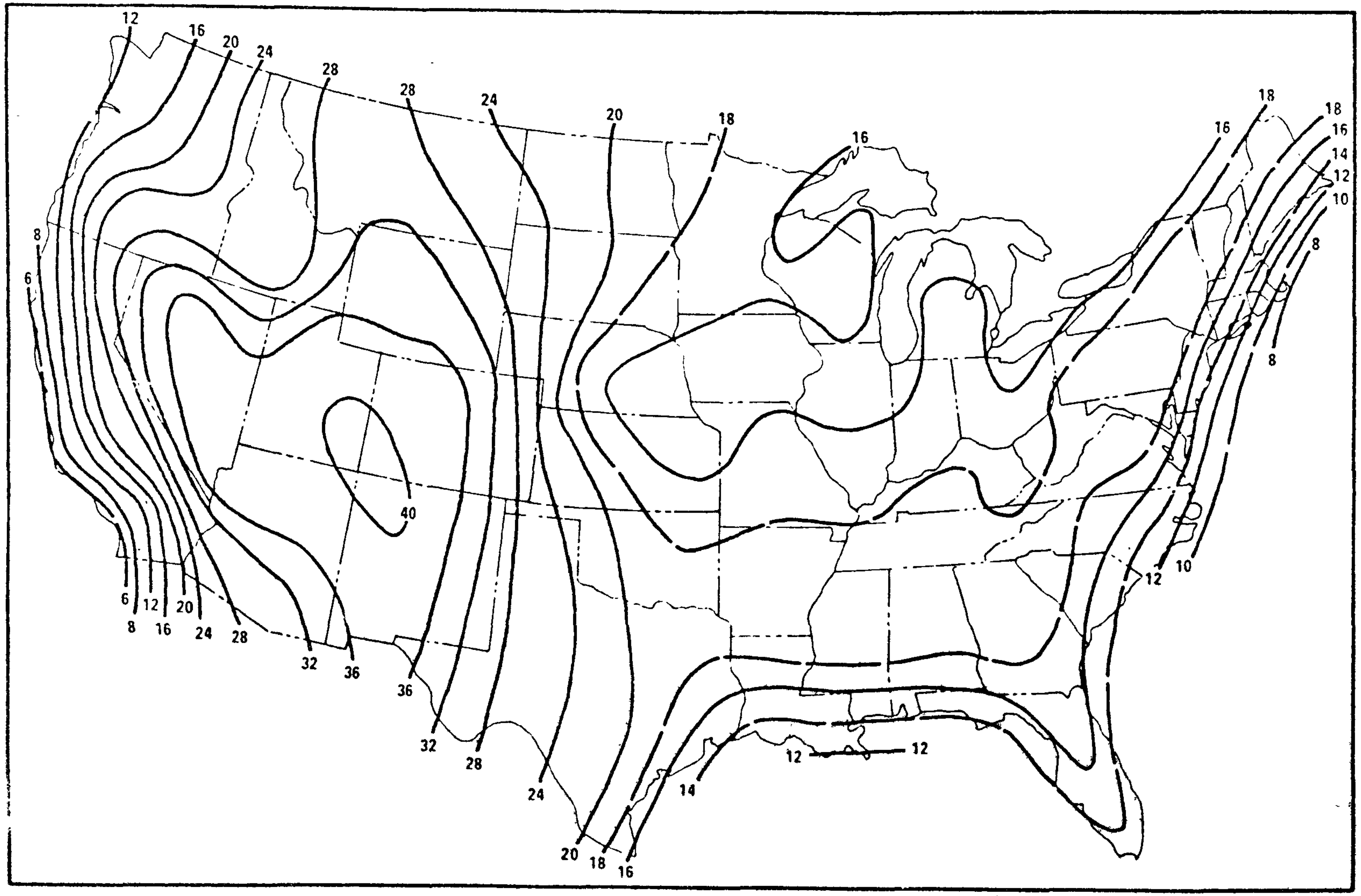


Figure 5. Isopleths (m x 10^2) of mean summer afternoon mixing heights

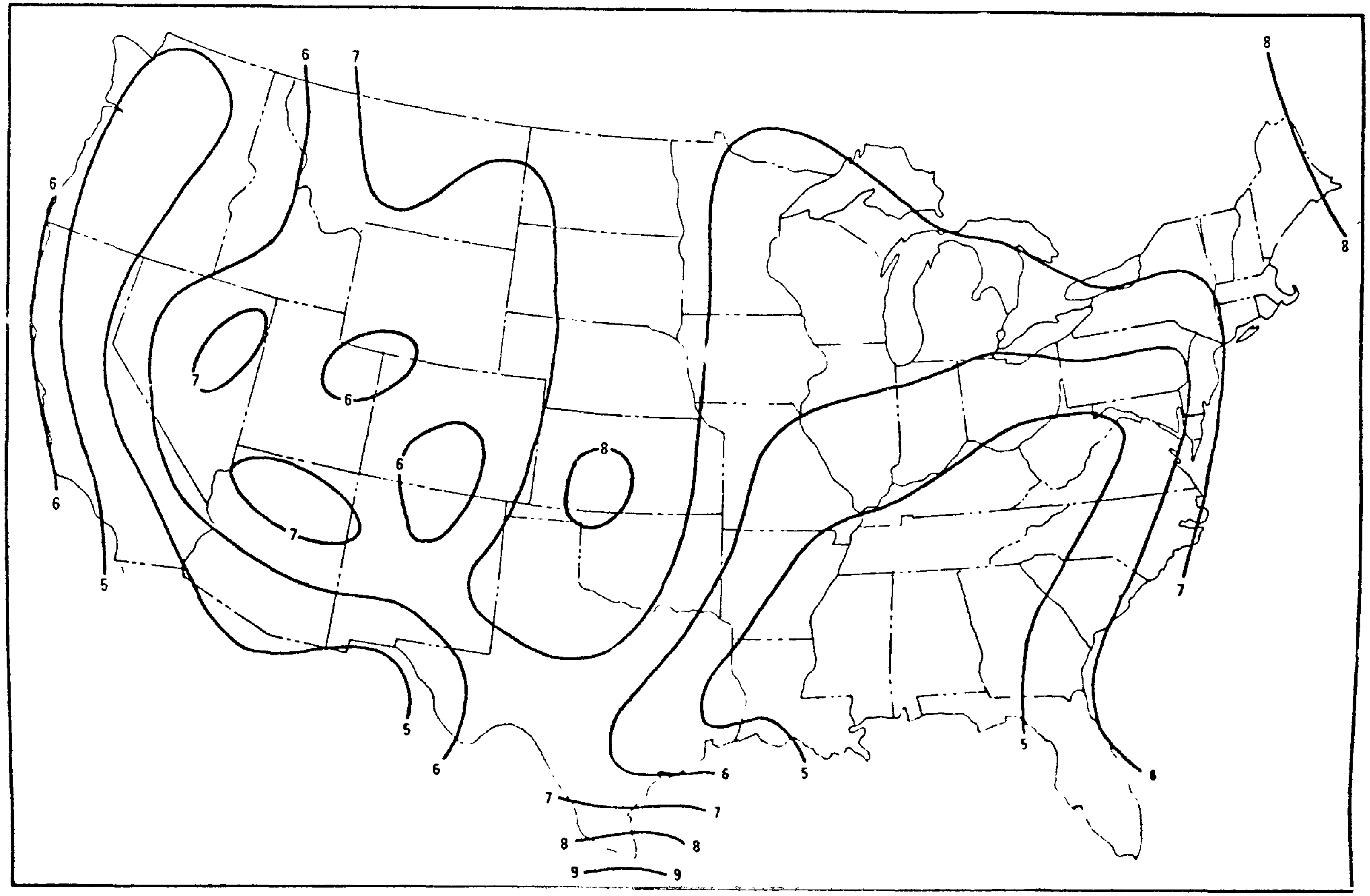


Figure 6. Isopleths (m sec^{-1}) of mean summer wind speed averaged through the afternoon mixing layer (Figure 5).

For most parts of the country, autumn is the season when these least favorable conditions are most likely to occur.

If one now considers that operating hours for airports are generally 7-8 a.m. to 11 p.m., then, from a meteorological point of view, the single hour least favorable for dispersing pollutants during that period is from 11 p.m. to midnight during the autumn season. The least favorable eight-hour period would be from 4 p.m. to midnight; composite use levels for airports during these periods can be derived as they were for Table 17, from Tables 13 and 16. During these times, the mixing height is usually estimated to still be at the afternoon value (Figure 5), not having lowered to the morning value till after midnight; the wind speed estimate is also still best given by the afternoon value (Figure 6). However, as the time proceeds toward the latter part of the evening period, stability classes D and E become prevalent.

QUALITATIVE GUIDELINES

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

1. Maintain the close-in public parking area as premium short-term space (low rates for short-term, very high rates for longer term). Keep valet and long-term parking in more distant and satellite lots, with free and frequent shuttles. Maintain low long-term rates in more distant lots to attract "park and fly" passengers. Use obvious and attractive markings to guide traffic accordingly.

2. Have adequate numbers of parking lot gates and gate capacities, and personnel and signs to guide parkers to lesser used exit gates.

3. Avoid traffic patterns that require left turn movement across traffic flow.

4. Maintain adequate terminal curb frontage for pick-up and discharge of passengers, and adequate road capacity for through flow. Allow no short-term method parking in this area, and use traffic control personnel to prevent excessive congestion.

5. More strongly encourage development of public rapid transit systems to airport terminal from city center and other major communities.

THE NINE QUESTIONS

While the specific information called for by the task work statement has been provided in the sections from Airport Parameters through Meteorological Aspects, the nine questions spelled out as part of the statement warrant specific response. This is given here, with the questions abbreviated.

1. Area allotted to or occupied by a single vehicle? The area ranges from 9 x 20 feet (180 ft^2) to 10 x 20 feet (200 ft^2).

2. Percentage of land and parking spaces potentially occupied by vehicles? The usual percentage? As indicated in the sections entitled Airport Parameters and Analysis, these data are only indirectly related to our methodology. To the extent that they are relevant, they are discussed in those sections.

3. Typical and peak values (absolute or fractional) of vehicles running for one- and eight-hour periods? These data are developed in sections Analysis through the Methodology.

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

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

6. Design parameters of the complex likely to be known beforehand? See section titled Airport Parameters.

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

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

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

SECTION IX

DATA SOURCES

BOOKS AND REPORTS

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PRIVATE COMMUNICATIONS

Information provided by management personnel of: Friendship International Airport, Baltimore; Washington National Airport; Dulles International Airport, Washington, D. C.

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16. ABSTRACT

A general methodology is presented for relating parameters of ground traffic behavior in and around airports, including trip generation rates and vehicle running time, to more readily available characteristics of airports, including size and nature of airport population and size and nature of air traffic. Such relationships are to be used to relate airport characteristics to air quality.

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