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VEHICLE BEHAVIOR IN AND AROUND COMPLEX SOURCES AND RELATED COMPLEX SOURCE CHARACTERISTICS VOLUME I - SHOPPING CENTERS

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

CONTENTS

		Page
Abstract		iii
List of Figures		v
List of Tables		vi
Sections		
I	Conclusions	1
II	Recommendations	2
III	Introduction	3
IV	Characteristics of Shopping Centers	7
V	Regional Shopping Center Parameters	9
VI	Traffic Parameters, Values and Derivations	19
VII	Analysis	26
VIII	Results	36
X	Data Sources	51
Appendix A		53
Appendix B		58

FIGURES

No.		Page
1	Montgomery Mall Shopping Center	11
2	Landmark Center	12
3	Schematic Representation of Vehicle Operating Modes at a Shopping Center	21
4	General Relationship Between Traffic Volume and Total Running Time	24
5	Generalized Methodology	37
6	Generalized Methodology Applied to Shopping Centers	38
7	Isopleths (m sec^{-1}) of mean autumn wind speed averaged through the afternoon mixing layer	45
8	Isopleths (m sec^{-1}) of mean winter wind speed averaged through the afternoon mixing layer	46
9	Isopleths (m x 10^2) of mean autumn afternoon mixing heights	47
10	Isopleths (m x 10^2) of mean winter afternoon mixing heights	48
B-1	Traffic Impact Study Saturday Hourly Variation of Traffic Entering and Leaving Montgomery Mall	60
B-2	Traffic Impact Study Weekday Hourly Variation of Traffic Entering and Leaving Montgomery Mall	59
B-3	Traffic Impact Study Saturday Hourly Variation of Traffic Entering and Leaving Landmark	64
B-4	Traffic Impact Study Weekday Hourly Variation of Traffic Entering and Leaving Landmark	63

TABLES

No.		Page
1	General Characteristics of the Three Major Types of Shopping Centers: Regional, Community, Neighborhood	7
2	Greater Washington Regional Shopping Centers	8
3	Parking Space Data for Greater Washington Regional Shopping Centers	14
4	Summary of ULI Data on Parking Spaces in Regional Centers of Various Sizes	15
5	Summary of Trip Generation Data (one-way) for Regional Shopping Centers from COG Report	16
6	Seasonal Demand for Shopper Parking	17
7	Vehicle Exhaust Emissions at Idle in Grams per Minute	20
8	Base Running Times by Operating Mode at Two Suburban Washington, D.C. Shopping Centers	23
9	Trip Generation Data from the COG Report, and Suggested Values for Use, as a Function of Regional Shopping Center Size	28
10	Example Queue Calculation when Gate Capacity is Exceeded	32
11	Key to Stability Categories (after Turner 1970)	43
B-1	Total Traffic Entering and Leaving the Shopping Center During Average Weekday and Saturday	58
B-2	Relative Use of Access Points at the Shopping Center for an Average Weekday and Saturday	58
B-3	Total Traffic Entering and Leaving the Shopping Center During Average Weekday and Saturday	62
B-4	Relative Use of Access Points at the Shopping Center for an Average Weekday and Saturday	62

SECTION 1

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 first (shopping centers) 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 guidance for relating the traffic characteristics of shopping centers to typical and peak air pollution concentrations.

SECTION III

INTRODUCTION

INTRODUCTION

OBJECTIVE AND SCOPE

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

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

1. Shopping centers
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 first task report, describes the methodology developed, and the analysis and results of its application to shopping centers.

APPROACH

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

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

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

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

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

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

1. To develop quantitative relationships between running times and various percent-usage parameters; and
2. To provide general usage patterns from which the usage pattern for a complex of interest can be inferred, if no measured data are available.

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

For any parameter of capacity (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 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 shopping centers, and the results obtained.

SECTION IV

CHARACTERISTICS OF SHOPPING CENTERS

The literature and practice of architecture and development widely recognizes that shopping centers may logically be divided into three principal categories: regional, community and neighborhood. These differ importantly from each other in major characteristics, and are so divided for a variety of purposes. Major differences are shown in Table 1.

Table 1. GENERAL CHARACTERISTICS OF THE THREE MAJOR TYPES OF SHOPPING CENTERS: REGIONAL, COMMUNITY, NEIGHBORHOOD

Type	Regional	Community	Neighborhood
Size (gross leasable floor space)	Average 400,000 sq.ft.; (300,000-1,000,000 and up)	Average 150,000 sq.ft.; (100,000-300,000 sq.ft.)	Average 50,000 sq.ft.; (30,000-100,000 sq.ft.)
Total acreage	$\geq$ 30 acres	10 to 30 acres	4 to 10 acres
Major stores	One or two major dept. stores	Variety, or junior dept. store, and supermarket	Supermarket
Population served	$\geq$ 150,000	40,000-150,000	5,000-40,000
Usual parking lot type	open, peripheral	open, one side	open, one side
Order of magnitude of average shopper stay	2 hours	45 minutes	15 minutes

Because of the major physical differences in the center types, and known differences in parameter values (parking capacity and use rate, e.g.), it was necessary to select one of the three types of center for data collecting and analysis, in the limited time available. The choice (regional centers) was obvious because of the large size and use rates involved, and was supported by the precedent of the Federal Register (Vol. 38, No. 116).

GREATER WASHINGTON REGIONAL SHOPPING CENTERS

All of the regional shopping centers in the Greater Washington area are listed in Table 2, along with data indicating the range of size represented by these twelve centers.

It is evident that a wide range of examples of the regional center exists in and near Greater Washington; further, these cover a variety of basic designs, and ages; our use of the body of information associated with examples from these centers, along with other more general data, would therefore be expected to not only apply to this locality, but also to be broadly applicable to regional centers in other parts of the county.

Table 2. GREATER WASHINGTON REGIONAL SHOPPING CENTERS

Name	Total Size	Building Square Footage	Number Stores	Annual Sales
Tyson's Corner	90 acres	1,500,000 sq.ft.	120	$120,000,000
Landover Mall	88 acres	1,350,000	125	---
Wheaton Plaza	80 acres	1,250,000	75	$100,000,000
Springfield Mall	88 acres	1,200,000	130	---
Prince George's Plaza	52 acres	872,000	81	---
Beltway Plaza	70 acres	800,000	75	$ 50,000,000
Montgomery Mall	55 acres	729,000	60	$ 60,000,000
Landmark Center	52 acres	665,000	36	$ 90,000,000
Iverson Mall	23 acres	640,000	72	$ 52,000,000
Columbia Mall	40 acres	625,000	102	$ 40,000,000
Seven Corners Center	38.5 acres	597,000	48	$ 48,000,000
Rockville Town Center Mall	-	500,000	29	---

SECTION V

REGIONAL SHOPPING CENTER PARAMETERS

In the following discussion of shopping center parameters and values, we emphasize those which are commonly known to, and used by, developers in the course of their work. In addition, other parameters are coming into use, more specifically oriented toward assessing the air pollution impact of the traffic and other emission sources associated with complex sources. An example of this increasing awareness and concern is found in Appendix A, copy of which was provided to us by the Maryland Bureau of Air Quality Control. This is an extract from a procedure proposed by the International Council of Shopping Centers as a model code and administrative procedure, for reviewing complex sources, which embodies the regulatory requirements related to state preparation, adoption and submittal of air quality implementation plans. This, we believe, represents a growing tendency of developers to attempt to anticipate the requirements of impact analysis for complex sources.

Customarily, the developer has a variety of sources of information available to him, some of which are in the form of constraints (e.g., zoning regulations) and others comprise information sought out by the developer to support his decisions (e.g., marketing analyses, demographic surveys, characteristics of the population to be served, and trip generation information or estimates). The information presented in this section involves that which is both available and applicable to the problem.

SIZE

The size of a center is most often given in terms of square footage of leasable store space, although total acreage and number of stores are sometimes useful indicators of size for various purpose. The store square footage is the most useful indicator for our purposes, as will be seen subsequently.

Specifics of regional center size will be presented subsequently in the discussion of parking spaces (see section titled Parking Spaces); hence only general comments are given here.

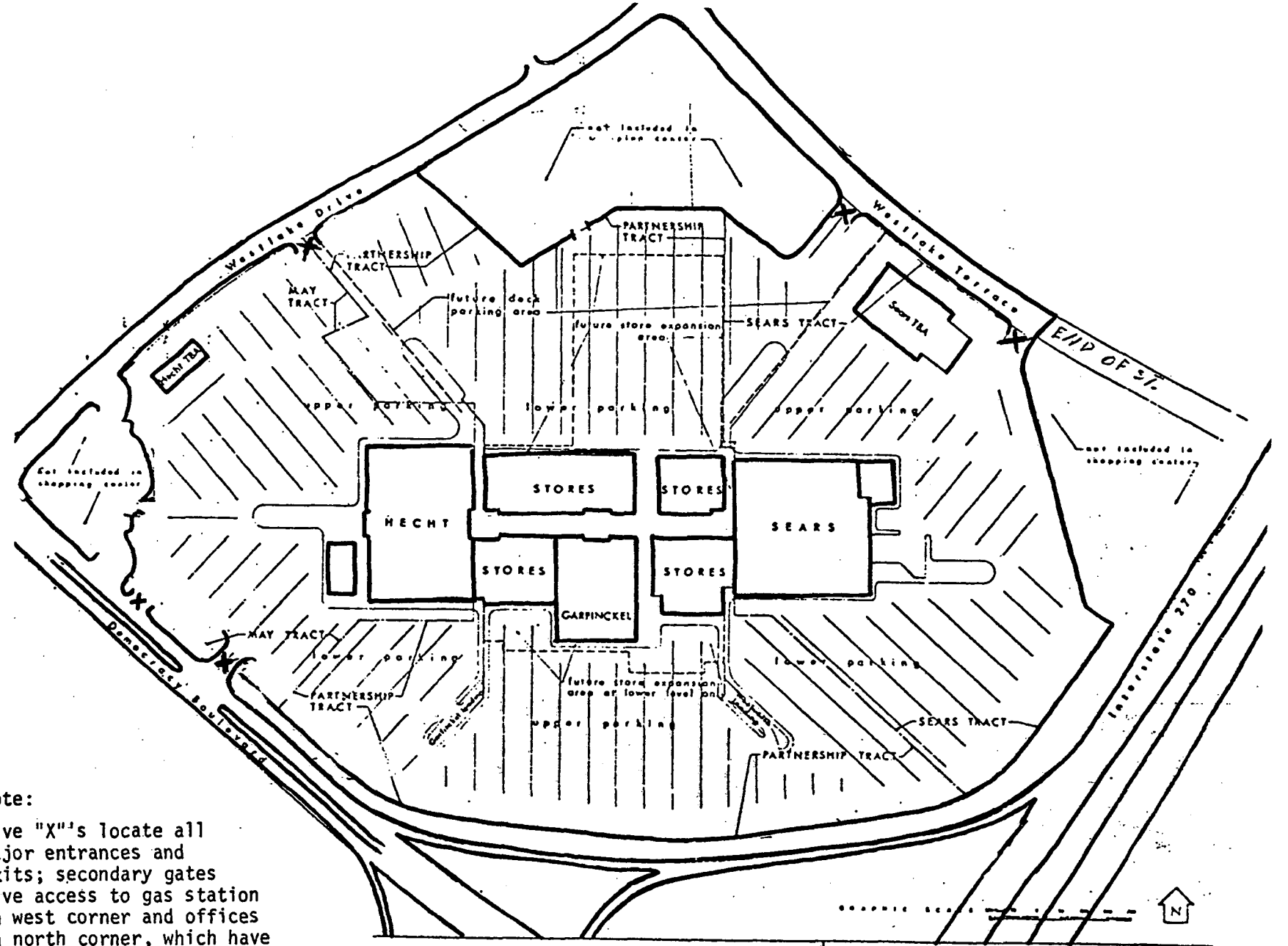
Regional centers range in size from some 300,000 sq. ft. in shopping area to the order of 1,500,000 sq. ft. with total size from around 30 to around 100 acres, or approximately 1 million to four million square feet. The number of stores can range from several dozen up to well over a hundred.

LAYOUT, BLUEPRINT OR SCHEMATIC DIAGRAM, AND RELATED DATA

Examples of this type of information, which is necessary for analysis of running times and gate use, are given in Figure 1 for Montgomery Mall, and Figure 2 for Landmark Center. In addition to the general layouts, gates, internal flow (which can be inferred or observed), and nature and characteristics of the access raods, all of which are implicitly or explicitly available from such diagrams, corollary data should be obtained or derived on gate capacitites, gate traffic controls, and their characteristics, and distribution of traffic volumes and densities on access roads.

PARKING SPACES

Parking space data represent vital parametric characteristics for any complex source, and regional shopping centers are no exception. A parameter frequently used is that of parking spaces (for customers) available per thousand square feet of leasable store space. As a matter of incidental information, the generally accepted range of space allotted for parked cars is from 9 x 20 feet (180 sq. ft.) to 10 x 20 feet (200 sq. ft.).



Note:

Five "X"'s locate all major entrances and exits; secondary gates give access to gas station on west corner and offices on north corner, which have access to streets.

Figure 1.

MONTGOMERY MALL SHOPPING CENTER

NOTE THE 3 ONE WAY ROADS IN THE CENTER

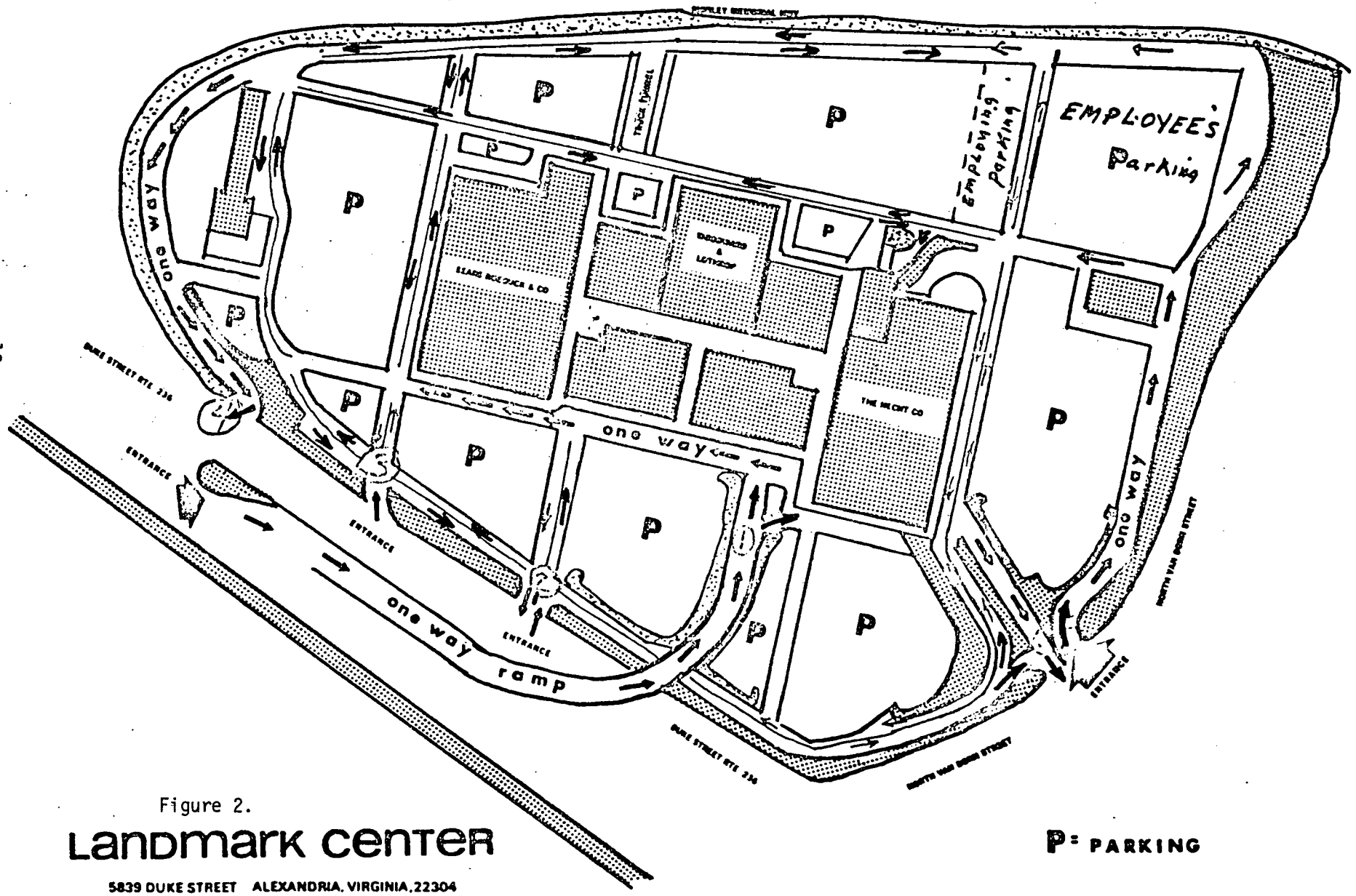


Figure 2.

LANDMARK CENTER

5839 DUKE STREET ALEXANDRIA, VIRGINIA, 22304

P = PARKING

Values encountered, for the critical parameter of parking spaces per thousand square feet of selling area, can range from as low as three for the older, high parking density centers (which are generally smaller, as well) through many centers in the five to six range, and ocassionally up to seven, eight or even nine. Seven is indicated by Baker and Funaro* to be a "desirable parking index," while the Urban Land Institute states that, based on a study of peak parking at 270 centers, 5.5 spaces per thousand square feet is adequate as a standard for meeting all but the 10 highest hours of parking demand during an entire year. There are many obviously conflicting requirements regarding this parameter - our primary interest is in expected values, ranges of values, and their influence on traffic.

Table 3 expands the data previously given for Greater Washington Regional Centers to now include data on parking capacitites as well. We see that, of the 11 centers for which parking space data could be obtained, six ranged between five and six spaces per 1000 square feet; three ranged between about 4.5 and 5.0, and two below four.

Additional extensive data on parking capacity is included as part of the Urban Land Institute's study on parking requirements for shopping centers. This is summarized in Table 4. In this table, the relative invariance of the reported mean values with center size (except for a slight tendency to decrease at the highest center sizes) is interesting, especially in view of the rather extreme ranges found at almost all center sizes. The median values are largest near the middle range of center sizes (500,000 to 900,000 sq. ft.), and are smaller than this peak for both smaller and larger centers.

TRIP GENERATION

The most prevalent and useful term for describing traffic activity associated with shopping centers is "trip generation." This term is defined by traffic engineers as follows: a trip usually refers to a single vehicular movement (one-way) having either an origin or a destination within the area or site of interest. Generation usually refers to the total number of trips

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* See Data Sources Section

Table 3. PARKING SPACE DATA FOR GREATER WASHINGTON REGIONAL SHOPPING CENTERS

	Total Acres	Total Sq. Ft.	Store Sq. Ft.	Nr Stores	Parking Spaces	Parking Spaces per 1000 sq.ft. of store space	Stores / Total %
1. Tyson's Corner	90	3,920,400	1,500,000	120	6600	4.4	38.3
2. Landover Mall	88	3,833,280	1,350,000	125	6200	4.6	35.2
3. Wheaton Plaza	80	3,484,800	1,250,000	75	6000	4.8	35.9
4. Springfield Mall	88	3,833,280	1,200,000	130	*	*	31.3
5. Prince Georges Plaza	52	2,265,120	872,000	81	4926	5.65	38.5
6. Beltway Plaza	70	3,049,200	800,000	75	4000	5.00	26.2
7. Montgomery Mall	55	2,395,800	729,000	60	4000	5.49	30.4
8. Landmark Center	52	2,265,120	665,000	36	3910	5.88	29.4
9. Iverson Mall	23	1,001,880	640,000	72	3500	5.47	63.9
10. Columbia Mall	40	1,742,400	625,000	102	2300	3.68	35.9
11. Seven Corners Mall	38.5	1,677,060	597,000	48	3000	5.03	35.6
12. Rockville Mall	-**	-**	500,000	29	1960	3.92**	-

*Being repaved and resurfaced - number unknown.
** Unusual design for regional center enclosed two-story parking under mall.

Table 4. SUMMARY OF ULI DATA ON PARKING SPACES IN REGIONAL CENTERS OF VARIOUS SIZES

Center Size Range Thousands of sq. ft.	Number of Centers	Parking Spaces per 1000 sq.ft.		
		Median	Mean	Range
300-399	33	5.95	6.59	2.66-11.45
400-499	21	6.31	6.70	3.66-10.01
500-599	10	7.12	6.77	4.09-8.55
600-699	12	6.92	6.61	4.46-9.41
700-799	4	6.48	6.57	5.66-7.66
800-899	3	7.19	6.51	5.03-7.30
900-999	5	5.90	6.16	5.58-7.16
1,000-1,250	5	5.41	5.67	4.32-7.92
Total	93*			

*The remaining 177 (total 270) centers were less than 300,000 sq. ft. in size, and thus not defined as regional centers.

within a given time period crossing a counting station. These trips can have either an origin or a destination within the site, and are ordinarily expressed as rates; for regional shopping centers, we quantify trip generation in numbers of trips generated per thousand square feet of store area.

A summary of some available data on trip generation for regional centers is presented in Table 5. This was obtained from a data review performed by the National Capital Region Transportation Planning Board of the Metropolitan Washington Council of Governments (COG), hereafter referred to as the COG report.

We also require data on seasonal, weekly, and hourly variations in trip generation rates in order to establish typical one-hour and eight-hour values, and also to determine when the peak one-hour and eight-hour rates will occur, and what their values will be.

Table 5. SUMMARY OF TRIP GENERATION DATA (ONE-WAY) FOR REGIONAL SHOPPING CENTERS FROM COG REPORT

Investigator	Number of Centers	Range of Shopping Area (1000's sq.ft.)	Range of Trip Generation Rates (per 1000 sq.ft.)	Median	Parking Spaces	Peak Hour Volume as % of Daily Volume
• National Cooperative Highway Research Program	15	300-800	8-27		1000-5000	11.3-18.3
			Av. week day			
• Los Angeles Regional Transportation Study	5	541-811	9-29	22	3200-6830	-
• California Division of Highways	1	528	-	39	2500	-
• St. Louis ITE Study	2	1,000-1,500	26.4-30.6	28	1200-7500	-
• Maryland State Roads Commission	6	294-530	22-31	26	1500-3500	-
• Bureau of Public Roads	1	503	-	16	2000	
			Peak hourly generation, average weekday			
• Wilbur Smith and Associates	3	275-483	2.80-4.67	3.46	2000-5000	-

In Baker and Funaro's work on parking, we find characteristic data on seasonal variations, as shown in Table 6, which shows the characteristic Easter and Christmas peaks, with Christmas the highest.

Table 6. SEASONAL DEMAND FOR SHOPPER PARKING

Month	Percent of Yearly Total
January	7.5
February	8.0
March	9.8 (Easter peak - secondary maximum)
April	9.0
May	8.5
June	9.4
July	5.4
August	6.3
September	7.2
October	7.5
November	7.9
December	13.5 (Christmas peak - maximum)

The same report presents some characteristic trip generation curves which show the hourly variation for typical weekdays and Saturdays; examination of these data in the context of other similar measurements, as exemplified by the surveys shown in Appendix B, shows that they reflect characteristic and relatively invariant behavior from center to center; the seasonal data are similarly representative. The weekday hourly peak occurs during the period 7 to 9 p.m., with the highest value usually in the 8-9 p.m. hour. The highest 8-hour weekday period extends from 1 p.m. to 9 p.m. The highest Saturday hour is found between 1 p.m. and 4 p.m., with the

highest usually at 3-4 p.m. For the eight hour period, it extends from 10 a.m. to 6 p.m.*

The highest one-hour period on Saturday is about one-and-one-half times the highest weekday hour. The highest eight-hour period on Saturday is also about one-and-one-half times the highest eight-hour weekday period. Thus, we find that Saturday one-hour and eight-hour periods are highest, and December is the highest month. Hence, the pre-Christmas Saturdays have both the maximum one-hour and eight-hour values. We are nonetheless also interested in the weekday evening maximum, for the meteorological reasons discussed in the section titled Meteorological Aspects, in considering the traffic conditions associated with the most adverse dispersion conditions (at least the most adverse during the center's operating hours).

The absolute magnitudes and ranges of these values to be used are developed in the section titled Analysis.

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*For each hour, we combined the trips entering and trips leaving, to obtain the number of cars moving during the hour; it is the maximum and/or typical values of this figure which we seek. In applications combining this figure with vehicle running times, we either use one-half the total, with complete cycle running times, or if there is a significant difference both in the number of vehicles entering and leaving, and in the entering and leaving running times, then they may be apportioned appropriately.

SECTION VI

TRAFFIC PARAMETERS, VALUES AND DERIVATIONS

CONCEPT OF EMISSIONS PER UNIT TIME

In parking areas of shopping centers, 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 with slight change in average operating speed.

For shopping centers, 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 shopping center 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 7. 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.

*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 7. 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 emissions from the shopping center 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 Modes in Shopping Centers

For purposes of analysis, traffic movement in the vicinity of a shopping center has been divided into eight characteristic operational modes. These are summarized below and shown schematically in Figure 3:

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 shopping center.

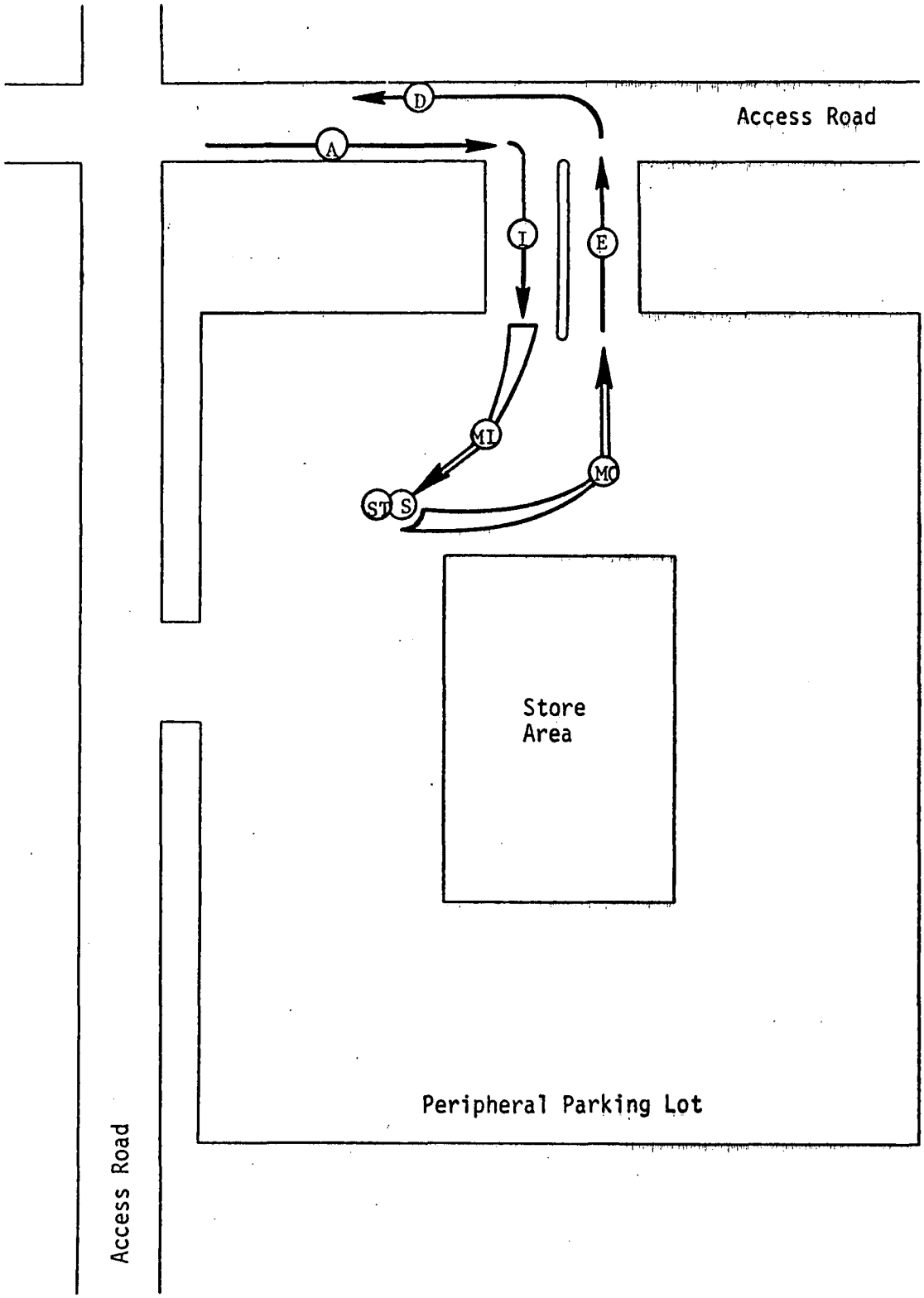

Figure 3. SCHEMATIC REPRESENTATION OF VEHICLE OPERATING MODES AT A SHOPPING CENTER

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 store entrances. Time spent searching for an open space is also included in this mode.

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

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

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

Exit (E) - Movement through the exitway, including waiting time 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 shopping center.

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

Base Running Time

There is an average minimum vehicle running time for each shopping center that is associated with periods of low or zero traffic congestion. This concept of a minimum or base running time is important because it usually is the most common (typical) operating condition at the shopping center, and because at most centers 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 shopping center with an additional knowledge of its traffic control devices and probable driving patterns.

Base running times for the two example shopping centers, Montgomery Mall and Landmark Center, have been constructed both by time measurement during simulated driving cycles and by estimates based on dimensions of the centers, entrance/exit configurations, and expected driving patterns. Total base running times and average times in each operational mode are shown in Table 8.

Table 8. BASE RUNNING TIMES BY OPERATING MODE AT TWO SUBURBAN WASHINGTON, D.C. SHOPPING CENTERS

Operational Mode	Base Running Time, Minutes	
	Montgomery Mall	Landmark Center
Approach	0.9	0.5
Entrance	0.1	0.1
Movement in	1.0	0.7
Stop	0.1	0.1
Start	0.1	0.1
Movement out	1.2	1.1
Exit	0.4	0.5
Departure	0.9	0.5
Total BRT	4.7	3.6

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 traffic control lights and signs at entrance/exits
- Queues created as vehicles attempt to exit onto uncontrolled access roads
- Traffic intersections and merging traffic lanes within the parking area
- Traffic aisles blocked by vehicles making dropoffs or pickups, 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 4. The base running time (BRT) can be determined for a specific shopping center as described above. The magnitude of increase above the BRT with increased traffic can be estimated from shopping center and trip generation parameters, by the procedure developed in the section titled Analysis.

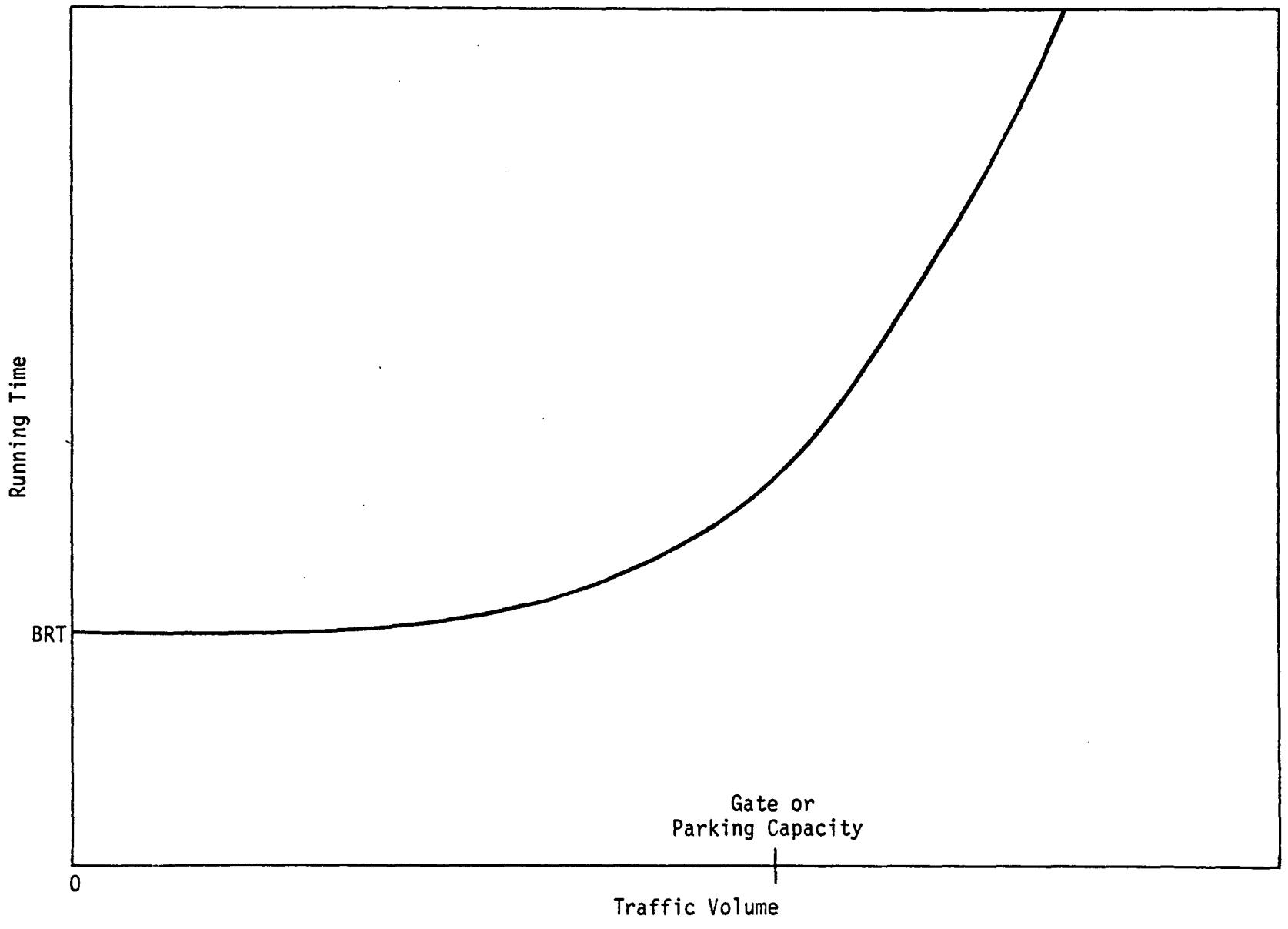

Figure 4. General Relationship Between Traffic Volume and Total Running Time

Identification of Critical Modes for Shopping Centers

Examination of the eight operational modes that were identified indicates that for shopping centers, running times in some modes are relatively constant, but that times in others may increase drastically from the base running time during peak usage and traffic conditions. For shopping centers, 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 shopping center entrance/exit ways. As these capacities are approached or exceeded, running times in the two modes rapidly increase. Waiting times in the resulting queues become the primary factors in determining total running times. However, because of diurnal variations in the number of vehicles entering and leaving shopping centers, egress and ingress capacities generally are not exceeded simultaneously.

Movement time into a parking space, the remaining critical mode, is a function of the number of free parking spaces. The time in this mode increases only slightly with shopping center 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.

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

SECTION VII

ANALYSIS

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

Typical and Maximum Trip Generation as Functions of Center Size

We need to be able to generate at least some approximate indicator of the typical and peak trip generation rates expected to be associated with a given center. While one might simply require the developer to provide such estimates (and we believe this should be done in any event), we felt it appropriate to examine data on such rates to ascertain any dependencies that might be unearthed, as well as to demonstrate characteristic values. The regional center data in the COG report turned out to be the most complete sample which was readily accessible, and the following statements and interpretations derive from that study. The basic trip generation parameter used is that of trips generated per 1000 square feet of shopping space, as the most generalized and customary form of use.

We sought dependencies, and were able to find none, in essence. For any dependence on parking capacity, data were sparse, and did not indicate any dependency; none was expected, in any event, with the possible exception that centers with very low parking capacities would dissuade potential

customers, and thus result in low trip generation. This situation would generally not be of interest.

The data on trip generation were stratified by center size, with the result seen the left-hand portion of in Table 9. Examining these data in a number of different ways indicates a relative independence of the trip generation rate from the center size (means and median nearly constant from 300,000 to 900,000 square feet in center size; above that, an apparent slight decrease). Of course, the absolute total number of trips generated is directly dependent on center size; that parameter has been factored out in seeking more precise dependencies. Some relationships appear for the rates, however, which we will accept in spite of the smaller number of cases at the larger sizes, because the relationships also appear to fit expectation. For example, the highest values seen in the "range" column tend to diminish at the larger center sizes; this would agree with the concept that there is a demographically-inposed limit on the absolute maximum value of trip generation which is possible. In other words, one cannot attract ever larger numbers of people simply by increasing shopping space ad infinitum. On the other hand, it is probable, for parallel but converse reasons, that the minimum values for the largest centers may be larger than those for smaller centers; this is only of incidental importance, however.

The ranges of values seen for each center size range are undoubtedly due to combinations of factors, including real demographic and shopping center differences, as well as the probabilities of sampling, and real differences in measurement procedures. We must accordingly interpret these as "expected" ranges, to be used for sensitivity study purposes, as first approximation for typical values for a center with no data, and as a comparison against which to assess the reasonableness of submitted estimates. The values proposed in the right-hand protion of the table (headed "Suggested for Use") are proposed for use where necessary in the succeeding methodology.

Table 9. TRIP GENERATION DATA FROM THE COG REPORT, AND SUGGESTED VALUES FOR USE, AS A FUNCTION OF REGIONAL SHOPPING CENTER SIZE

Center Size 1000's sq.ft.	Number of Centers	"Average Day" One-Way Trip Generation Rates (per 1000 sq.ft. per day)					
		From the COG Report			Suggested for Use		
		Median	Mean	Range	Median	Mean	Range
300-399	11	20	20	8-31	20	20	10-30
400-499	3	15	17	14-21	20	19	10-30
400-599	10	20	19	9-29	20	19	10-30
700-900	4	18	18	9-26	18	18	10-25
1,000-1,500	2	14	14	13-15	15	15	10-15
Total	30						

Certain additional numbers are required for the methodology. These are obtained from, and are here added to, the material which concludes the section titled Regional Shopping Center Parameters. Table 9 above provides a selection of "average day" rates for any center of interest. Multiplied by the thousands of square feet in the center gives the typical total one-way trips generated as our base figure. Data from the section titled Regional Shopping Center Parameters, augmented here, gives us the information that, of that total, the weekday peak hour is 11 percent and the weekday peak eight-hour period is 70 percent. The Saturday total is 1.15 times the weekday, and, of the Saturday total, its peak hour is 15 percent and its peak eight-hour is 80 percent. Recalling that all these are typical values, from the seasonal variability data of the section titled Regional Shopping Center Parameters we see that, for the seasonal December peak, we would multiply all values by a factor of 1.4. Thus, we can evolve all the necessary trip generation data from this section.

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

Average running times for entrance and exit are primarily functions of three parameters: traffic trips in and out of the center, 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 a shopping center, by use of a methodology employing queueing theory.

The entrance and exit capacities for a shopping center are each considered to be constant over the time frame (one-hour) of this analysis, although they actually do vary with the traffic volumes on arterials adjacent to the center. 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, time sequences on traffic control lights at the gates, and respective percentages of traffic making left and right turns.

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

This procedure, utilizing total gate capacities and trip generation data for the center, assumes that the shoppers will distribute themselves among the available gates so as to minimize their running times. While this assumption has some validity based on observed behavior, it may be desirable to perform the analysis on an individual gate basis if significant deviations in waiting time are known (or suspected) to exist, and if data on traffic volumes at each gate can be obtained. Unbalanced use of gates is most likely to occur where a single arterial or freeway carries most of the traffic to and from the center.

Estimates of running times for the entrance and exit 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:

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

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.

c = added running time at a discontinuous entrance/exit (traffic control signal), min.

= 0.5 (fraction of signal cycle on red) (length of red light, min.)

An example calculation when the traffic flow <u>does not</u> exceed capacity is as follows. If the traffic flow through all entrances during a one-hour period is 1400 vehicles, the combined entrance capacity is 2000 vehicles per hour, and entrances to the center are controlled by lights on 1.5 minute cycles with 50 percent red, the average running time for the entrance mode would be:

$$RT = \frac{60}{2000}\left(\frac{0.7}{1-0.7}\right) + 0.5\ (0.5)\ (1.5)$$

$$= 0.445 \text{ minutes.}$$

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 10. 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.

Table 10. 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)

PARKING CAPACITY EXCEEDANCE AS A FUNCTION OF TRIP GENERATION, CENTER SIZE, AND PARKING CAPACITY - RESULTING RUNNING TIME INCREASE

All of the information analyzed, interpreted and used in this section comes from the Urban Land Institute (ULI) survey of parking requirements for shopping centers. Their data were analyzed and interpreted by them as supporting the contention that "in operational practice and hence for development planning purposes, where there is virtually no walk-in trade nor public transit usage, the provision of 5.5 car parking spaces per thousand square feet of gross leasable area is adequate as a standard to meet the demand for parking space at shopping centers. This standard accommodates the need for parking spaces for all but the 10 highest hours of demand during the entire year. These 10 highest hours occur during the three peak days of the year. It is uneconomic to provide parking space for such limited peak demands."

The data they generated to study the occasions of exceedance of parking lot capacity is of use to us here in determining the extent of, and reasons for, this exceedance.

It is of utmost importance as a preliminary, to note that some center managers who have problems of parking exceedance on extreme occasions, will take special steps to alleviate the situation, such as leasing adjacent parking space and lots for the critical period. If such exceedance is anticipated, and such remedial steps are planned, than the following phase of the analysis becomes irrelevant and should be bypassed. Developers should be queried on this point, to ascertain whether they anticipate, and will arrange for, this problem.

Continuing, as an adjunct to the ULI survey on parking capacity exceedance, we may add the qualitative observations made by some of the Greater Washington center managers, which ranged from "the parking lot has never been full," through "the lot is full on Saturdays before Christmas," to "the lot is full every Saturday, on sale days, and from Thanksgiving to Christmas." These comments generally fit qualitatively with the corresponding parking space rate data, (in spaces per thousand square feet of shopping space), in the sense that higher rates cause fewer full lot cases, and vice versa. The problem is complicated, however, by the trip generation phenomenon.

Continuing further with the analysis: ULI confirmed the pre-Christmas period as that of the peak demand, and focussed their survey study of 270 centers on that peak. Ninety-three of the 270 centers were 300,000 square feet in shopping space, and hence qualified as regional centers and were used in our analysis.

We will focus exclusively on the peak hour rather than the peak eight-hour period, since our interpretation of the ULI data indicates that such one-hour peaks appear to be of short duration, and thus would not seriously affect the peak eight-hour period. Since the one-hour peak occurs within the peak eight-hour period, its increased number of vehicles and running times may be used to augment the eight-hour value, if the one-hour figures are significant compared to the eight-hour.

The ULI data on peak one-hour parking capacity exceedance have been analyzed with the results given below. Remember that these data are measured for the peak hour, and they thus only apply to the peak hours derived as described in the section titled Typical and Maximum Trip Generation as Functions of Center Size. We find that of the 93 peak hours for regional centers, 22, or about 25 percent, reached or exceeded the parking lot capacity. This distillation by us of a rather extensive and varied body of data indicates that, on the average, in one case in four the parking lot capacity will be exceeded during the peak hour. This summary finding is elaborated below.

It is logical to assume that the 25 percent parking exceedance cases will occur for those centers with the lower parking rates and the higher range of trip generation values. Thus we found, for all these exceedance cases, that there is also a dependence, as might be expected, on parking space rate per 1000 square feet of shopping space. This is demonstrated by the following: for centers with parking space rates less than four spaces per thousand square feet of shopping space, the parking capacity is exceeded two times out of three (66 percent of the time) at times of peak use; at parking rates of four to less than six, the exceedances occur 30 percent of the time; at rates of 6 to 8, 20 percent; and above 8, essentially not at all. As expected, the exceedance decreases as we provide (relatively) more parking spaces.

We interpret this quantitatively as follows: when working with peak Christmas hours, if the parking space rate is less than 4, and the trip generation rate is in the higher two-thirds of the possible range, then parking exceedance must be accounted for, as discussed below. Similarly, the parking exceedance must be analyzed, when parking rates are 4 to 6 and the trip rate is in the highest 30 percent; or with parking rates of 6 to 8 and the high 20 percent of trip generation. Above parking rates of 8, parking exceedance is not expected to be a problem.

The above accounts for the circumstances when parking exceedance will be a problem, on the average. As to the amounts of the exceedances, the number of extra cars which will be running during the peak hour of concern, also derived from the ULI data, will be as follows, as percentages of the parking lot capacity: 20 percent of the parking lot capacity will be the number of cars running for the <4 parking rate case; for the 4-6 case, 10 percent; and for the 6-8 case, 5 percent. Each of these percentages represent a number of additional vehicles (as a fraction of the number of parking spaces) which will be running during the peak hour, because of the exceedance.

We thus have a process of elimination which determines the cases of peak hours for which parking exceedance must be accounted for and how to account for them. First, if the parking rate is eight spaces per thousand square feet of shopping space, or greater, parking exceedance is almost certainly not a problem. For parking rates of 6 up to 8, and peak hourly trip generation rates in the high 20 percent, parking exceedance will consist of 5 percent of the parking lot capacity, in numbers of cars running during the peak hour. For parking rates of 4 up to 6, and peak trip rates in the high 30 percent, parking exceedance will consist of 10 percent of the lot capacity, and rates less than 4, and peak trip rates in the high 66 percent, the corresponding parking exceedance figure will be 20 percent.
These numbers become input to the analytical methodology described in the section titled The Methodology.

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 5 , 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 shopping centers, as shown in Figure 6 , the methodology proceeds from basic information about a given shopping center (see the section titled "Regional Shopping Center Parameters"), via traffic behavior data (see the section titled "Traffic Parameters, Values and

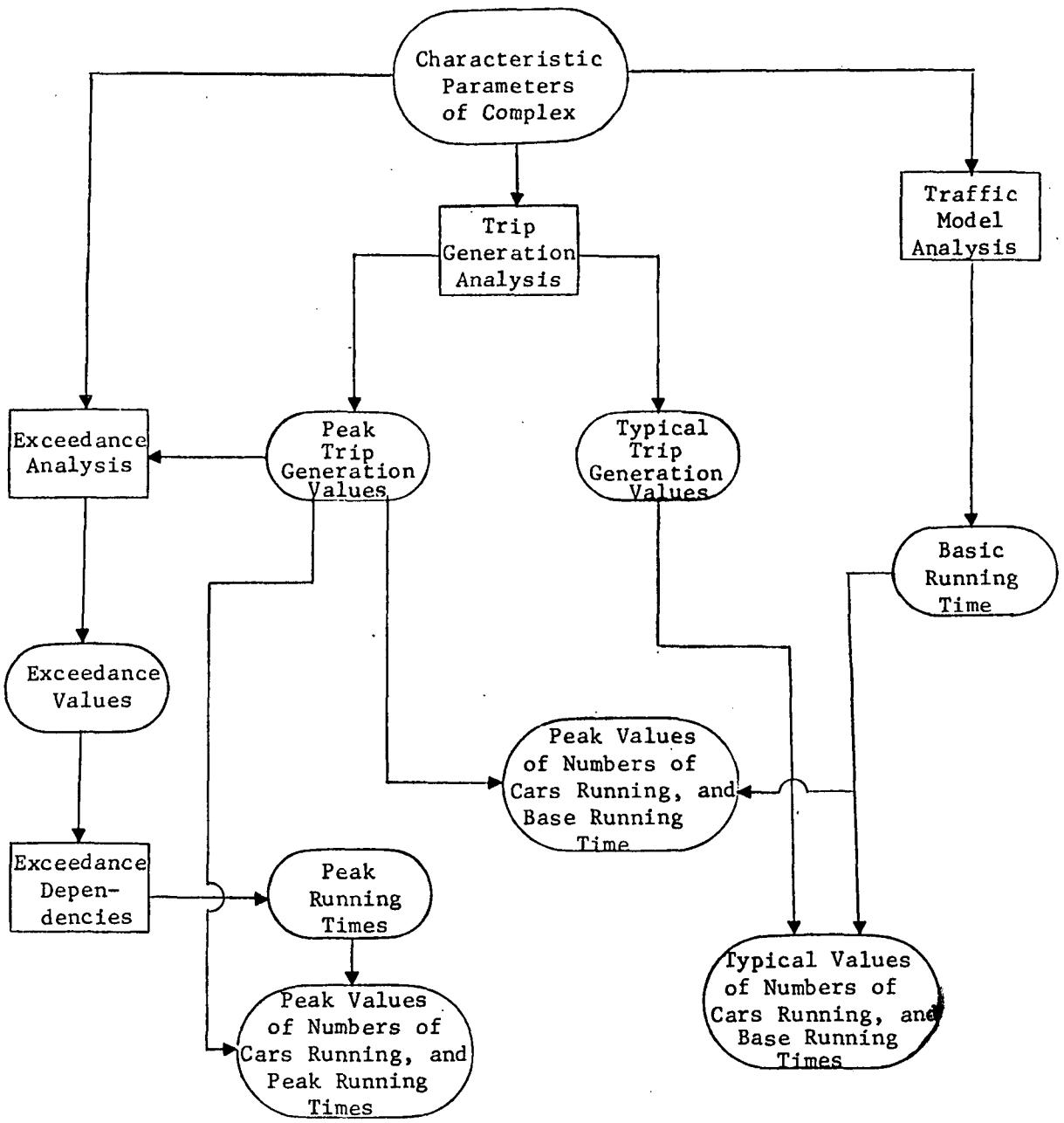

Figure 5. Generalized Methodology

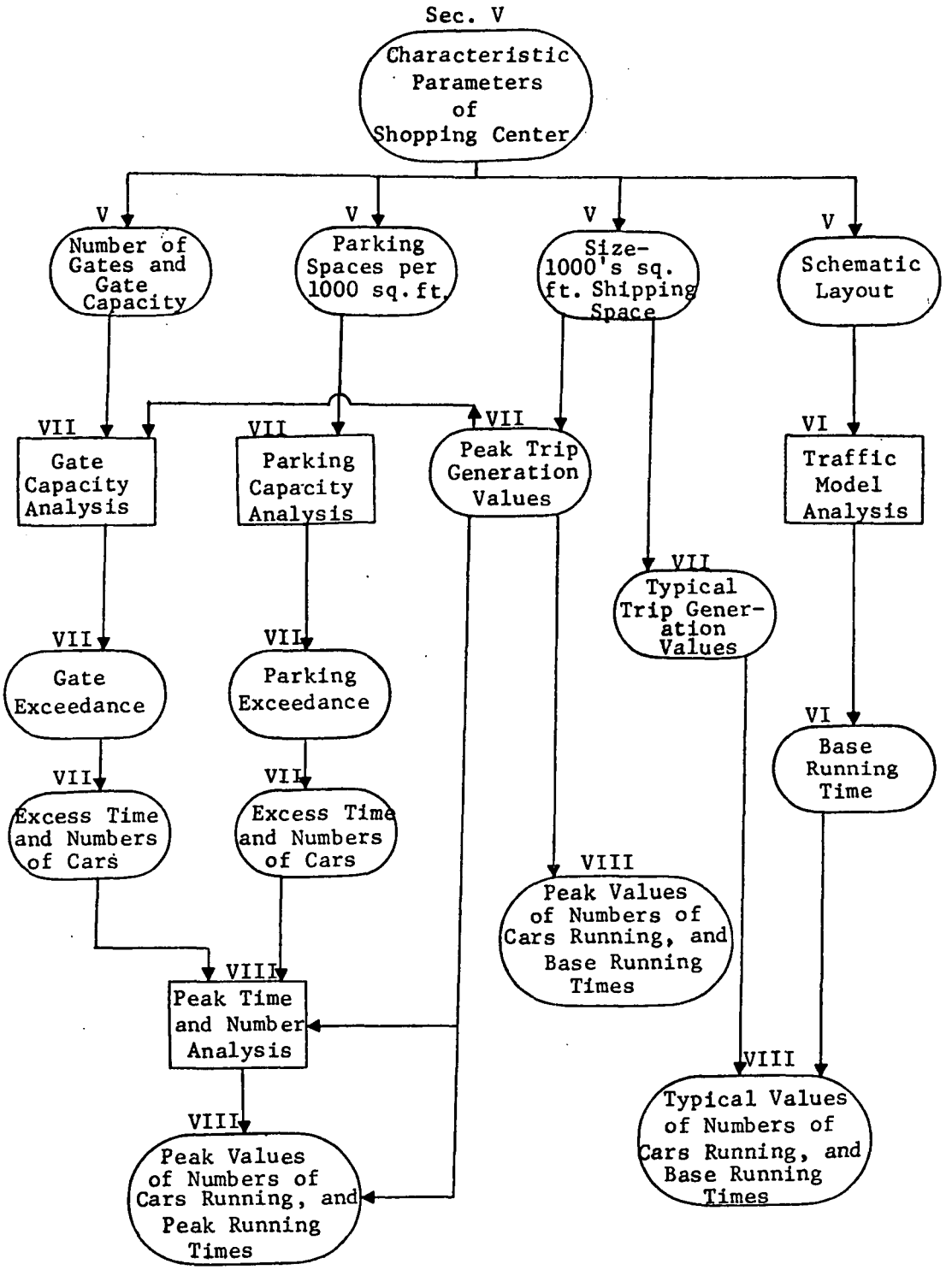

Figure 6. Generalized Methodology Applied to Shopping Centers

Derivations"), and typical trip generation data (see the section titled "Typical and Maximum Trip Generation as Functions of Center Size"), to generate estimates of typical numbers of vehicles and associated running times for one-hour and eight-hour periods; these are two of the required end products of the task. For the maximum case, maximum trip generation rates are estimated (see the section titled "Typical and Maximum Trip Generation as Functions of Center Size") and then used to obtain exceedance estimates for both gate capacity and parking capacity, the two principal controlling parameters (see the sections titled "Gate Capacity Exceedance as Functions of Trip Generation and Gate Capacity - Resulting Running Time Increase (E)" and "Parking Capacity Exceedance as Functions of Trip Generation, Center Size and Parking Capacity - Resulting Running Time Increase (MI)"); these latter generate the associated increases in both numbers of vehicles running, and vehicle running times. These increases are combined with the base numbers described above, to provide the other two major products, the peak running times and vehicle numbers for one-hour and eight-hour periods.

The specifics of the procedure, 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 center by means of a schematic diagram, and available or estimated data on: the area covered by commercial enterprise, the number of parking spaces, and the number of entrances and exits and their capacity; also required are best estimates of typical and maximum trip generation rates. If any of these parameter values are uncertain, then the estimated range should be provided, 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 time, according to the procedures set forth in the section titled "Traffic Parameters, Values and Derivations." Estimates are made as shown in Figure 3 and Table 8 of that section; the example values given there for

Greater Washington's Montgomery Mall and Landmark Center are 4.7 and 3.6 minutes, respectively.

If typical and peak trip generation data are not available, then Table 9 of the section titled "Typical and Maximum Trip Generation as Functions of Center Size" may be used to estimate the probable range of typical and peak trip generation rates which may be encountered for a center of the selected size (thousands of square feet) of commercial floor space. Some indication must be provided, however, of approximately where, in the probable ranges, the center's values will fall.

The trip generation data may be in the form of trips into, or out of, the center, or both. The traffic mode cycle includes both, so that any equivalent value of trips into or out of the center will suffice. Thus, as a good first approximation, at least for shopping centers, we can safely assume that any trip in, in a given typical or peak hour, is accompanied by a trip out, so that the number of vehicles running is given by the one-way trip generation rate; the accompanying running time is usually the average base running time for a complete cycle (see the section titled "Traffic Parameters, Values and Derivations"). However, typical trip generation for the center must be checked against the section titled "Gate Capacity Exceedance as Functions of Trip Generation and Gate Capacity - Resulting Running Time Increase (E)" to ensure that there are not gate queues under typical conditions. If so, see the next paragraph.

We now proceed, for the peak case, to the methods of the sections titled "Gate Capacity Exceedance as Functions of Trip Generation and Gate Capacity - Resulting Running Time Increase (E)" and "Parking Capacity Exceedance as Functions of Trip Generation, Center Size and Parking Capacity - Resulting Running Time Increase (MI)" to estimate the effects of the given peak trip generation rate on vehicle running time, resulting from any exceedances of gate or parking capacity which may result. Using the equation and the hypothetical example tables of the section titled "Gate Capacity Exceedance as Functions of Trip Generation and Gate Capacity - Resulting Running Time Increase (E)," we find that at a given peak trip generation rate, the "exit"

running times are increased, because of gate capacity exceedance, from a value of 0.15 minutes for the non-peak case (from the equation, with a 900 vehicle 1/2-hour traffic volume entering a gate with 1200 vehicle 1/2-hour capacity) to almost 20 minutes, in the last half-hour of the peak two-hour demand (as shown in the table).

The "movement in" running times might also be increased, as exemplified by the hypothetical calculation in the section titled "Parking Capacity Exceedance as Functions of Trip Generation, Center Size and Parking Capacity - Resulting Running Time Increase (MI)."

The resulting increases in times are added to the base running time to give the peak running time; the peak trip generation rate will, as for the typical case, give the base peak number of vehicles running, to which we add any additional vehicles running because of gate and/or parking exceedance.

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

GEOGRAPHIC DISTRIBUTION

Running times, and hence emissions, from a shopping center complex can usually be considered as being distributed fairly uniformly over the area of the center during typical operating periods (base running times), as indicated by the schematic in Figure 3 and the example data in Table 8 (see the section titled "Traffic Parameters, Values and Derivations"). For most analyses, an assumption of a geographically uniform emission density is thus sufficiently accurate.

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.

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 10 . For ground level sources, such as automobiles in shopping centers, 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 shopping centers is cited as the 12 shopping days preceding Christmas in the section titled "Regional Shopping Center Parameters," with the highest day usually being the Saturday before Christmas. The peak hour of use on any given Saturday is generally 3 to 4 p.m. The peak eight-hour period is generally 10 a.m. to 6 p.m. A secondary one-hour peak use period occurs during weekday evening hours at various times between 7 and 9 p.m. This peak averages about two-thirds of the Saturday afternoon peak.

Since the pre-Christmas period occurs during the transition from autumn to winter, the meteorological conditions which characterize the period of peak use of shopping centers should be estimated by interpolating

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

Table 11. 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.

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 7 through 10, taken from Holzworth, 1972. For most locations the diurnal variation in mean wind speeds is small, and the values shown for afternoon means may also be used for the secondary evening peak use period. Also, since the transition to a strong restraining nighttime mixing height has generally not occurred by early evening hours, the afternoon mixing height can serve as a useful estimate for the evening peak use period. For the Saturday afternoon peak, atmospheric stability classes B, C, and D may occur with classes C and D being the most prevalent. During the evening hour peak, classes D and E may occur. Atmospheric dispersion calculations reported by Turner (1970) for stability classes D and E show that ground level concentrations from ground level sources will generally be twice as high for class E as for class D. Therefore, the secondary evening peak use period, which is associated with more stable conditions, is the more critical period for air quality considerations from the viewpoint of joint consideration of peak use and adverse meteorology.

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

If one now considers that operating hours for shopping centers are generally 10 a.m. to 10 p.m., then, from a meteorological point of view, the single hour least favorable for dispersing pollutants during that period is from 9 to 10 p.m. during the autumn season. The least favorable eight-hour period would be from 2 to 10 p.m. Use levels for shopping centers during these periods run around 67 percent of the Saturday afternoon peak for the single-hour value, and around 60 percent of the eight-hour value.

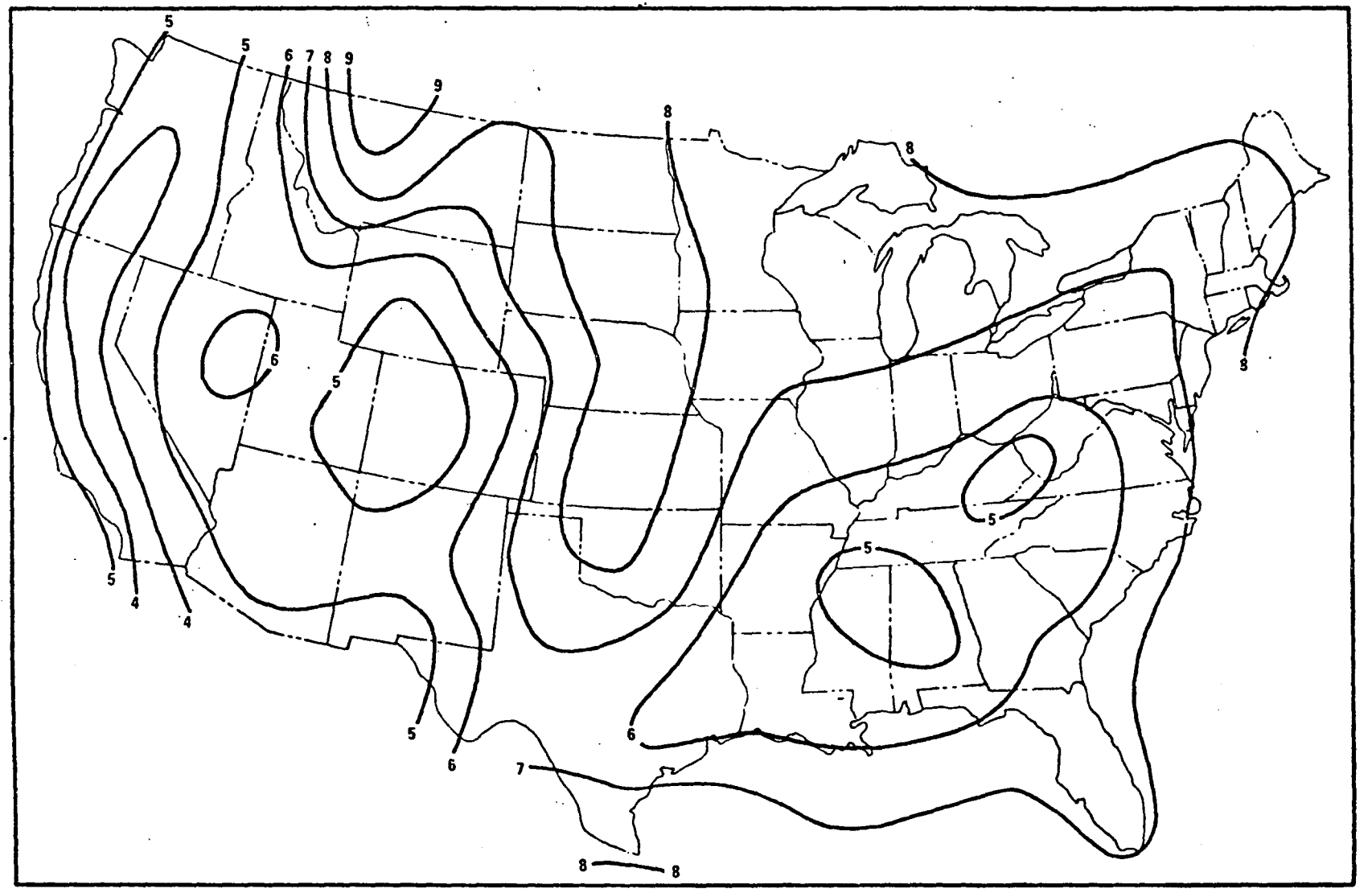


Figure 7. Isopleths (m sec^{-1}) of mean autumn wind speed averaged through the afternoon mixing layer

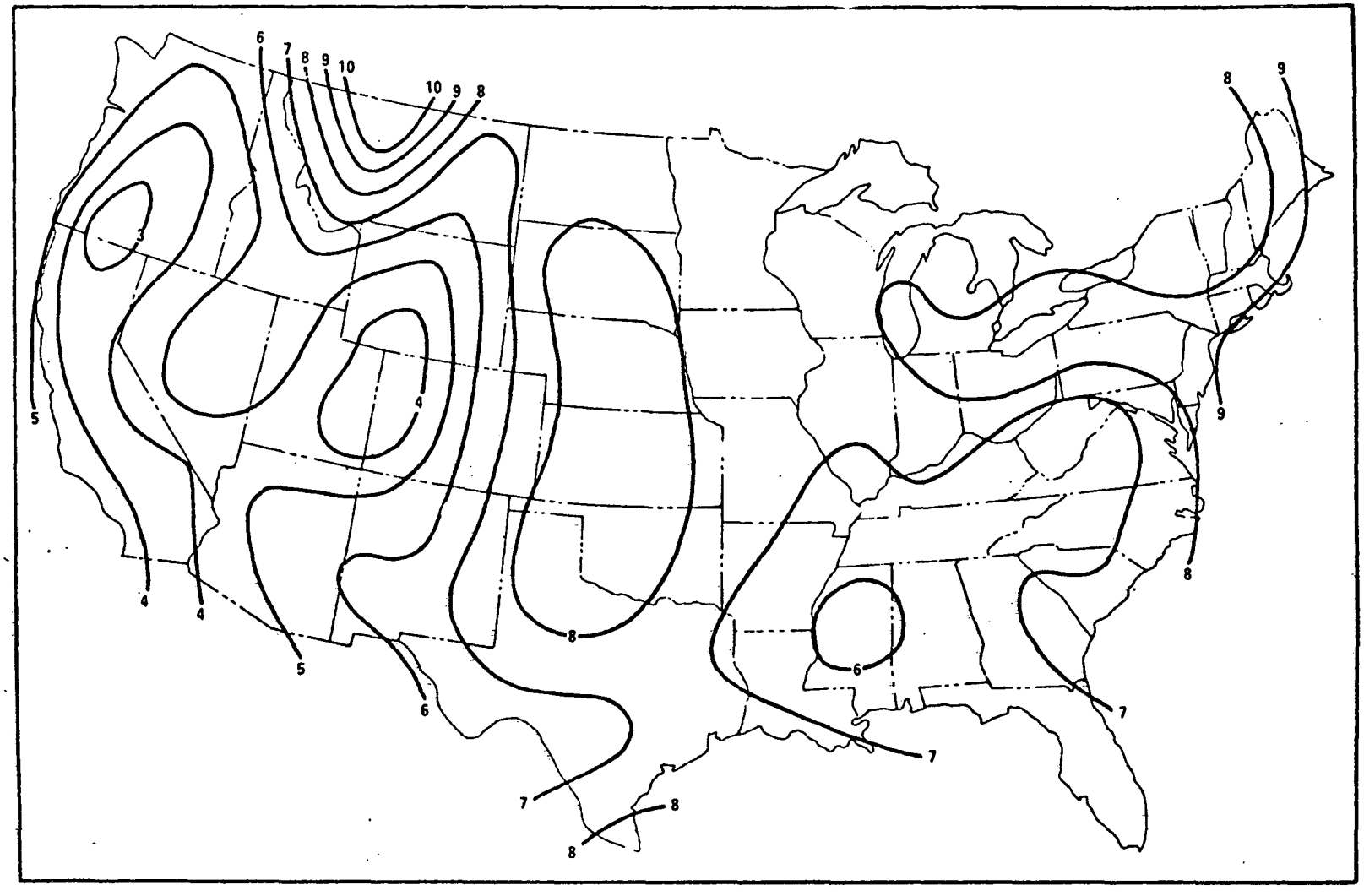


Figure 8. Isopleths (m sec^{-1}) of mean winter wind speed averaged through the afternoon mixing layer

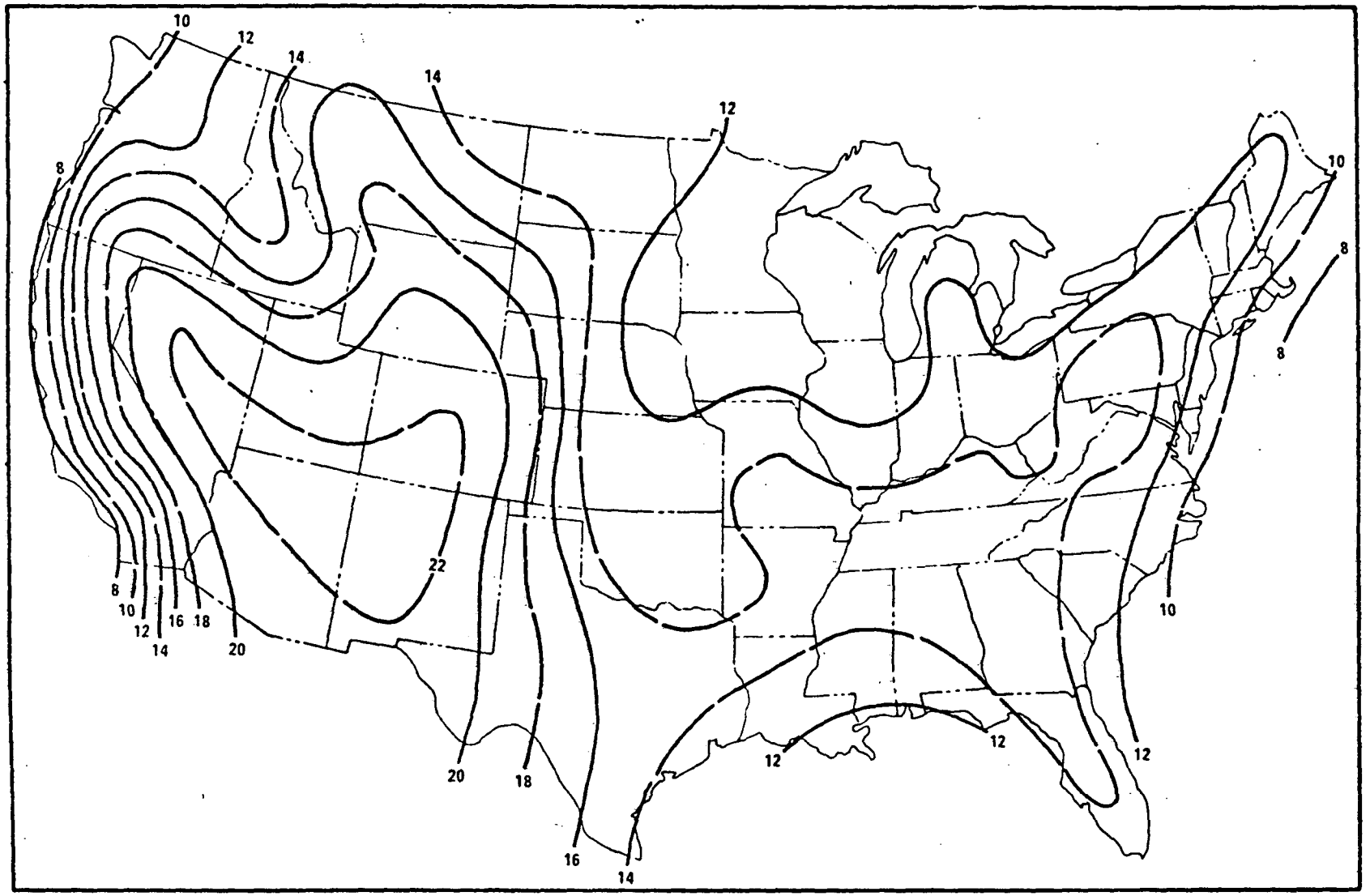


Figure 9. Isopleths (m x 10^2) of mean autumn afternoon mixing heights

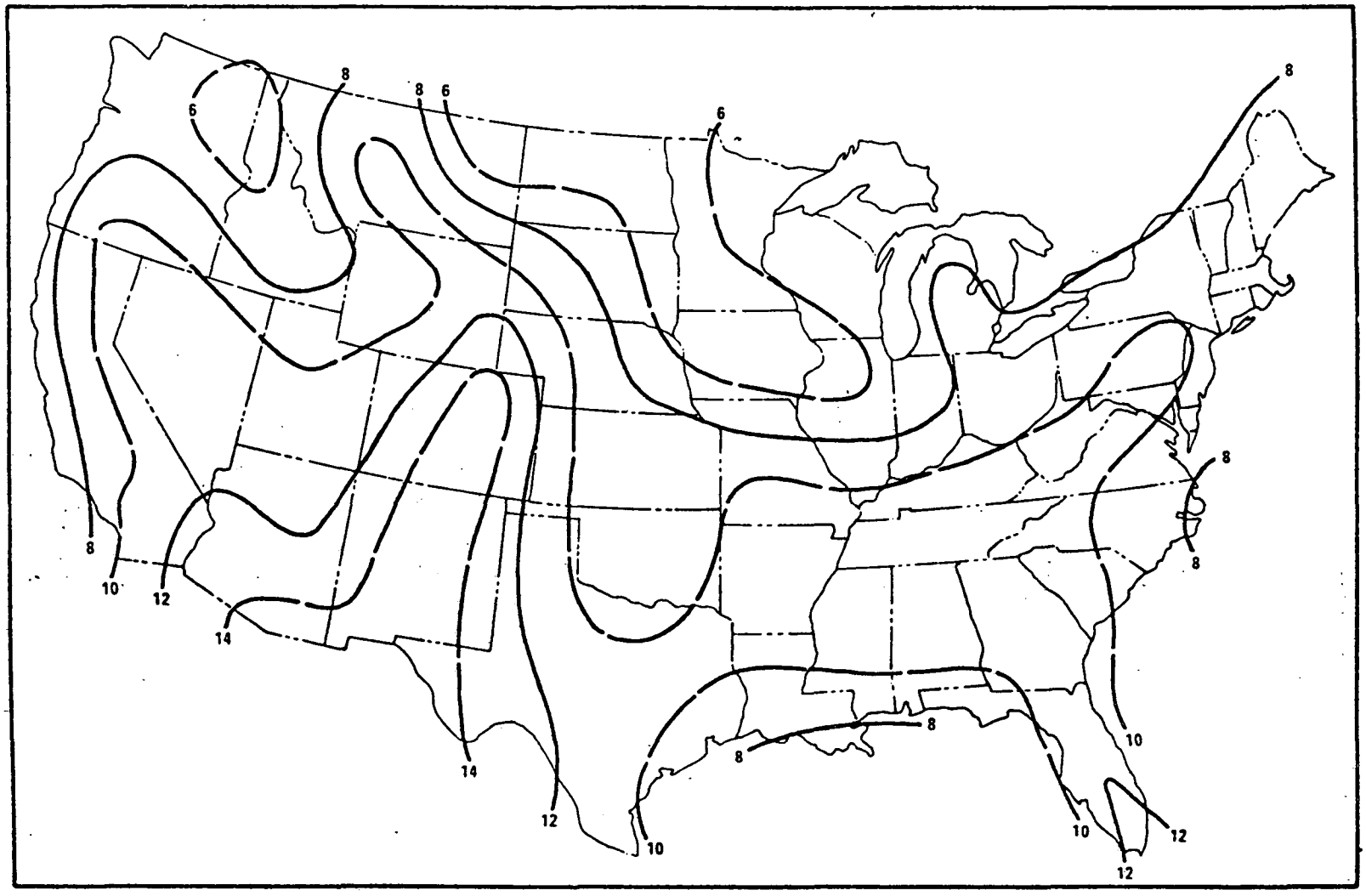


Figure 10. Isopleths (m x 10^2) of mean winter afternoon mixing heights

QUALITATIVE GUIDELINES

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

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

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

3. At centers with multiple entrance/exits, the vehicles will generally tend to distribute themselves among the available gates to minimize their running times. However, if unbalanced gate use does occur, it may be reduced by stationing personnel in the parking area to divert outgoing traffic from the overburdened exit or by the use of traffic information signs.

4. Personnel (including police) may also be effectively used to speed traffic flow during periods of highest congestion.

5. Prior provision for overflow parking in a temporary or remote lot may be an appropriate requirement for centers with anticipated marginal parking capacities.

6. The design of curbed entrances and exit "streets" within the parking lot (but separate from the parking areas) may reduce the interference of exit queues with in-lot movement and move congestion points away from the gates to a more desirable (or controllable) location in the lot.

THE NINE QUESTIONS

While the specific information called for by the task work statement has been provided in the sections from Regional Shopping Center Parameters through Meteorological Aspects, the nine questions spelled out as part of

the statement warrant specific response. This is given here, with the question 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? These data are given in section titled Regional Shopping Center Parameters and used in the sections titled Analysis through The Methodology.

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 Geo-Graphic Distribution.

6. Design parameters of the complex likely to be known beforehand? See section titled Regional Shopping Center 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 Regional Shopping Center Parameters through sections titled Traffic Parameters, Values and Derivation and Analysis.

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

Baker, Geoffrey, and Bruno Funaro. Shopping Centers - Design and Operation. Reinhold Publishing Corporation, Progressive Architecture Library. New York City.

Baker, Geoffrey, and Bruno Funaro. Parking. Reinhold Publishing Corporation, Progressive Architecture Library. New York City.

Lynch, Kevin. Site Planning. The M.I.T. Press, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Gruen, Victor, and Larry Smith. Shopping Towns U.S.A - the Planning of Shopping Centers. Reinhold Publishing Corporation, Progressive Architecture Library. New York City.

Metropolitan Washington Council of Governments, National Capital Region Transportation Planning Board. Traffic Characteristics of Shopping Centers - A Review of Existing Data. Technical Report No. 3, July 1970.

Urban Land Institute. Planning Requirements for Shopping Centers - A Survey. Technical Bulletin 53. Research sponsored by the Research Foundation of the International Council of Shopping Centers.

Automotive Environmental Systems, Inc. A Study of Emissions from Light Duty Vehicles in Six Cities. EPA Document No. APTD-1497. March 1973.

Maryland Bureau of Air Quality Control. Method for Estimating Light Duty Vehicle Emission on a Sub-Regional Basis. Report BAQC-TM 73-107. April 1973.

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

Architectural Record. Building Types Study 432: Shopping Malls in Suburbia. Vol. 151, No. 3. March 1972.

Zoning Ordinances for Various Communities.

Washingtonian Magazine. Supermalls! August 1973, pp. 58-63.

PRIVATE COMMUNICATIONS

Information provided by the General Managers of the following Greater Washington Shopping centers: Tysons Corner, Landover Mall, Wheaton Plaza, Prince Georges Plaza, Beltway Plaza, Landmark Center, Iverson Mall, Seven Corners Center, and Rockville Mall.

Information provided by Felipe LeBron and Alvin Bowles, Maryland Bureau of Air Quality Control.

APPENDIX A

Illustrative Notices of Construction and Modification for Complex Sources - Data Required from Developer to Enable the Determination of Air Quality Impact to be Made

The following information is typical of that needed for an air quality impact determination of direct on-site stationary source activities and indirect mobile source activities. The information listed within is merely typical and can be tailored in kind, and format, to suit specific agency requirements.

It is suggested that the requirement for filing of Parts I-III (basic data submission) be made mandatory and for Part IV (air quality impact evaluation) be made at the discretion of the developer. The incentive to the developer for filing Part IV would be based on the developer's desire to be acquainted with the technical requirements of complex source design and the shorter time period required for review if Part IV were to be voluntarily filed.

Operating information required from developers should be based on anticipated normal operations, particularly where maximum or worst case conditions are to be calculated by the agency, i.e., the worst case to be calculated should be that worst for a condition of normal daily operations. It is misleading to submit data for the absolutely worst case that could ever occur since this would be a complex situation that in any event would be covered by emergency actions on the part of air pollution control agencies.

APPENDIX

NOTICE FOR CONSTRUCTION OR MODIFICATION OF COMPLEX SOURCE

PART I General Information

1. Owner of Installation
2. Mailing Address
3. Date of Application
4. Telephone Number
5. Applicant or Authorized Agent
6. Telephone of Authorized Agent
7. Mailing Address
8. Street Address of Complex Source
9. City, Town or P.O. and County of Complex Source
10. Installer or Contractor (if new or replacement)
11. Telephone of Installer or Contractor
12. Mailing Address
13. Starting Date of Construction
14. Completion Date of Construction
15. Date Existing Installation Placed in Operation
16. Signature of Owner or Authorized Company Official
17. Title of Owner or Authorized Company Official
18. Type of Registration

    (1) Existing Installation (Initial Registration)
    (2) New Installation (To be constructed)

(3) Replacement
   (a) Alteration
   (b) Addition
   (c) Change of Ownership

(4) Other (Specify)

19. Operating Procedures

(1) Usual number of hours per day this installation will operate

(2) Busiest Day(s) of Year Normally Anticipated

(3) Busiest Hour(s) of Day Normally Anticipated*

PART II Mobile Source Information

(1) Parking Facility
   (a) Normal Capacity for Motor Vehicles
   (b) Avg. distance driven
(2) Number of Vehicles Entering the Parking Facility per Time Period during Normal Operation
   (a) Vehicles per peak hour of operation
   (b) Vehicles per busiest day of the year
   (c) hourly rate during operating period

PART III Stationary Source Information

A. Heating and Cooling

(a) On-Site
(b) Purchased Steam
(c) Electric
(d) Other

1.0 If On-Site Fuel Burning Systems are to be used, Complete the following.

1.1 Identical Installations at this Location
   (a) Number of Units

* Maximum incoming/outgoing traffic.

1.2 Name of Fuel Supplier
(a) Address of Fuel Supplier
(b) Telephone of Fuel Supplier

1.3 Stack Height above Ground Level (in feet)

1.4 Type of Fuel used

1.5 Type of Burner used

1.6 Amount of Fuel Consumed Annually

1.7 Sulfur Content of Fuel to the Nearest tenth of one percent

1.8 Maximum Firing rate (BTU per hour input)

B. Incineration

1.0 If On-Site Incineration is to be used, complete the following

1.1 Name of Manufacturer

1.2 Rated Capacity

1.3 Type of Air Pollution control device

Part IV <u>Impact of Complex Source on Air Quality</u> - to be filed at discretion of developer

1. <u>On-Site Air Quality</u>

(a) Calculation maximum on-site carbon monoxide. Concentration: _____ppm per _____hour(s).

2. <u>Traffic Data and Off-Site Air Quality</u>

Describe the condition of traffic within a one-half mile radius of the proposed complex source for the current year, and projected for the complex sources first and fifth full years of operation. In this discussion include the following and illustrate how all data was obtained or calculated.

(a) A current and projected map of local streets, expressways and freeways within a one-half mile radius of the proposed site.

(b) Current ambient carbon monoxide concentrations along the roadways cited in (a).(Include only if available from local air pollution control agency).

(c) Current and projected vehicular flow (per hour, day, and year) along the roadways cited in (a).

(d) Current and projected vehicular carbon monoxide emissions along the roadways cited in (a).

(e) Projected ambient carbon monoxide concentrations along the roadways cited in (a). (Include only if available from local air pollution control agency.)

TRAFFIC CHARACTERISTICS
FOR
MONTGOMERY MALL

June 1970

APPENDIX B

TRAFFIC SUREYS FOR MONTGOMERY MALL AND LANDMARK CENTER

June 10-15, 1970
June 24-30, 1970

TABLE B1. TOTAL TRAFFIC ENTERING AND LEAVING THE SHOPPING CENTER DURING AVERAGE WEEKDAY AND SATURDAY.

Average Weekday: 26,500

Saturday : 31,800

TABLE B2. RELATIVE USE OF ACCESS POINTS AT THE SHOPPING CENTER FOR AN AVERAGE WEEKDAY AND SATURDAY.

Ent./Exit Number*	Avg. Weekday		Saturday	
	In	Out	In	Out
1	66%	64%	65%	63%
2	6%	5%	6%	5%
3	14%	15%	14%	15%
4	2%	2%	1%	1%
5	12%	14%	14%	16%
Total	100%	100%	100%	100%

*See Figure A1 for location of Entrances/Exits.

Figure B2.

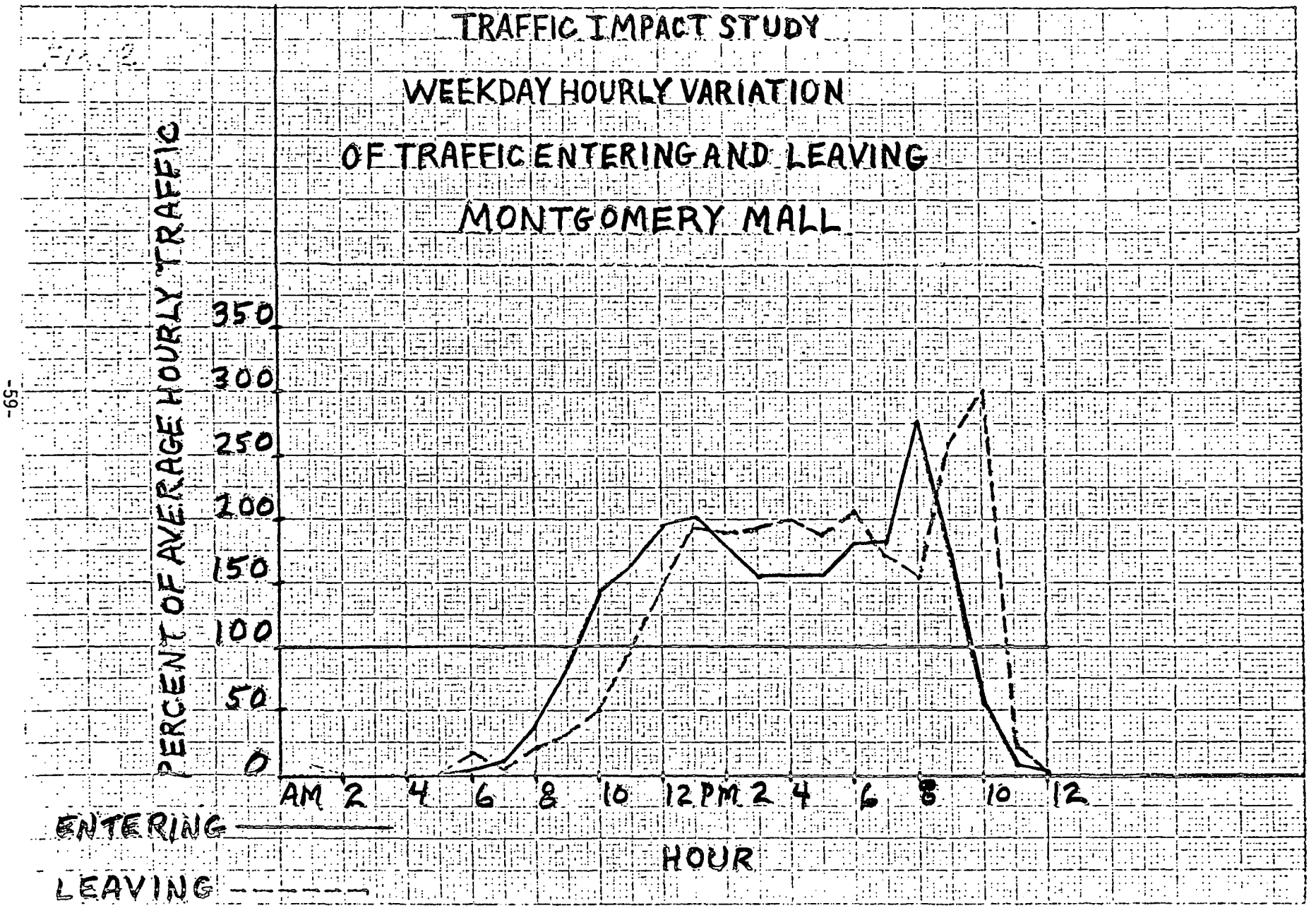
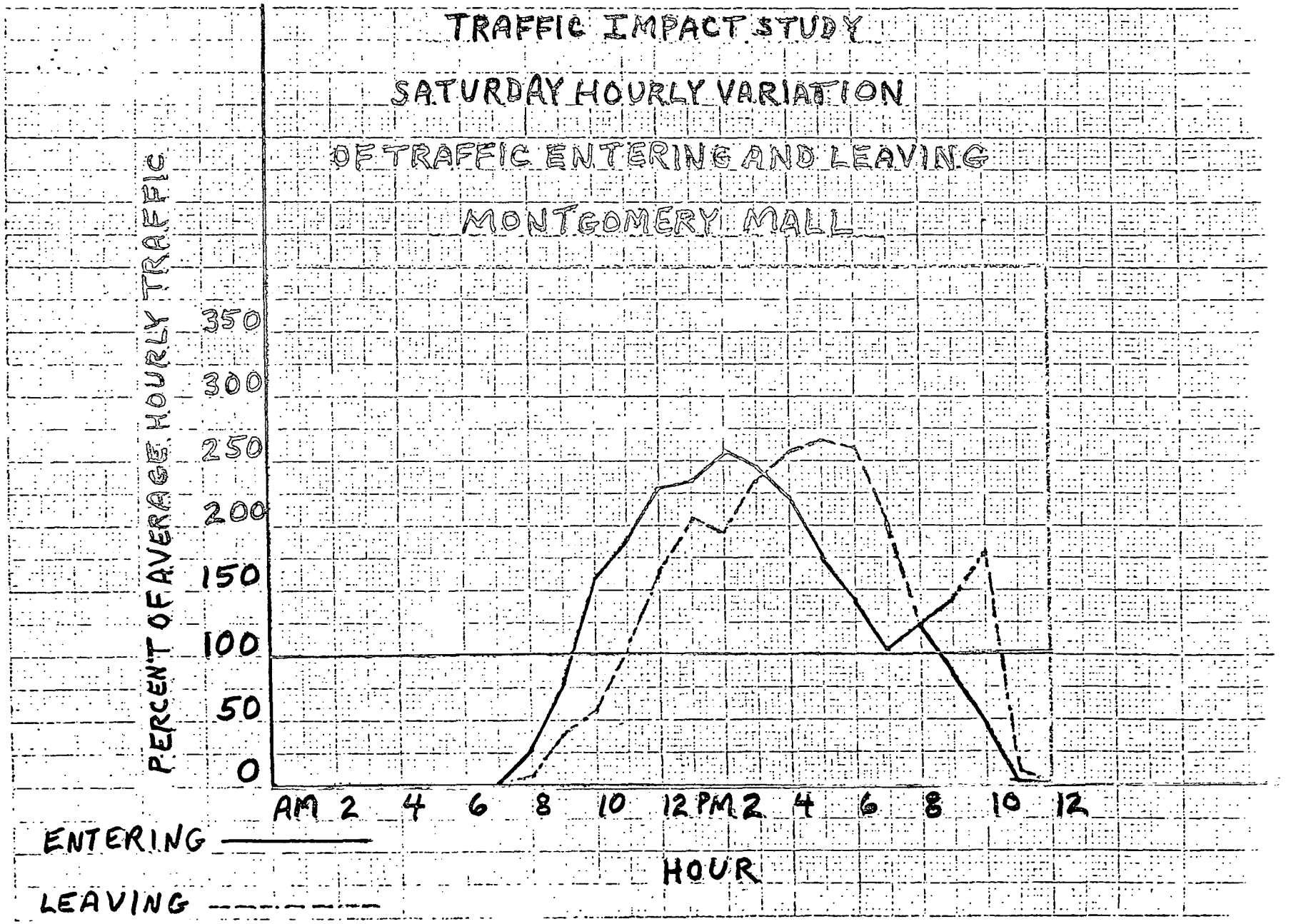

TRAFFIC IMPACT STUDY
WEEKDAY HOURLY VARIATION
OF TRAFFIC ENTERING AND LEAVING
MONTGOMERY MALL
PERCENT OF AVERAGE HOURLY TRAFFIC
350
300
250
200
150
100
50
0
AM 2 4 6 8 10 12 PM 2 4 6 8 10 12
HOUR
ENTERING
LEAVING

FIGURE B1.


TRAFFIC IMPACT STUDY
SATURDAY HOURLY VARIATION
OF TRAFFIC ENTERING AND LEAVING
MONTGOMERY MALL
PERCENT OF AVERAGE HOURLY TRAFFIC
350
300
250
200
150
100
50
0
AM 2 4 6 8 10 12 PM 2 4 6 8 10 12
HOUR
ENTERING
LEAVING

TRAFFIC CHARACTERISTICS

FOR

LANDMARK SHOPPING CENTER

May 1970

I. TRAFFIC DATA COLLECTION

The results presented in this report are based on traffic counts taken at the shopping center from May 22-28, 1970.

II. TRAFFIC DATA ANALYSIS

Table B-3 lists the total vehicles counted entering and leaving the shopping center during the average weekday and Saturday.

Table B-2 shows the relative use of entrances and exits at the shopping center during an average weekday and a Saturday. Figure 1 shows the locations of the entrances and exits.

Figures 3 and 4 show the hourly volumes expressed as a percent of the average hour in and out of the shopping center for the average weekday and for Saturday.

TABLE B3. TOTAL TRAFFIC ENTERING AND LEAVING THE SHOPPING CENTER DURING AVERAGE WEEKDAY AND SATURDAY.

Average Weekday:	29,500
Saturday :	33,000

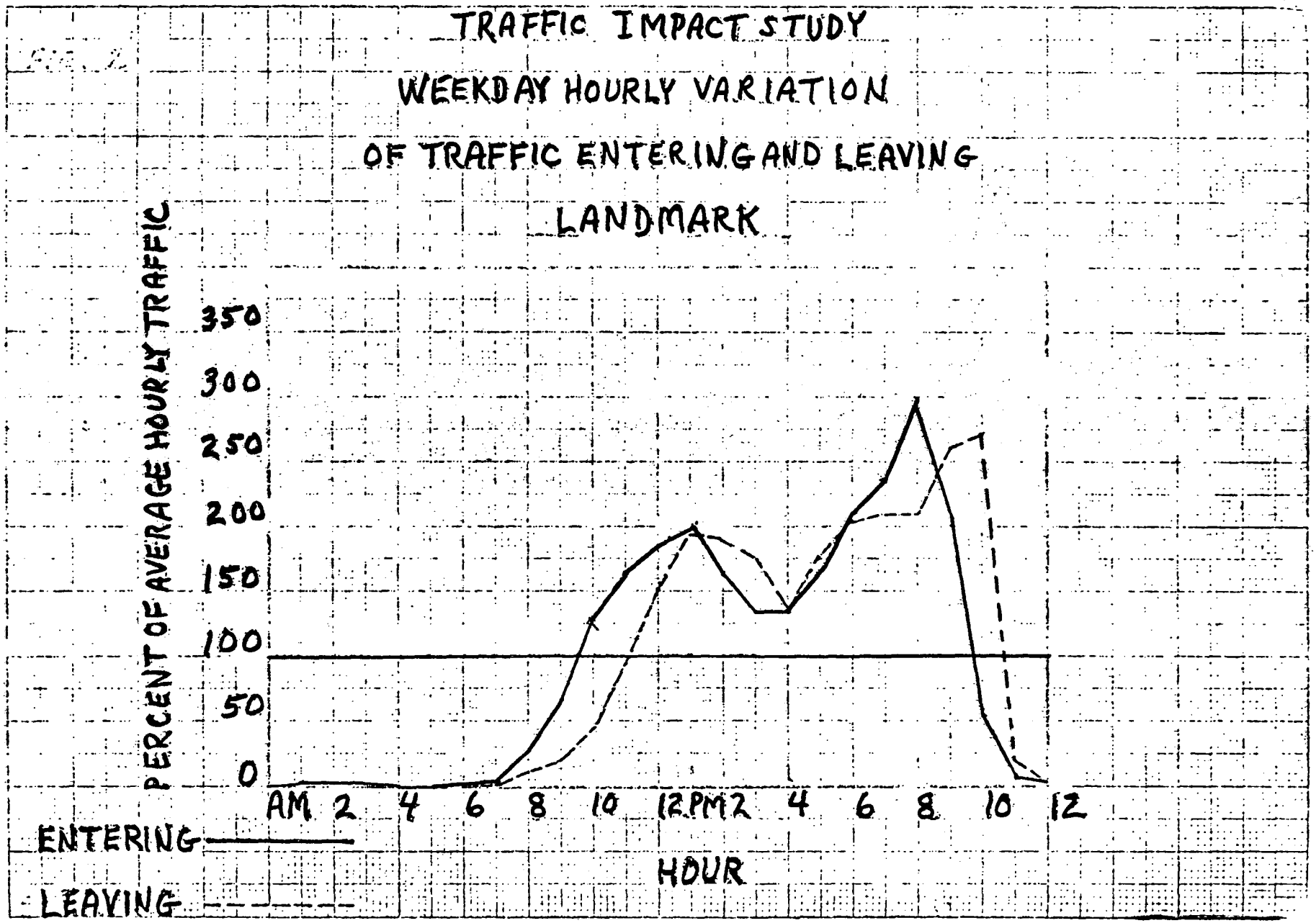
TABLE B4. RELATIVE USE OF ACCESS POINTS AT THE SHOPPING CENTER FOR AN AVERAGE WEEKDAY AND SATURDAY.

Ent./Exit Number*	Avg. Weekday		Saturday	
	In	Out	In	Out
1	53%	--	51%	--
2	13	22	14	26%
3	2	--	2	--
4	--	42	--	31
5	32	36	33	43
Total	100%	100%	100%	100%

* See Figure 2 for location of Entrances/Exits

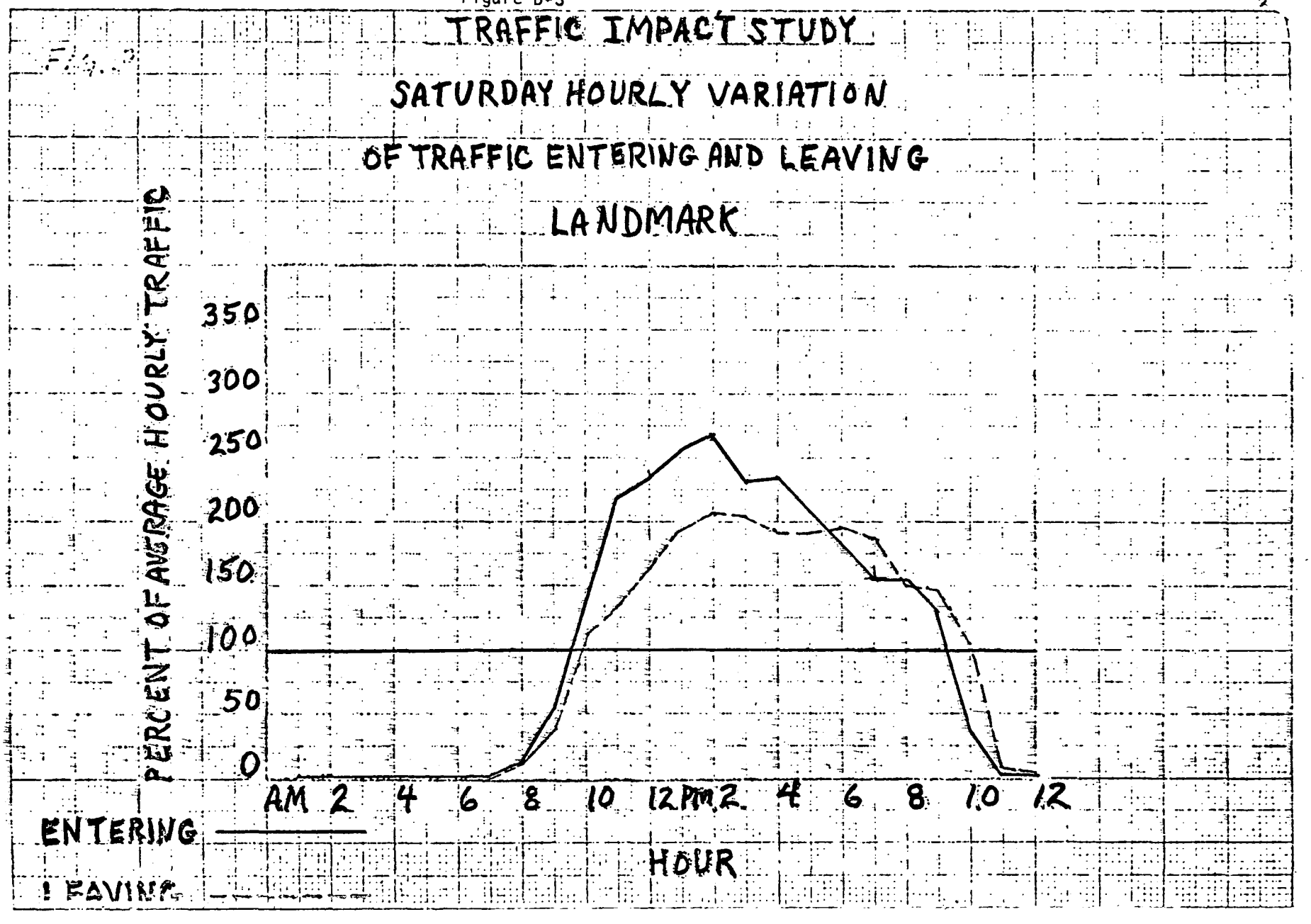
LANDMARK Center

Figure B-4.



LANDMARK Center

Figure B-3



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		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Scott D. Thayer, Kenneth Axetell, Jr., Consultant		8. PERFORMING ORGANIZATION REPORT NO.
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		14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

A general methodology is presented for relating traffic behavior parameters of shopping centers, including peak trip generation rates and vehicle running time, to more readily available characteristics of shopping centers, including average trip generation rates and parking, exit, and entrance capacities. Such relationships are to be used to relate shopping center characteristics to air quality.

17. KEY WORDS AND DOCUMENT ANALYSIS

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