# HIGHWAY RESEARCH RECORD

## Number 237

# Parking

2 Reports

Subject Area

53 Traffic Control and Operations
55 Traffic Measurements

HIGHWAY RESEARCH BOARD

DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

Washington, D.C., 1968

Publication 1624

Price: $1.20

Available from

Highway Research Board
National Academy of Sciences
2101 Constitution Avenue
Washington, D.C. 20418

## *Department of Traffic and Operations*

Harold L. Michael, Chairman
Purdue University, Lafayette, Indiana

HIGHWAY RESEARCH BOARD STAFF

E. A. Mueller

### COMMITTEE ON PARKING

(As of December 31, 1967)

Paul C. Box, Chairman
Skokie, Illinois

Alvin A. Acton
Frank E. Barker
James A. Bates
Herman Botzow
Charles A. Culp
Seymour Gage
Thomas Hicks
S. T. Hitchcock, Secy.
Matthew J. Huber
Madison J. Hunnicutt
Herbert S. Levinson
Abraham Marcus
Norene D. Martin
William R. McGrath
Donald M. McNeil
Edward W. Melchen
Merritt A. Neale
Stephen G. Petersen
Walter S. Rainville
Woodrow W. Rankin
Richard C. Rich
J. A. Ross
Thomas J. Seburn
Paul W. Shuldiner
Harry B. Skinner

### COMMITTEE ON ORIGIN AND DESTINATION

(As of December 31, 1967)

Alan M. Voorhees, Chairman
Alan M. Voorhees and Associates, Inc.
McLean, Virginia

Mark M. Akin
Willard H. Armstrong
Herman Basmaciyan
Austin E. Brant
Glenn E. Brokke
Henry W. Bruck
Nathan Cherniack
Donald E. Cleveland
Francis E. Coleman
James H. Cox
Roger L. Creighton
John A. Dearinger
Thomas Deen
Harold Deutschman
George A. Ferguson
Michael G. Ferreri
Thomas H. Floyd
W. L. Grecco
Harold W. Hansen
C. S. Harmon
Philip Hazen
Kevin E. Heanue
Donald M. Hill
Frank Horton
Thomas F. Humphrey
G. H. Johnston
Louis E. Keefer
Norman Kennedy
Dewey Lonsberry
Dana E. Low
Ted Luke
Frank J. Mammano
Brian V. Martin
James J. McDonnell
W. L. Mertz
John K. Mladinov
Norman Mueller, Secy.
John D. Orzeske
Robbie W. Parker
William S. Pollard
Lloyd A. Rivard
James J. Schuster
Arthur Schwartz
Billy J. Sexton
Paul W. Shuldiner
Jacob Silver
Bob L. Smith
Vergil G. Stover
Edwin N. Thomas
Anthony R. Tomazinis
Robert E. Whiteside
George V. Wickstrom
David K. Witheford
Martin Wohl
Robert T. Wood
Richard Worrall
Robert H. Wortman
J. E. Wright
Houston F. Wynn

# Foreword

Parking is a critical factor in successful business endeavors and is needed in varying amounts for almost any type of land use. The two papers in this RECORD discuss parking and traffic characteristics at suburban industrial centers and the use of origin-destination data for parking analyses. Those concerned with the provision of adequate parking, whether for a proposed industrial site or shopping center or for alleviation of parking problems in business districts, will find this material of value. Transportation planners, traffic engineers, and those working with the many comprehensive urban planning studies will find much of interest.

The first paper explores the relationships between parking, loading, and traffic generation and land building area and employment at some 22 suburban industries. Most of the areas studied had ample expansion room, so that most of the usual constraints on parking supply were absent. The research pursues several correlations of the parking factors with those of the industrial areas. It was found that good correlations were achieved using parking demand and employment (1 car space for every 2 employees); building area gave the poorest correlation. Between 37 and 113 percent of the parking demand was generated during the peak hour with the mean being 60 percent. The research also points out the variances between the factors at the different size facilities.

The other paper presents case studies of southeastern Massachusetts urban areas, indicating how parking demand for the central areas was determined from the use of origin-destination data rather than by the usual medium of a separate parking demand study. The paper describes the procedures necessary and compares them with results of parking studies obtained from other places. It concludes that O-D data are accurate enough to indicate the specific areas where additional parking facilities are needed.

# Contents

# Parking and Traffic Characteristics of Suburban Industrial Developments

WILLARD A. ALROTH, Paul C. Box and Associates, Skokie, Illinois

This paper explores the relationships of parking, loading, and traffic generation with land, building areas, and employment. The data were gathered from a sample of 22 suburban industries ranging in size of developed land area from 20, 400 to 860, 000 square feet, with employment varying between 20 and 1000. The normal constraints of expansion problems found in fully developed areas were not present since most industries sampled had expansion room.

Parking characteristics were related to employment, land area, and building area. Traffic generation for automobiles and trucks was related to employment, land area, building area, parking demand, and loading facilities.

•HISTORICALLY, parking and loading requirements have evolved from past experience in reviewing existing industrial developments. Local zoning ordinances stipulating minimum parking and loading requirements have been drawn from either model ordinances or from firsthand experience and knowledge. The Institute of Traffic Engineers offers a guide for estimating parking requirements by means of an employment questionnaire, or by a rule-of-thumb measure of one car for every two employees per shift (1). Usually these practices have created efficient industrial developments. However, examples can be found where inadequate parking and loading facilities can create a multitude of traffic and parking problems.

A noticeable lack of actual field data on existing industrial parking and loading facilities and traffic generation is evident when examining the literature. Very few studies have been made which confirm typical zoning requirements (unlike the wealth of data for shopping centers, for example). Information of this nature should be useful to the land developer, architect, and planner.

## DESCRIPTION OF STUDY AREA

Niles, Illinois, has a number of large areas zoned and developed as industrial. It is a suburb of nearly 30, 000 population, adjacent to the City of Chicago, and borders several other close-in suburban communities.

Public mass transportation is nearly nonexistent. There are a few suburban bus lines with irregular and infrequent service. The Chicago Transit Authority operates a bus line along the Chicago-Niles border with regular service. This line is nearly a half mile from the study area, however, and its influence is quite small.

The industry study area encompassed over 0. 4 square mile and included 22 companies. The industries sampled are typical of suburban developments. Figure 1 shows the general plan of the study area, giving the size of developed land area and general description of operation. The general location and description of each driveway is also shown in the figure.

Nine of the 22 companies are developed to the full extent of their land area. The remaining 13 plants range from 25 to 90 percent developed, with the average being 67

Paper sponsored by Committee on Parking and presented at the 47th Annual Meeting.

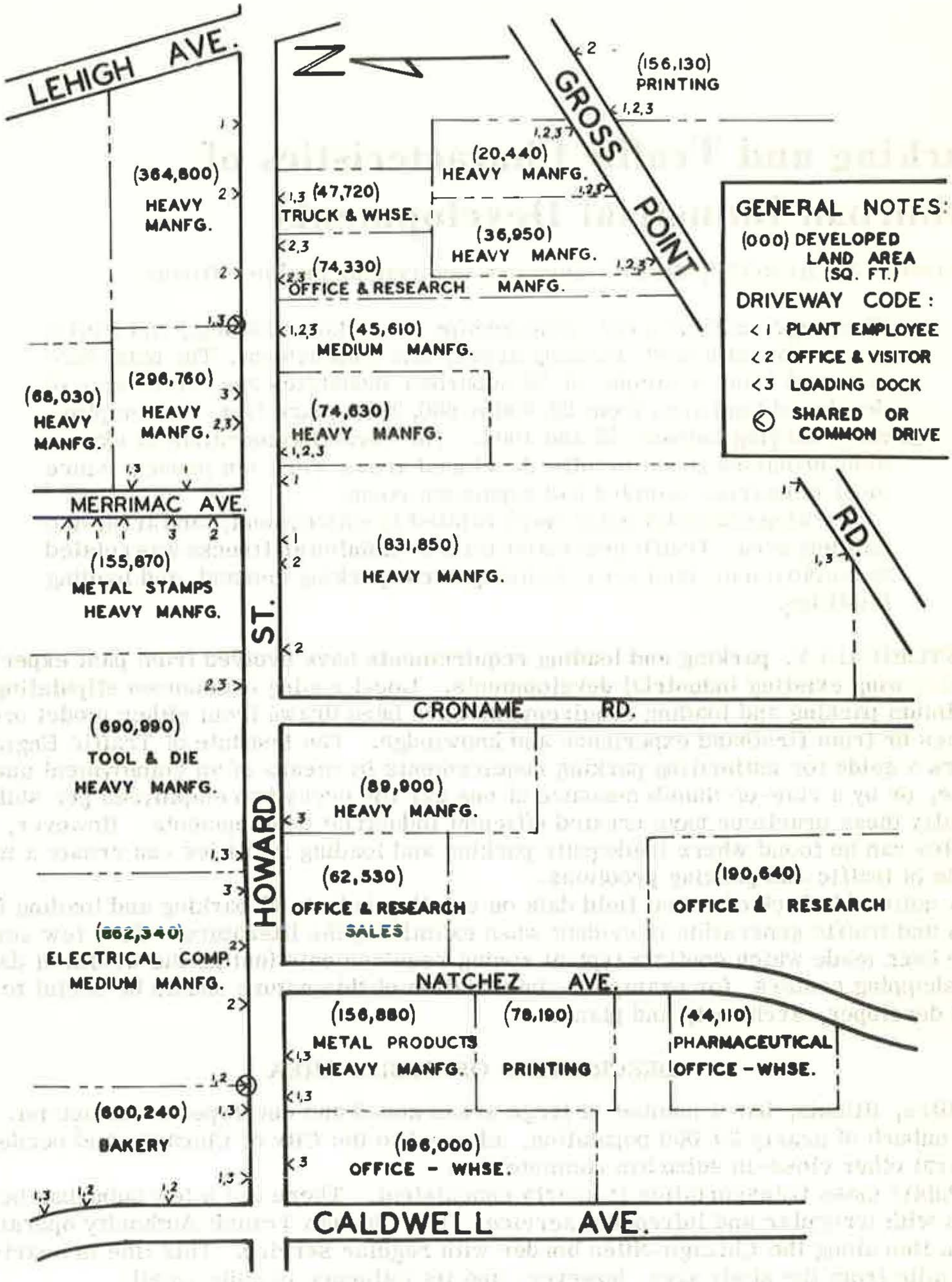



Figure 1. Study area—Niles, Illinois.

percent. This indicates the industries are generally expanding with sufficient land area and therefore do not have significant artificial restraints to restrict parking or loading supply.

## STUDIES PERFORMED

The studies performed included traffic counts, parking lot accummulation and occupancy checks, and parking and loading facility inventories.

Traffic counts were conducted during the latter part of March, when it was assumed employment would be at a normal level and absenteeism due to vacations would be minimal. The counts were made at each driveway for 2 hours during each of the morning and evening peak periods, i. e., 7:00 to 9:00 a. m. and 4:00 to 6:00 p.m. If the individual driveway peak movements did not coincide with the normal count period, the driveway count was extended to cover that industry's peak movement. In all cases, where a parking lot or loading dock had more than one access point, each driveway serving the facility was counted simultaneously so that complete coverage could be maintained.

A few driveways served as common access to two separate parking lots. No attempt was made to specifically isolate the two groups. However, with extended counts (or in one case where a special study was conducted when one of the two plants was closed for vacation) estimates were made as to the contribution of each plant to the total driveway volume.

Parking lot occupancy checks were made before and after each counting period, and the highest value was used. As far as possible, the peak occupancy was found by this procedure. The method was particularly important for the two shift plants.

Complete data were not obtained for each industry. No driveway counts were taken at four of the plants, and only the loading facilities were observed at three others, due to limitations of the traffic count study. Employment data were not obtained from five companies. However, it was felt that in spite of these limitations, there were sufficient data to complete the analysis.

The purpose of this paper was to explore the relationships of parking, loading, and traffic generation with land and building areas and employment. The traffic volume and parking data have been analyzed for consistency, and where correlation is found, it may be used as a guide for planning future industrial developments fitting the same general criteria of a suburban development.

## PARKING CHARACTERISTICS

In order to establish a common base for comparative analysis, only developed land areas were used. Undeveloped land was considered vacant land not being used for legal setbacks, buildings, parking lots, driveways, loading areas, or permanent landscaping.

The 22 samples were grouped into three ranges of developed land sizes to compare the portion that was occupied by buildings:

| Total Developed Land Area (sq ft) | Percent Developed Land Occupied by Building |
|---|---|
| 20, 000-100, 000 | Mean 45 |
| 100, 000-500, 000 | Mean 48 |
| Over 500, 000 | Mean 40 |
| | Total Mean 45 |

An average of 55 percent of the developed land is devoted to driveways, parking and loading facilities, and landscaping. However, for individual industries, the range was 16 to 67 percent. A detailed analysis is given in Table 1, where building area is related to developed land area by similar types of industries.

The extreme cases are quite consistent with their use. For example, a truck storage and terminal has nearly 85 percent of its area devoted to trailer storage, driveways, etc. The two printing operations used an average of 61 percent of their area for building purposes, probably due to the large machinery involved.

TABLE 1

RELATIONSHIP OF BUILDING AREA TO DEVELOPED LAND

| Industry Classification | Total Developed Land Area (sq ft) | Building Area (sq ft) | Percent Developed Land Occupied by Building |
|---|---|---|---|
| Bakery | 600, 240 | 259, 890 | 43 |
| Office and research | 62,530 | 30,220 | 48 |
| | 74,330 | 35,160 | 47 |
| | 190,640 | 60,000 | 31 |
| | | | Average 42 |
| Office and warehouse | 44,110 | 22,270 | 51 |
| Truck storage and terminal | 47,720 | 7,730 | 16 |
| Printing | 78,190 | 43,250 | 55 |
| | 156,130 | 104,940 | 67 |
| | | | Average 61 |
| Medium manufacturing and fabrication (electrical components, etc.) | 45,610 | 18,540 | 41 |
| | 862,340 | 296,350 | 34 |
| | | | Average 37.5 |
| Heavy manufacturing and fabricating (machine, tool and die, metal stamp, etc.) | 20,440 | 8,425 | 41 |
| | 36,945 | 20,240 | 55 |
| | 68,030 | 30,300 | 44 |
| | 74,630 | 34,650 | 46 |
| | 89,900 | 50,230 | 56 |
| | 155,870 | 59,860 | 38 |
| | 296,760 | 187,260 | 63 |
| | 364,815 | 161,850 | 44 |
| | 831,850 | 306,980 | 37 |
| | 690,990 | 321,590 | 47 |
| | | | Average 47 |
| | | | Mean 45 |

## Building Area Relationships

The relationship of building area to parking demand and supply is given in the following, where the building areas are also grouped into three ranges, and the average values for the ratio of building area to parking and the inverse ration of parking per unit area of building are given:

| Building Area (sq ft) | Sq ft of Building Area Per Parking | | Parking Spaces Per 10, 000 sq ft of Building Area | |
|---|---|---|---|---|
| | Demand | Supply | Demand | Supply |
| 0-30, 000 | 750 | 510 | 18. 0 | 22. 8 |
| 30, 000-100, 000 | 900 | 625 | 13. 0 | 18. 5 |
| Over 100, 000 | 1020 | 760 | 11. 5 | 14. 6 |
| Total Mean | 910 | 640 | 14. 2 | 18. 6 |

It is significant that the mean value for building area per space increases with increasing building size and the inverse value correspondingly decreases. However, large variations within each group make the average values misleading. As expected, there was less variation with the parking supply values, due to the constraint caused by zoning codes. Because of this, only parking demand (spaces occupied) will be examined in detail and used for analysis. The values on supply are listed however, where appropriate.

TABLE 2

RELATIONSHIP OF BUILDING AREA TO PARKING DEMAND

| Industry Classification | Building Area (sq ft) | Number of Occupied Spaces | | Sq ft of Building Per Space | Occupied Spaces Per 10,000 sq ft of Building Area |
|---|---|---|---|---|---|
| Bakery | 259,890 | 175 | | 1480 | 6.7 |
| Office and research | 30,000[a] | 34 | | 890 | 11.2 |
| | 35,160 | 75 | | 470 | 21.4 |
| | 60,000 | 122 | | 490 | 20.4 |
| | | | Average | 620 | 17.7 |
| Office and warehouse | 22,270 | 14 | | 1590 | 6.3 |
| Truck storage and terminal | 7,730 | 18 | | 430 | 23.3 |
| Printing | 43,250 | 42 | | 1030 | 9.7 |
| | 104,940 | 71 | | 1480 | 6.8 |
| | | | Average | 1260 | 8.3 |
| Medium manufacturing and fabrication (electrical components, etc.) | 18,540 | 52 | | 360 | 28.0 |
| | 296,350 | 670 | | 440 | 23.6 |
| | | | Average | 400 | 25.8 |
| Heavy manufacturing and fabrication (machine, tool and die, metal stamp, etc.) | 8,425 | 18 | | 470 | 21.4 |
| | 20,240 | 22 | | 920 | 10.9 |
| | 34,650[b] | 27 | | 1280 | 7.8 |
| | 50,230 | 47 | | 1070 | 9.4 |
| | 59,860 | 103 | | 580 | 17.2 |
| | 76,020 | 55 | | 1380 | 7.2 |
| | 153,830 | 141 | | 1090 | 9.2 |
| | 195,550 | 182 | | 1070 | 9.3 |
| | 306,980 | 370 | | 830 | 12.0 |
| | 321,590 | 424 | | 760 | 13.2 |
| | | | Average | 940 | 11.8 |
| | | | Total Mean | 910 | 14.2 |

[a]Training center for sales personnel.
[b]Company occupies approximately half of building; remainder either vacant or leased for storage.

Concerning the relationship of building area to parking demand, Table 2 shows the large spread. The average values appear in general to fit the industry classification, despite the wide range. The intensive uses, such as office and research, and electrical component manufacture (with limited machinery and extensive manual assembly), require more parking.

The largest sample size was represented by the heavy manufacturing group. Analysis showed that the values ranged from 7.2 to 21.4 occupied spaces per 10,000 sq ft of building area. The mean occupancy was 11.8 and the standard deviation, 4.24. At the 90 percent confidence level, the mean occupancy varied between 9.21 and 14.39. While it appeared to be a wide variation, the range of the probable mean value was still consistent with the heavy manufacturing data.

A study by Thompson and Stegmaier found a 2.3 parking space demand per 10,000 sq ft of building area (2). They studied a 1,913,000 sq ft Baltimore plant in 1948. Recently, Keefer tabulated floor area and parking supply data resulting from a manufacturing questionnaire (3). A sample of six industries had floor areas ranging from 1,090,000 sq ft to 2,174,000 sq ft, and had an average of 7.0 spaces provided per 10,000 sq ft of floor area with a range of 4.0 to 11.9. Another sample of 12 plants, with floor areas ranging from 185,000 to 964,000 sq ft, found an average of 19.5 spaces supplied for 10,000 sq ft of floor area. The values ranged from 6.4 to 55.8. The similarity of the decreasing parking demand per unit of floor area with increasing plant size should be noted.

A study by Latchford and Williams examined 4 plants and 6 industrial estates in Great Britain (4). Figure 2, the relationship between floor space and parking, was prepared to compare the data found in the Niles study and Keefer's sample with the British values. The British curve is lower, but is quite consistent with the United States studies. Both are based on parking demand. Note, however, that Keefer's values are for parking supply, rather than demand.

## Developed Land Area Relationships

Developed land area is related to parking demand and supply as follows:

| Developed Land Area (sq ft) | Ratio of Land Area to Parking (sq ft per space) | | Parking Spaces Per 10,000 sq ft of Land Area | |
|---|---|---|---|---|
| | Demand | Supply | Demand | Supply |
| 0-100, 000 | 1890 | 1390 | 6. 3 | 8. 4 |
| 100,000-500, 000 | 2040 | 1470 | 5. 2 | 7. 9 |
| Over 500, 000 | 2140 | 1790 | 5. 3 | 6. 2 |
| Total Mean | 1980 | 1490 | 5. 7 | 7. 8 |

The relationship of developed land area with parking demand grouped within similar industrial uses is given in Table 3. The increase in parking demand per unit land area is similar to that of building area. The heavy manufacturing group sample indicates that the land area relationship provides better correlation than building area. The mean value of 5. 4 spaces per 10, 000 sq ft of land area has a standard deviation of 1. 48. Testing for confidence limits of 90 percent, the probable mean value lies between 4.5 and 6. 3.

## Employment Relationships

Table 4 relates employment to parking demand. The value of 0. 54 car per employee is quite consistent with a standard deviation = 0.133. Assume all lots which were filled 80 percent of capacity could be at optimur balance between parking supply and demand for the individual industry. The mean for the condition is 0. 57 occupied spaces per employee with a standard deviation shows even better correlation.

The highest ratio found was one space for each 1. 27 employees (where nearly all drove). The lowest was nearly 3. 5 employees per space. The Niles zoning code requires 1 space for every 3 employees. The more frequently used rule of thumb of 1 space for each 2 employees generally applies for the study sample, but can be an underestimate.

Office, executive, and visitor parking was examined in Table 5 with the small amount of data available. The mean of 0. 69 office spaces occupied was higher than the overall mean of 0. 54 spaces occupied per employee. A higher standard deviation and broader range of values (from 0.20 to 1. 00 occupied spaces per employee) was also found in the limited office sample.

Also, two samples were available relating office building area to office parking demand. Seventeen occupied spaces per 10, 000 sq ft were found for a 5300-sq ft

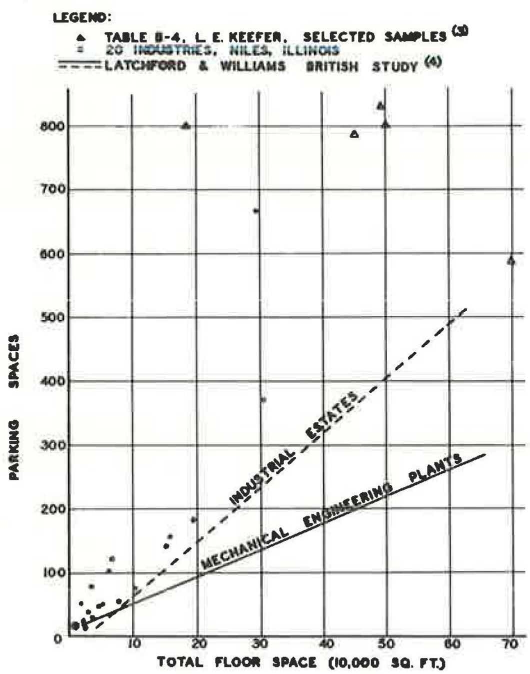



Figure 2. Parking related to building area.

TABLE 3
RELATIONSHIP OF DEVELOPED LAND AREA TO PARKING DEMAND

| Industry Classification | Land Area (sq ft) | Number of Occupied Stalls | Sq ft of Land per Car | Occupied Parking Spaces per 10,000 sq ft of Land Area |
|---|---|---|---|---|
| Bakery | 600,240 | 175 | 3430 | 2.9 |
| Office and research | 62,530 | 34 | 1840 | 5.4 |
| | 74,330 | 75 | 990 | 10.1 |
| | 190,640 | 122 | 1560 | 6.4 |
| | | | Average 1460 | 7.3 |
| Office and warehouse | 44,110 | 14 | 3150 | 3.2 |
| Truck storage and terminal | 47,720 | 18 | 2650 | 3.8 |
| Printing | 78,190 | 42 | 1860 | 5.4 |
| | 156,130 | 55 | 2850 | 3.5 |
| | | | Average 2350 | 4.5 |
| Medium manufacturing and fabrication (electrical components, etc.) | 45,610 | 52 | 880 | 11.4 |
| | 862,340 | 670 | 1290 | 7.8 |
| | | | Average 1090 | 9.6 |
| Heavy manufacturing and fabricating (machine, tool and die, metal stamp, etc.) | 20,440 | 18 | 1140 | 8.8 |
| | 36,945 | 22 | 1680 | 6.0 |
| | 74,630 | 227 | 2760 | 3.6 |
| | 89,900 | 47 | 1910 | 5.2 |
| | 155,870 | 103 | 1510 | 6.6 |
| | 156,880 | 55 | 2850 | 3.5 |
| | 296,760 | 141 | 2100 | 4.8 |
| | 364,815 | 182 | 2000 | 5.0 |
| | 690,990 | 424 | 1630 | 6.1 |
| | 831,850 | 370 | 2240 | 4.4 |
| | | | Average 1980 | 5.4 |
| | | | Total Mean 1980 | 5.7 |

TABLE 4
RELATIONSHIP OF EMPLOYMENT TO OCCUPIED AND AVAILABLE PARKING SPACES

| Total Number of Employees | Number of Spaces Occupied | Number of Occupied Spaces per Employee | Number of Available Spaces | Percent of Available Spaces Occupied |
|---|---|---|---|---|
| 0-100 | | | | |
| 20 | 14 | 0.70 | 25 | 56 |
| 33 | 18 | 0.55 | 23 | 78 |
| 50 | 27 | 0.54 | 57 | 47 |
| 70 | 42 | 0.60 | 50 | 84 |
| 75 | 22 | 0.29 | 35 | 63 |
| 75 | 47 | 0.63 | 46 | 102 |
| 85 | 34 | 0.40 | 70 | 49 |
| 92 | 52 | 0.57 | 65 | 80 |
| | | Average 0.54 | | |
| 100-500 | | | | |
| 120 | 76 | 0.63 | 68 | 112 |
| 130 | 103 | 0.79 | 134 | 77 |
| 193 | 122 | 0.63 | 175 | 70 |
| 240 | 71 | 0.30 | 132 | 54 |
| 240 | 141 | 0.59 | 187 | 75 |
| 400 | 182 | 0.45 | 265 | 69 |
| 465 | 175 | 0.38 | 209 | 84 |
| | | Average 0.54 | | |
| Over 500 | | | | |
| 824 | 370 | 0.45 | 493 | 75 |
| 850 | 424 | 0.50 | 466 | 91 |
| 1000 | 679 | 0.68 | 763 | 89 |
| | | Average 0.54 | | |
| | | Total Mean 0.54 | | |
| | | Standard deviation 0.133 | | |

office area, and 34 occupied spaces per 10, 000 sq ft for an 83, 600-sq ft office area. These were typical figures for a dense employment use.

Table 6 is presented to further show the consistent parking-to-employment relationship according to industrial classification. Interestingly, one of the highest ratios, 0. 70, is for a combination office and pharmaceutical warehouse. The absolute values within each category are presented to show the variation.

TABLE 5

RELATIONSHIP OF OFFICE EMPLOYMENT TO OFFICE AND VISITOR PARKING

| Number of Office Employees | Number of Spaces Occupied | Number of Occupied Spaces per Employee | Number of Available Spaces | Percent of Available Spaces Occupied |
|---|---|---|---|---|
| 20 | 20 | 1. 0 | 26 | 77 |
| 25 | 9 | 0. 36 | 18 | 50 |
| 35 | 31 | 0. 89 | 34 | 91 |
| | Average | 0. 75 | | |
| 225 | 130 | 0. 58 | 209 | 62 |
| 450 | 287 | 0. 64 | 322 | 89 |
| | Average | 0. 61 | | |
| | Total Mean | 0. 69 | | |
| | Standard Deviation = | 0. 228 | | |

TABLE 6

RELATIONSHIP OF EMPLOYMENT TO PARKING DEMAND

| Industry Classification | Number of Employees | Number of Occupied Spaces per Employee |
|---|---|---|
| Bakery | 465 | 0. 38 |
| Office and research | 75 | 0. 63 |
| | 85 | 0. 40 |
| | 193 | 0. 63 |
| | Average | 0. 55 |
| Office and warehouse | 20 | 0. 70 |
| | 70 | 0.60 |
| Printing | 240 | 0. 30 |
| | | 0. 45 |
| Medium manufacturing and fabrication (electrical components, etc.) | 92 | 0. 57 |
| | 1000 | 0. 67 |
| | Average | 0. 62 |
| Heavy manufacturing and fabricating (machine, tool and die, metal stamp, etc.) | 33 | 0. 55 |
| | 50 | 0. 54 |
| | 75 | 0. 29 |
| | 120 | 0. 63 |
| | 130 | 0. 79 |
| | 240 | 0. 59 |
| | 400 | 0. 45 |
| | 824 | 0. 45 |
| | 850 | 0. 50 |
| | | 0. 53 |
| | Total Mean | 0. 54 |

## TRAFFIC CHARACTERISTICS

### Automobile Generation

Nearly all of the traffic counts were conducted during the normal 2-hour morning and evening peak periods. However, four of the plants work on a staggered shift which did not coincide with the normal peak period. Special counts were conducted at these plants so the absolute peak driveway movement could be determined.

Table 7 shows industrial automobile traffic related to the three basic factors of developed land area, gross building area, and employment. These were shown for three critical time segments during both morning and evening peak periods. The most consistent values were found with employment.

The best correlation appears to be generation related to employment. The evening peak hour (which was higher than the morning) had a mean generation of 0. 34 vehicles per employee, with a standard deviation of 0. 160. The average factor for morning and evening combined was 0. 33, with a standard deviation of 0. 156. Note that the combined 30-minute flow rate was equal to 0. 44 vehicles per employee, or 1/3 higher than the peak hour.

Developed land area and gross building area related to generation showed consistent mean values similar to the employment relationship. However, inspection of individual values and standard deviations shows a wider spread, particularly for building areas.

TABLE 7

INDUSTRIAL AUTO TRAFFIC GENERATION CHARACTERISTICS

| Factor | Average Morning Volume Generated | | | Average Evening Volume Generated | | |
|---|---|---|---|---|---|---|
| | Peak 30 Min. | Peak Hour | Peak 2 Hours | Peak 30 Min. | Peak Hour | Peak 2 Hours |
| Developed land area (sq ft) | (per 10,000 sq ft) | | | (per 10,000 sq ft) | | |
| 0-100,000 | 3. 0 | 4. 5 | 6. 0 | 3. 8 | 5. 3 | 6. 7 |
| 100,000-500,000 | 2. 5 | 3. 9 | 5. 2 | 1. 7 | 2. 8 | 4. 2 |
| Over 500,000 | 1. 8 | 2. 9 | 3. 9 | 2. 4 | 3. 8 | 5. 1 |
| Total Mean | 2. 4 | 3. 8 | 5. 2 | 2. 6 | 4. 1 | 5. 5 |
| Building area (sq ft) | (per 10,000 sq ft) | | | (per 10,000 sq ft) | | |
| 0-30,000 | 10. 5 | 15. 6 | 19. 4 | 10. 4 | 15. 6 | 20. 8 |
| 30,000-100,000 | 6. 2 | 8. 6 | 11. 5 | 6. 3 | 7. 5 | 9. 8 |
| Over 100,000 | 4. 4 | 7. 5 | 9. 8 | 4. 9 | 8. 4 | 11. 4 |
| Total Mean | 6. 5 | 10. 0 | 12. 8 | 6. 7 | 10. 1 | 13. 5 |
| Employment | (per employee) | | | (per employee) | | |
| 0-100 | 0. 17 | 0. 25 | 0. 35 | 0. 20 | 0. 31 | 0. 39 |
| 100-500 | 0. 24 | 0. 37 | 0. 48 | 0. 20 | 0. 31 | 0. 47 |
| Over 500 | 0. 19 | 0. 32 | 0. 42 | 0. 25 | 0. 42 | 0. 55 |
| Total Mean | 0. 21 | 0. 32 | 0. 42 | 0. 22 | 0. 34 | 0. 46 |

TABLE 8

RELATIONSHIP OF MAXIMUM PARKING DEMAND TO PEAK HOUR FLOW

| Industry Classification | Maximum Peak Parking Demand | Morning Peak Hour | | | Evening Peak Hour | | | Peak Hour Flow (vph) As Fraction of Maximum Parking Accumulation | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Two-Way Volume | Percent In | Percent Out | Two-Way Volume | Percent In | Percent Out | | Two-Way | One-Way |
| Bakery | 175[a] | 57 | 65 | 35 | 68 | 22 | 78 | | 0.39 | 0.30 |
| Office and research | 75 | 45 | 90 | 10 | 65 | 6 | 94 | | 0.87 | 0.81 |
| Truck storage and warehouse | 18 | 20 | 65 | 35 | 13 | 31 | 69 | | 1.10 | 0.72 |
| Printing | 72 | 58 | 69 | 31 | 29 | 24 | 76 | | 0.81 | 0.56 |
| Medium manufacturing | 52 | 34 | 94 | 6 | 47 | 7 | 93 | | 0.90 | 0.84 |
| and fabrication (electrical components, etc.) | 670 | 511 | 92 | 8 | 530 | 6 | 94 | | 0.79 | 0.74 |
| | | | | | | | | Average | 0.85 | 0.79 |
| Heavy manufacturing | 18[a] | 11 | 100 | 0 | 12 | 50 | 50 | | 0.67 | 0.33 |
| and fabricating | 22 | 10 | 90 | 10 | 12 | 8 | 92 | | 0.55 | 0.51 |
| (machine, | 27[a] | 9 | 78 | 22 | 10 | 10 | 90 | | 0.37 | 0.33 |
| tool and die, | 55 | 44 | 84 | 16 | 34 | 21 | 79 | | 0.80 | 0.67 |
| metal stamp, | 103 | 79 | 92 | 8 | 25 | 8 | 92 | | 0.77 | 0.71 |
| etc.) | 141 | 127 | 86 | 14 | 115 | 12 | 88 | | 0.90 | 0.77 |
| | 182 | 142 | 82 | 18 | 167 | 34 | 66 | | 0.92 | 0.61 |
| | 370[a] | 229 | 81 | 19 | 417 | 25 | 75 | | 1.13 | 0.84 |
| | 424[a] | 147 | 83 | 13 | 195 | 11 | 89 | | 0.46 | 0.41 |
| | | | | | | | | Average | 0.73 | 0.58 |
| From Williams and Latchford (4), Table 1: | | | | | | | | | | |
| Mechanical Engineering | | | | | | | | | | 0.71 |
| Electrical Engineering | | | | | | | | | | 0.60 |
| Plastics | | | | | | | | | | 0.48 |
| Textiles and Clothing | | | | | | | | | | 0.78 |

[a]Plant on double shift.

Comparison of data was made with the Keefer study (3). The data were extracted from his tables for plant sizes between 185,000 and 500,000 sq ft. These were among the smallest plant sizes in his sample and were selected to correspond with Niles building areas. Using Keefer's data, a figure of 0.27 vehicles per employee for traffic generation related to employment was found, which was quite similar to the Niles evening peak hour figure of 0.34.

Another comparison with the Keefer study was made of automobile generation related to plant size. The range of plant sizes between 185,000 and 500,000 sq ft was again used and compared with the seven Niles samples for building areas over 100,000 sq ft. Wide variation was found within Keefer's peak hour data, with a range from 2.3 to 21.4 cars per 10,000 sq ft of building area. The mean value was 10.4, however, which compared closely with the 8.4 vehicles per 10,000 sq ft of building area for Niles.

Niles data were also compared with Keefer's daily traffic generation figures. From his data, an average of over 35 percent of daily traffic occurred during the peak hour. Studies of this particular industrial area in Niles have shown that about 27 percent of the traffic generated during a normal 12-hour period, 6 a.m. to p.m., occurs during the peak period. (No 12-hour counts were available at any of the individual plants, so no direct relation can be made.)

TABLE 9

PEAK HOUR TRUCK TRIP RELATIONSHIPS

| Factor | Average Morning Volume Generated | Average Evening Volume Generated |
|---|---|---|
| Developed land area (sq ft) | (per 10,000 sq ft) | (per 10,000 sq ft) |
| 0-100,000 | 0.37 | 0.55 |
| 100,000-500,000 | 0.20 | 0.26 |
| Over 500,000 | 0.24 | 0.20 |
| Total Mean | 0.28 | 0.35 |
| Building area (sq ft) | (per 10,000 sq ft) | (per 10,000 sq ft) |
| 0-30,000 | 1.07 | 1.69 |
| 30,000-100,000 | 0.58 | 0.53 |
| Over 100,000 | 0.48 | 0.55 |
| Total Mean | 0.63 | 0.76 |
| Loading berths | (per dock) | (per dock) |
| 1-4 | 0.74 | 1.01 |
| 5-10 | 1.15 | 1.55 |
| Over 10 | 1.35 | 0.95 |
| Total Mean | 0.96 | 1.19 |

Also of interest, the same studies indicated that over 50 percent of the 12-hour traffic is generated in both of the 2-hour morning and evening peak periods. By adding the Niles morning and evening 2-hour peaks (Table 7), the employment generation was 0.88 trips per employee. In fact, for plants employing over 500 people, 0.97 trips per employee were found during the 4 peak hours. These figures far exceed the 50 percent value. However, no direct comparison can be made since some industries have well over a 1.0 ratio, if there are considerable sales or visitor trips, for example.

TABLE 10

RELATIONSHIP BETWEEN TRUCK GENERATION AND DEVELOPED LAND AREA, BUILDING SIZE, AND NUMBER OF LOADING DOCKS

| Industry Classification | Morning Peak Hour Generation | | | Evening Peak Hour Generation | | |
|---|---|---|---|---|---|---|
| | Per 10,000 sq ft Land Area | Per 10,000 sq ft Building | Per Dock | Per 10,000 sq ft Land Area | Per 10,000 sq ft Building | Per Dock |
| Bakery | 0.6 | 1.4 | 1.5 | 0.3 | 0.7 | 0.7 |
| Office and research | 0.5 | 1.1 | 1.0 | 0.4 | 0.9 | 0.75 |
| | 0.3 | 0.7 | 1.0 | 0.2 | 0.4 | 0.5 |
| Truck storage and terminal | 2.9[a] | 18.1[a] | 1.2 | 3.1[a] | 19.4[a] | 1.2 |
| Printing | 0.1 | 0.2 | 0.3 | 0.8 | 1.2 | 2.2 |
| Medium manufacturing and fabrication (electrical components, etc.) | 1.1 | 2.7 | 2.5 | 1.1 | 2.7 | 2.5 |
| | 0.1 | 0.3 | 2.0 | 0.05 | 0.1 | 1.0 |
| Heavy manufacturing and fabricating (machine, tool and die, metal stamp etc.) | 0 | 0 | 0 | 1.0[a] | 1.4[a] | 1.0 |
| | 0.3 | 0.5 | 0.5 | 0 | 0 | 0 |
| | 0.4 | 0.9 | 1.0 | 0.1 | 0.3 | 0.3 |
| | 0.2 | 0.5 | 1.5 | 0.2 | 0.5 | 1.5 |
| | 0.1 | 0.3 | 0.7 | 0 | 0 | 0 |
| | 0.1 | 0.1 | 0.3 | 0.1 | 0.2 | 0.7 |
| | 0.4 | 0.9 | 1.6 | 0.3 | 0.6 | 1.1 |
| | 0.2 | 0.5 | 2.1 | 0.4 | 0.9 | 4.0 |
| | 0.4 | 0.1 | 0.75 | 0.05 | 0.1 | 1.0 |
| Mean | 0.28 | 0.63 | 0.96 | 0.35 | 0.76 | 1.19 |

[a]Not included in mean, due to biased sample.

Table 8 relates peak hour flow to maximum parking demand classified by similar industries. The double-shift industries can be quickly determined by their extreme high or low values. The high value designates a complete turnover of office and plant for the shift change, while low values represent only a portion of the plant, such as the factory, changing shifts while the office cars remain in place.

The one-way flow column for the peak hour was developed to compare Niles generation with values found in Great Britain (4). The values are quite similar.

TABLE 11

RELATIONSHIP OF LAND AREA AND BUILDING SIZE TO LOADING FACILITIES

| Industry Classification | Total Developed Land Area (sq ft) | Building Area (sq ft) | Number of Truck Docks | | Number of Berths Per 10,000 sq ft Land Area | Number of Berths Per 10,000 sq ft Building Area |
|---|---|---|---|---|---|---|
| Bakery | 600,240 | 259,890 | 24 | | 0.40 | 0.92 |
| Office and research with warehouse | 62,530 | 30,220 | 3 | | 0.48 | 0.99 |
| | 74,330 | 35,160 | 4 | | 0.54 | 1.14 |
| | 190,640[a] | 60,000 | 1 | | 0.05 | 0.17 |
| | | | | Average | 0.36 | 0.77 |
| Truck storage and terminal | 47,720 | 7,730 | 12 | | 2.52 | 15.52 |
| Printing | 78,190 | 43,250 | 2 | | 0.26 | 0.46 |
| | 156,130 | 104,940 | 6 | | 0.38 | 0.57 |
| | | | | Average | 0.32 | 0.52 |
| Medium manufacturing and fabrication (electrical components, etc.) | 45,610 | 18,540 | 2 | | 0.44 | 1.08 |
| | 862,340 | 296,350 | 5 | | 0.06 | 0.17 |
| | | | | Average | 0.25 | 0.62 |
| Heavy manufacturing and fabricating (machine, tool and die, metal stamp, etc.) | 20,440 | 8,425 | 2 | | 0.98 | 2.38 |
| | 36,945 | 20,240 | 2 | | 0.54 | 0.99 |
| | 74,630 | 34,650 | 3 | | 0.40 | 0.87 |
| | 89,900 | 50,230 | 3 | | 0.33 | 0.60 |
| | 155,870 | 59,860 | 2 | | 0.13 | 0.33 |
| | 156,880 | 76,020 | 5 | | 0.32 | 0.66 |
| | 296,760 | 187,260 | 6 | | 0.20 | 0.32 |
| | 364,813 | 161,850 | 9 | | 0.25 | 0.56 |
| | 690,990 | 321,590 | 7 | | 0.10 | 0.22 |
| | 831,850 | 306,980 | 8 | | 0.09 | 0.26 |
| | | | | Average | 0.33 | 0.62 |

[a]Office and research only.

### Truck Generation

Truck generation values are considerably more variable than the automobile data. Little correlation was found. This can be seen in Tables 9 and 10.

Within similar uses, and specifically heavy manufacturing, a peak hour truck movement of about 0.3 vehicles per 10, 000 sq ft of land appears consistent, however. Also, with relation to 10, 000 sq ft of building area, a mean of 0. 7 truck movements appears reasonable.

Reference is again made to the Keefer study, where a sample of four plants was used within a range of 185, 000 to 500, 000 sq ft. Considerable variation was found, ranging from 0. 10 to 1.03 truck movements per 10, 000 sq ft of floor area. The mean value of 0. 41 movements is reasonably close to the Niles mean of 0. 55 movements per 10,000 sq ft of building for this size group. Both means were calculated from peak hour data.

## LOADING FACILITIES

The number of loading docks related to land area is shown in Table 11. Like the parking supply, the rate of berths generally diminishes with increasing land area. While the local zoning code serves as an artificial constraint, the rate of berths per 10, 000 sq ft varies considerably within similar industry types and building sizes. It would appear that loading dock requirements are highly dependent on the individual industrial operation regardless of similarity of type of operation. Unfortunately, the sample is much too small and lacks sufficient detail to establish any correlation.

## SUMMARY AND CONCLUSIONS

As stated earlier, considerable information is available pertaining to zoning requirements. Little work has been performed to field test the actual needs.

The Keefer study concerned trip generation and trip prediction methods. The British study by Latchford and Williams examined traffic generation and parking demand, similar to the Niles study. However, conditions relating to motoring habits are different for each country, and direct comparison is difficult.

### Parking

In all cases, building area relationships with parking characteristics in the Niles study were widely variable and produced only general trends. In general, parking requirements decreased with the size of building. This relationship appeared to be very sensitive to the type of industrial operation, because of the highly variable employment densities involved.

The statistical analysis for the heavy manufacturing group in Table 2 showed that the range of the expected mean at the 90 percent confidence level was somewhat consistent with the values found for the heavy manufacturing group. However, the spread of the expected mean was found to be 5. 18. Therefore, because of the variance found in the actual tabular values and the sample statistical analysis, the average values listed in Table 2 should be used only as general indicators.

Developed land area relationships with parking supply were more consistent. Using developed land area such as landscaping, driveways, and parking areas tended to reduce the influence of the unpredictable employment variable. If the type of industry is known, the influence of factors such as employment and machinery density tends to further decrease, reducing the variables and providing for better correlation. Therefore, the figures in Table 3 indicate a general range that could be expected for the specific type of industrial operation listed. The sample statistical analysis made for the heavy manufacturing group gave an expected range of ± 0. 9 for a mean value of 5. 4 spaces per 10, 000 sq ft at the 90 percent confidence level.

Employment had the best correlation of the three factors. It clearly showed that one space for each two employees was generally valid for suburban industrial developments. It should be considered minimum in such cases. Twelve industries had a parking demand in excess of 0. 5 spaces per employee, ranging up to 0. 79 spaces per employee. A condition was assumed where only a hypothetical optimum balance between parking supply and demand occurred. By analyzing only those parking lots, a mean of 0.57 occupied spaces per employee was calculated with a standard deviation of only 0.084.

## Traffic

Traffic analysis produced slightly more favorable correlation than did parking relationships. There was some correlation between the Niles data and other studies.

Of the three factors studied, employment was again the most consistent. A mean value of about 0.33 cars per employee was generated during the peak hour. When averaged with the generation value of 0.27 extracted from the Keefer data, a peak hour generation factor of 0.3 cars per employee appears valid.

Because truck volumes were so low, and observations were made for such a relatively short period of the day, the truck generation factors are very questionable. However, the small sample was expected since normal truck deliverers avoid the peak traffic periods.

Considering the factors influencing truck generation, a relationship with the number of loading docks appears most significant. Truck traffic generation is affected considerably by the type of industrial operation with respect to building areas. Classification of industrial activity affects land area to a lesser degree, when considering the land area relationship to truck generation. Therefore, building area and land area relationships should only be considered within the same type of industrial classification. In general, one truck movement per dock seems to be a reasonable generation factor.

Considerably more field studies are needed over the country to develop additional data. This analysis has been made from a limited sample, and the results can only be generalizations. The small sample size also restricts the significance of the statistical analysis. However, there are indications that parking demand and traffic generation can be approximated by factors other than employment.

## REFERENCES


1. Industrial Plant Parking. Institute of Traffic Engineers, Washington, 1959; also, Traffic Engineering, Vol. 29, No. 6, p. 25-31, March 1959.
2. Thompson, J. Trueman, and Stegmaier, Joseph T. The Effect of Building Space Usage on Parking Demand. HRB Bull. 19, p. 6-13, 1949.
3. Keefer, L. E. Urban Travel Patterns for Airports, Shopping Centers, and Industrial Plants. NCHRP Report 24, 1966.
4. Latchford, J. C. R., and Williams, T. E. H. The Prediction of Traffic in Industrial Areas. Traffic Engineering and Control, Vol. 7, No. 10, p. 628-630, Feb. 1966.
5. LeCraw, C. S., Jr., and Smith, W. S. Zoning Applied to Parking. ENO Foundation for Highway Traffic Control, Saugatuck, Conn., 1947.
6. Mogren, E. G., and Smith, W. S. Zoning and Traffic. ENO Foundation for Highway Traffic Control, Saugatuck, Conn., 1952.
7. Levin, D. R. Zoning for Truck-Loading Facilities. HRB Bull. 59, 1952.
8. Levin, D. R. Parking Requirements in Zoning Ordinances. HRB Bull. 99, 1955.

# Use of Origin-Destination Survey Data for Parking Analyses

AUSTIN E. BRANT, Jr., Associate Partner, and
JACK KINSTLINGER, Associate, Tippetts-Abbett-McCarthy-Strattion

To be truly comprehensive, transportation planning studies require consideration of terminal and transfer facilities, one of the most important of which is vehicular parking in the central business district of an urban area. The adequacy of parking can have a major effect on travel patterns and even on the continued vitality and existence of central areas, and the demand for parking is an essential element in evaluating this adequacy.

This paper describes procedures by which parking demand can be determined from the origin-destination data normally collected as part of the travel pattern survey phase of a comprehensive transportation planning study. Results obtained by applying these procedures in five urban areas in southeastern Massachusetts are presented. The accuracy of the parking demand computed through use of these procedures is evaluated by comparisons with both supply and usage, and the appropriateness of the procedures for determining parking needs is indicated.

•SOUTHEASTERN Massachusetts is an area of 950 square miles with a population of 480,000 persons and includes five major urban centers: Fall River, New Bedford, Attleboro, Taunton, and Plymouth. The central business districts of these centers contain some of the principal employment opportunities and shopping and business activities in the region and attract vehicular trips from both local and distant areas.

The data collection phase of a comprehensive transportation planning study of the Southeastern Massachusetts Region was completed in late 1966 by Tippetts-Abbett-McCarthy-Stratton for the Department of Public Works of the Commonwealth of Massachusetts in cooperation with the U. S. Bureau of Public Roads. An essential element in the study was consideration of terminal and transfer facilities because, as stated in the Bureau of Public Roads Guidelines supplementing the definitions and interpretations in Instructional Memorandum 50-2-63,

> The effectiveness and efficiency of the urban transportation system is dependent to a large measure upon the availability of adequate terminal and transfer facilities at trip origins and destinations.

One of the principal terminal facilities is vehicular parking space in the central business district of an urban area. The data collection phase of the study included analyses of current supply, usage, and demand for vehicular parking in the central business districts of the five urban areas listed above; in a subsequent phase of the project, demand is being forecast and the future needs for additional terminal facilities for vehicles are being evaluated. This paper describes the methods by which only data concerning supply and usage were obtained by direct observations and information on demand was provided

Paper sponsored by Committee on Origin and Destination.

by the analysis of data collected as part of the travel pattern surveys included in the comprehensive study.

## COMPONENTS OF PARKING ANALYSES

Analyses of parking in the central business district of an urban area usually consist of three separate phases: a parking inventory of existing supply; a parking usage study measuring utilization of parking spaces; and a parking demand study which provides information on the individual parker's desires.

The parking supply (inventory) study includes a compilation of information concerning location, design, and legal restrictions on the use of parking spaces at the time of the study and a determination of the effect of planned changes in land use, parking controls, and street usage on parking supply.

The parking usage study indicates the number, duration of stay, and location of parked vehicles in an area and permits determination of parking accumulation, parking characteristics, and extent of parking violations. Data obtained in the parking usage study are limited to the actual location where a vehicle is parked which is influenced not only by the location of trip destination or desire, but also by the availability of parking space.

The parking demand study considers the ultimate destination and purpose of the individual making a trip; since parking demand is a true indication of the individual parker's desires, demand is the only legitimate criterion for judging adequacy of parking supply and the type and extent of the need for additional parking facilities.

In the conventional parking study, parking demand is determined by means of a parking demand interview survey. One type of demand survey involves personal interviewing of every parker within the area selected for study. An alternative method involves the distribution of questionnaire cards left on vehicles or handed to drivers to be filled in and returned by mail. Since only a fraction of the questionnaire forms will be filled in and returned, sample data must be expanded to represent the total of all vehicles parking in the area and even then results may be of questionable value. The studies reported in this paper indicate that a separate parking interview survey is not required where adequate data on travel in an area are available from a comprehensive origin-destination survey. To be adequate for use in determining parking demand, travel origins and destinations within the central business district should be coded on a block basis and the travel interview sample rate should be sufficiently high to yield statistically reliable data on downtown parking demand. Processing and evaluation of the O-D data which meet these criteria will provide complete information concerning parking demand within a central business district, where the need for parking space is usually most acute.

## PARKING SUPPLY STUDIES

The central business districts of Fall River, New Bedford, Attleboro, Taunton, and Plymouth for which parking studies were conducted were defined with the cooperation of city or regional planning agencies and generally included major downtown department stores and other shopping facilities; business, financial, and professional offices; cultural and civic institutions; and governmental agencies. Some of the districts also contained manufacturing establishments and one (Plymouth) included a major tourist attraction. Data on parking supply and usage were obtained for all on-and-off-street parking facilities within this area as well as for on-street parking on the peripheral streets and off-street parking facilities which had direct access to these streets. The central business districts included 53 blocks in Fall River, 71 blocks in New Bedford, 25 blocks in Attleboro, 22 blocks in Taunton, and 22 blocks in Plymouth.

The parking supply in each area was inventoried by means of direct field observation, and data were obtained on the type of both on-street and off-street facilities. On-street parking included various types of free spaces (unrestricted or posted for specific durations) and metered spaces with varying time limits. Off-street parking included both pay facilities and free facilities, some of which were restricted to customers or employees of specific establishments. In addition, the effect of parking control modifica-

TABLE 1

CURRENT PARKING SUPPLY IN CENTRAL BUSINESS DISTRICTS
(Vehicle Spaces)

| Type of Parking Spaces | Attleboro | Fall River | New Bedford | Plymouth | Taunton |
|---|---|---|---|---|---|
| On-street | 753 | 1,064 | 1,176 | 980 | 768 |
| Off-street | 2,647 | 3,244 | 2,535 | 1,004 | 1,921 |
| Total supply | 3,400 | 4,308 | 3,711 | 1,984 | 2,689 |
| Less: On-street spaces to be eliminated to increase street capacity | -218 | -298 | -319 | -254 | -261 |
| Total: Adjusted supply | 3,182 | 4,010 | 3,392 | 1,730 | 2,428 |

tions which were proposed to increase the capacity of existing streets was analyzed and the resulting change in parking supply was determined. Table 1 summarizes the current parking supply and expected changes in on-street parking.

## PARKING USAGE STUDIES

The average weekday parking usage in each area was determined by means of direct field observations in which the license number, location, type of vehicle, and type of parking for each parked vehicle was noted at an interval of one-half the legal parking limit, but not exceeding 30 minutes, from 7 a. m. to 7 p. m. on an average weekday. The total number of vehicles parked and the space hours of parking used are shown in Table 2. Table 3 shows the number of vehicles parked at the moment of peak parking accumulation.

## PARKING DEMAND STUDIES

The data obtained in the survey of travel patterns conducted as part of the comprehensive study were used to determine parking demand. Data on parking of passenger vehicles operated by residents of the study area were obtained from the internal dwelling unit survey in which detailed information was obtained on trip origin and destination, mode of travel, time of trip starting and ending and purpose of trip. Data on parking of trucks and taxis garaged within the study area were obtained from owner interviews (except for the duration of truck and taxi parking, which was obtained from the usage survey). Data on parking locations, time of parking, and purpose for passenger vehicles owned by nonresidents of the area and for trucks and taxis garaged outside the area were obtained in the external roadside interview survey; information on parking duration and type of parking for these external vehicles was not obtained in the roadside interviews, so factors developed from studies of internal vehicles were used.

The data developed from these analyses were used in studies of parking demand in the central business districts both during the period from 7 a. m. to 7 p. m. and at the moment of peak parking accumulation. A brief description of the procedures used in determining parking demand follows.

TABLE 2

USAGE OF PARKING SPACES IN CENTRAL BUSINESS DISTRICTS
(7 a. m. -7 p. m. )

| Parking Category | Attleboro | Fall River | New Bedford | Plymouth | Taunton |
|---|---|---|---|---|---|
| (a) Number of Vehicles | | | | | |
| On-street legal* | 2,786 | 3,821 | 6,026 | 2,482 | 3,697 |
| On-street illegal | 429 | 1,283 | 1,610 | 337 | 430 |
| Off-street | 5,119 | 4,666 | 4,439 | 1,664 | 5,317 |
| Total | 8,334 | 9,770 | 12,075 | 4,483 | 9,444 |
| (b) Space Hours | | | | | |
| On-street legal | 2,043 | 4,725 | 6,375 | 2,915 | 3,318 |
| On-street overtime | 1,482 | 2,338 | 3,443 | 703 | 1,557 |
| On-street illegal | 723 | 2,370 | 2,227 | 562 | 494 |
| Off-street | 18,771 | 14,099 | 13,103 | 3,881 | 10,398 |
| tal | 23,019 | 23,532 | 25,148 | 8,061 | 15,767 |

Includes overtime parking at legal spaces.

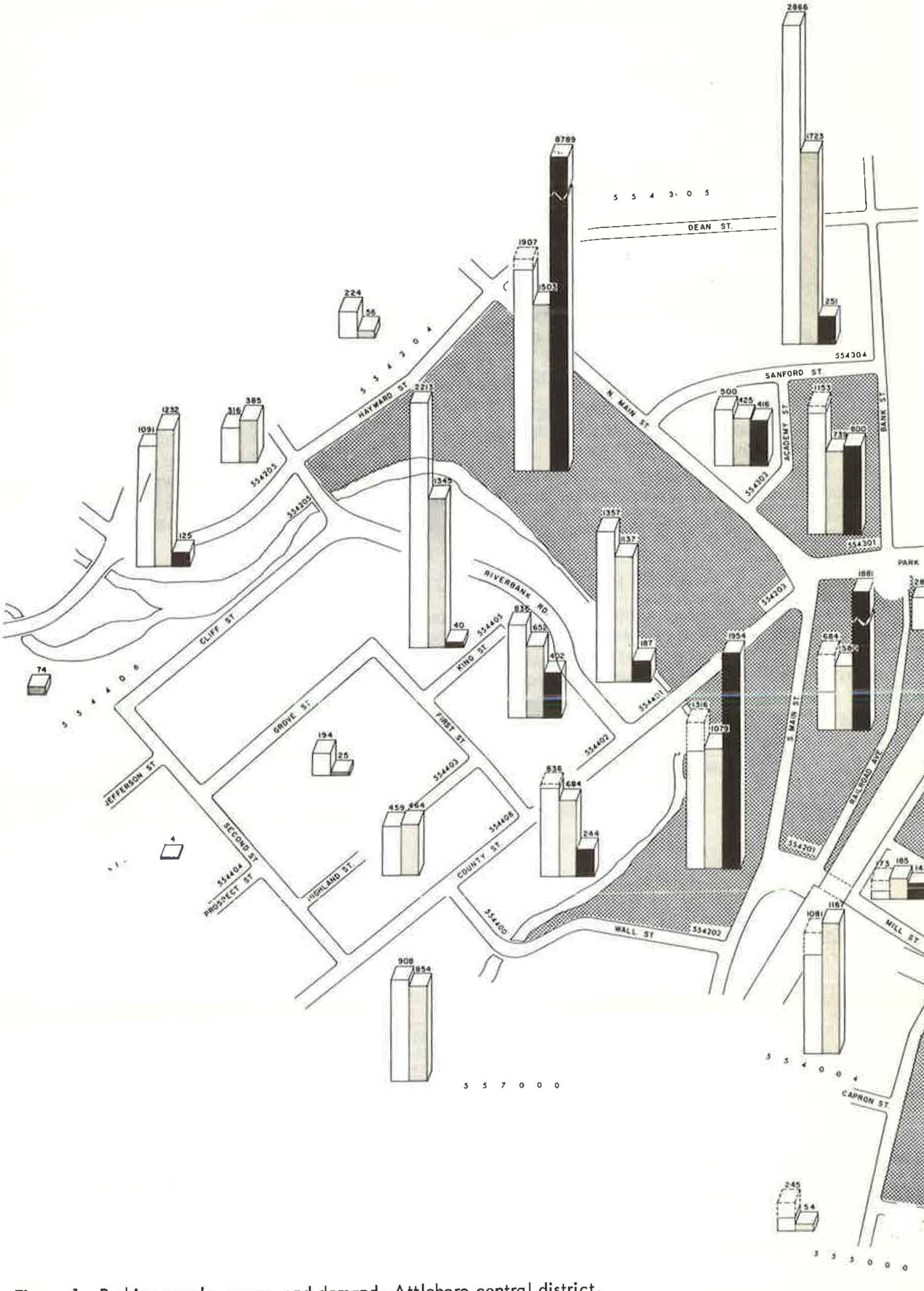
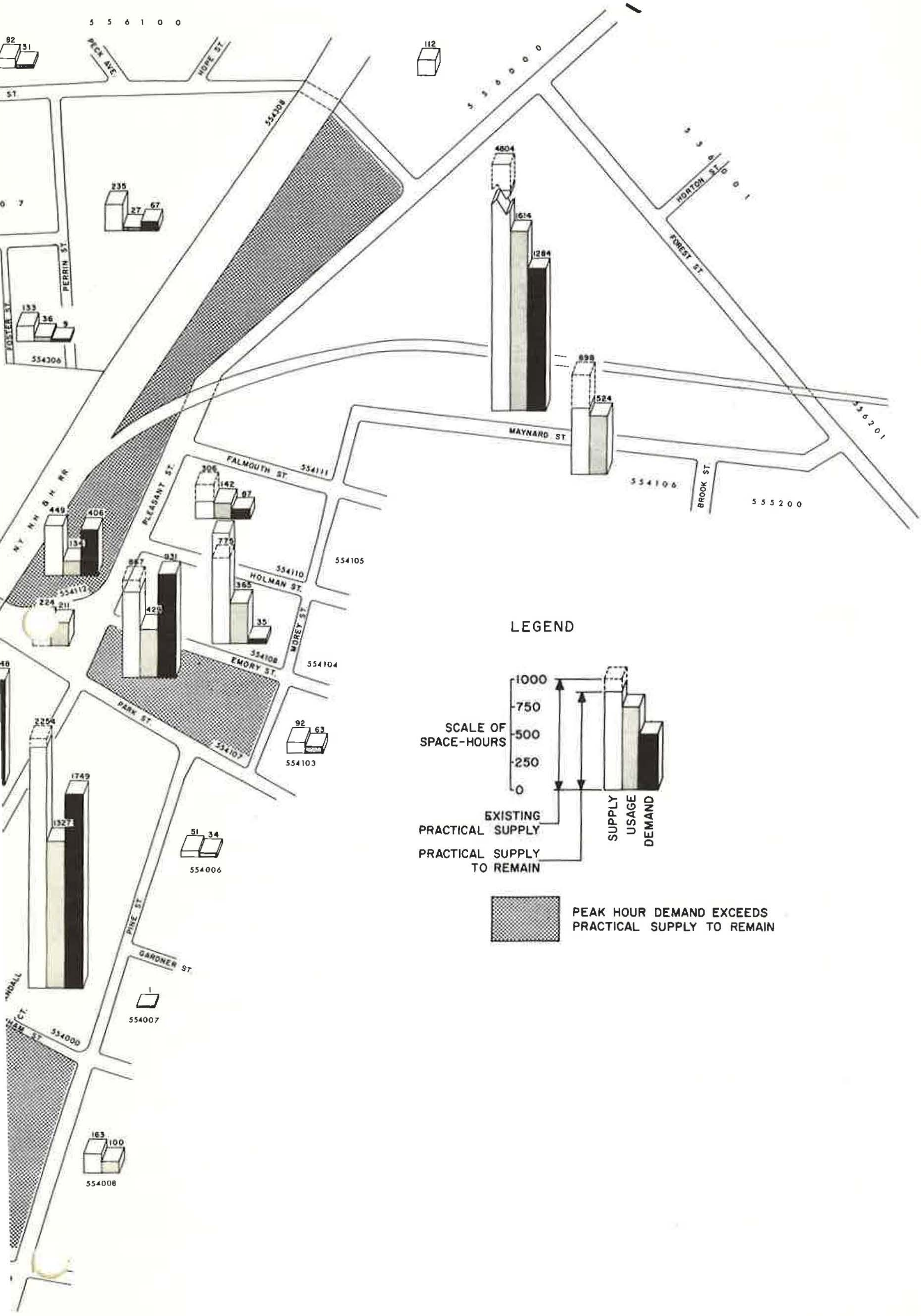



Figure 1. Parking supply, usage, and demand—Attleboro central district.



556100
PECK AVE.
HOPE ST.
ST.
82
31
112
555000
554308
4804
1614
1284
HORTON ST.
556001
FOREST ST.
235
27
67
PERRIN ST.
FOSTER ST.
133
36
9
554306
898
524
MAYNARD ST.
556201
554106
BROOK ST.
555200
FALMOUTH ST.
554111
PLEASANT ST.
306
142
87
N.Y. N.H. & H. RR
449
406
134
775
554110
554105
HOLMAN ST.
887
931
425
365
35
554112
224
211
MOREY ST.
554108
EMORY ST.
554104
PARK ST.
554107
92
63
554103
2254
1749
1327
51
34
554006
PINE ST.
GARDNER ST.
1
554007
554000
163
100
554008
LEGEND
1000
750
500
250
0
SCALE OF SPACE-HOURS
EXISTING PRACTICAL SUPPLY
PRACTICAL SUPPLY TO REMAIN
SUPPLY
USAGE
DEMAND
PEAK HOUR DEMAND EXCEEDS PRACTICAL SUPPLY TO REMAIN

TABLE 3

USAGE OF PARKING SPACES IN CENTRAL BUSINESS DISTRICTS
(Number of Vehicles, Peak Accumulation)

| Parking Category | Attleboro | Fall River | New Bedford | Plymouth | Taunton |
|---|---|---|---|---|---|
| On-street legal* | 345 | 722 | 981 | 389 | 495 |
| On-street illegal | 62 | 291 | 207 | 69 | 55 |
| Off-street | 1,898 | 1,757 | 1,453 | 419 | 1,175 |
| Total | 2,305 | 2,770 | 2,641 | 877 | 1,725 |

*Includes overtime parking at legal spaces.

## Resident Parking Demand—7 a. m. to 7 p. m.

Parking demand for the central business districts between the hours of 7 a. m. and 7 p. m. on an average weekday was analyzed for passenger vehicles operated by residents of the study area. The data required were contained in the dwelling unit survey trip cards for both internal and external trips for which a resident was an autodriver. Only trips with origin or destination in central business district zones and with an origin or destination time between the hours of 7 a. m. to 7 p. m. were considered.

Trip cards falling within these limits were analyzed by sample number, vehicle number, and trip time sequence. Each parking act was defined as a pair of trip ends with the same sample number and vehicle number which follow in time sequence and where the destination of the earlier trip and the origin of the following trip represent the same location in the CBD. The number of parking acts in the CBD and the time elapsed between the arrival in the CBD of one trip and the departure of the following trip were accumulated by trip purpose and multiplied by the appropriate expansion factor appearing in the trip cards. For vehicles whose first trip after 7 a. m. was a departure from the CBD, a previous trip arriving at the CBD at 7 a. m. was created; for vehicles whose last trip before 7 p. m. was an arrival in the CBD, a subsequent trip leaving the CBD at 7 p. m. was created.

Using these data, tabulations were prepared for parking demand by trip purpose in terms of number of parked vehicles, space hours of demand, and average parking dv tion. Tabulations were also made of the distribution of parking demand by purpose fu. incremental parking durations, for various types of parking facilities, and for various distances walked between place of parking and ultimate destination.

## Parking Demand by Block—7 a. m. to 7 p. m.

Determination of the adequacy of existing supply and the need for additional parking facilities was based on a comparison of parking supply and demand on a block basis. To permit analysis of parking demand by block, each block in the CBD was assigned a separate subzone designation prior to the data collection phase, and trip end locations were coded according to subzone. Parking demand by subzone was analyzed in terms of number of vehicles and space hours of parking.

Demand by passenger vehicles owned by study area residents was determined through analysis of internal trip cards as discussed above, with the number of parking acts and time elapsed between time of arrival and time of departure for each act accumulated by traffic subzone.

For nonresident passenger vehicle trips, external station interview cards with inbound trips to the central business districts by nonresident passenger vehicles were selected. For each external station, time limits were established which corresponded to the times when an inbound trip passing through the station would arrive at the CBD between the hours of 7 a. m. and 7 p. m. A tabulation was made of the number of such inbound trips by subzone and trip purpose. Parking demand in terms of space hours was determined by multiplying the number of parking destinations by an average parking duration by trip purpose obtained from the internal trip cards.

To determine parking demand generated by trucks and taxis garaged within the area, internal truck and taxi survey cards were reviewed for trips involving a parking act within the CBD between the hours of 7 a. m. and 7 p. m. Parking demand for external truck and taxi trips was determined through an analysis of the external station interview cards for inbound truck trips destined to the CBD for trucks with non-study area garage zones. Again, cards were limited to those with interview times such that the vehicle would reach a CBD between 7 a. m. and 7 p. m. Parking demand in space hours was determined by applying to the number of parking acts an average parking duration for trucks and for taxis as obtained in the parking usage survey.

## Parking Demand by Block–Peak Parking Period

To analyze parking demand, consideration was given to the situation during periods of peak parking accumulation. While parking demand may be less than available parking supply measured in terms of space hours over an entire day, the supply may nevertheless be inadequate during peak periods. Supply remains constant throughout the day while the demand exhibits peaking characteristics which may exceed supply during certain periods.

A realistic evaluation of parking supply was obtained through an analysis of demand by block during the peak period. The time when peak parking occurs was determined for each central business district from an analysis of parking accumulation revealed in the parking usage study.

Parking demand in terms of number of vehicles desiring to park during the peak moment for resident autos was determined by accumulating trip card origins or destinations by subzone and expanding the results in accordance with expansion factors appearing on trip cards. To reflect demand from nonresident autos and trucks and taxis, the demand determined for resident autos was expanded by the ratio of 12-hour parking demand for all vehicles to the 12-hour parking demand for resident autos only. Separate ratios were computed for each subzone.

Tabulations were prepared comparing parking supply, usage, and demand by subzone during the peak parking moment. A graphical presentation of this comparison for the Attleboro central business district is shown in Figure 1.

To determine whether additional parking spaces were required, parking deficits in blocks where peak demands exceeded practical supply were distributed to adjoining blocks having a surplus in peak period supply and located within an acceptable walking distance from trip destination. Deficits in parking supply which could not be balanced with adjacent surpluses formed the basis for making recommendations for providing additional parking facilities.

## EVALUATION OF ACCURACY OF DEMAND

The dwelling unit, truck and taxi and roadside interviews conducted in the comprehensive transportation study involved the use of sampling procedures. The sampling rates used were approximately 1:15 for dwelling unit interviews, 1:5 for truck owner interviews, 1:3 for taxi owner interviews, and 1:2 for roadside interviews. The sample data were expanded to represent current travel patterns and, as described in this paper, to represent current parking demand. The accuracy of the overall procedure was evaluated by comparisons of population, employment, and school enrollment obtained from expanded data with similar data developed from other sources. An evaluation of the accuracy of the travel information obtained was made through comparisons of expanded data with counts made on screenlines and cordon lines and at major control points. Evaluation of the accuracy of the parking demand obtained from expanded survey data is described in the following.

TABLE 4

COMPARISON OF DEMAND AND SUPPLY AT TIME OF PEAK PARKING ACCUMULATION IN CENTRAL BUSINESS DISTRICTS
(Number of Vehicles)

| Category | Plymouth | Attleboro | Taunton | Fall River | New Bedford |
|---|---|---|---|---|---|
| Practical supply | 1, 690 | 2, 900 | 2, 290 | 3, 660 | 3, 160 |
| Demand | 875 | 2, 546 | 2, 390 | 4, 108 | 3, 936 |
| Demand/supply ratio | 0. 52 | 0. 88 | 1. 04 | 1. 12 | 1. 25 |

TABLE 5

COMPARISONS OF DEMAND AND USAGE IN CENTRAL BUSINESS DISTRICTS

| Category | Plymouth | Attleboro | Taunton | Fall River | New Bedford |
|---|---|---|---|---|---|
| (a) Number of Vehicles, Peak Accumulation | | | | | |
| Demand | 875 | 2,546 | 2,390 | 4,108 | 3,936 |
| Usage | 877 | 2,305 | 1,725 | 2,770 | 2,641 |
| Demand/usage ratio | 1.00 | 1.11 | 1.38 | 1.50 | 1.49 |
| (b) Space Hours, 7 a.m. -7 p.m. | | | | | |
| Demand | 7,624 | 23,493 | 18,808 | 27,129 | 31,595 |
| Usage | 8,061 | 23,019 | 15,767 | 23,532 | 25,148 |
| Demand/usage ratio | 0.94 | 1.02 | 1.19 | 1.15 | 1.26 |

To evaluate properly the accuracy of the procedures described in this paper, a parker interview survey should be conducted to measure demand, and the demand thus obtained should be compared with the demand developed from the expanded survey data. Because a parker interview survey involves the expenditure of considerable funds, a less rigorous evaluation method was adopted involving comparison of the computed parking demand with observed parking usage. In application of this method, consideration must be given to the relationships of usage and demand to supply.

Table 4 gives a comparison of computed demand at the time of peak parking accumulation with the practical supply (practical supply is defined as 85 percent of actual supply to allow for time lost in parking and unparking and for spaces unoccupied between parking acts). In Plymouth, peak period demand is considerably less than supply and it would be expected that demand would be approximately equal to usage, or even less than usage if drivers having non-CBD destinations parked in the CBD because of the convenience of the parking facilities in that area. In Attleboro, peak period demand is only slightly less than supply, and demand would be expected to be about equal to usage. In Taunton, peak period demand is slightly greater than supply, and demand would be expected to be more than usage. Finally, in Fall River and New Bedford, peak period demand is considerably greater than supply, and it would be expected that demand in peak periods and on a daily basis would be considerably more than usage as drivers desiring to park in the CBD are forced to park in adjoining areas and walk to their destination.

Table 5 gives a comparison of demand and usage for both peak periods and on a daily basis.

The demand/usage ratios in Table 5 are reasonable and consistent when viewed in light of the demand/supply ratios given in Table 4. This reasonableness and consistency indicates that the procedures described in this paper for determining parking demand are sufficiently accurate for analyses of the adequacy of parking supply in central business districts under appropriate conditions of geographic coding and sample rate, and can be used to indicate areas where additional parking facilities are needed. For revenue forecasts at specific facilities, more detailed studies would be required involving parker interviews.

## ACKNOWLEDGMENTS

The Southeastern Massachusetts Comprehensive Transportation and Arterial Study was performed under the direction of the Department of Public Works of the Commonwealth of Massachusetts, represented by Daniel S. Horgan, Chief Engineer, and George L. Wey, Director of the Bureau of Transportation Planning and Development. Valuable assistance was given by the U. S. Bureau of Public Roads, especially Philip Robinson, Massachusetts Division Planning and Programming Engineer, and John F. McCaffrey, Assistant Division Planning and Programming Engineer.