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Environmental Effects on Bus Durability

Sandra L. Arlinghaus
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ENVIRONMENTAL EFFECTS
ON
BUS DURABILITY

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TO OUR SPOUSES:

William C. Arlinghaus

Gwen L. Nystuen

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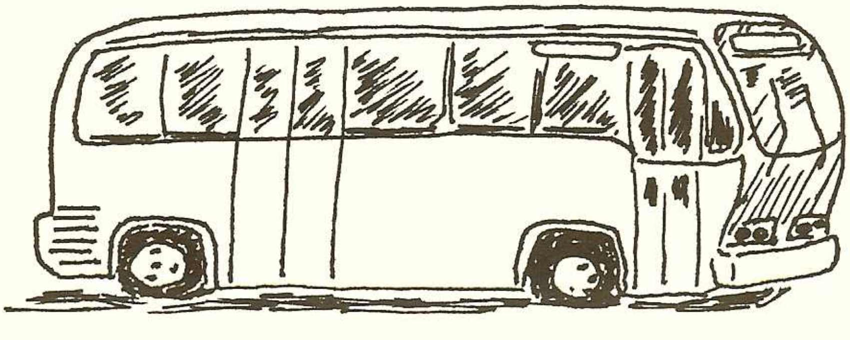

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Sandra L. Arlinghaus, John D. Nystuen

Ann Arbor, MI December, 1989.

CHAPTER 1: CLIMATIC EFFECTS

INTRODUCTION

Cars and buses heavily scarred from rusty sores are a familiar sight to residents of the Great Lakes Basin as well as to those in other regions that experience heavy concentrations of snow and road salt, or heat and airborne salt, near urban surface routes. Other environmental stresses that contribute to the aging of a bus fleet might involve the steepness of the underlying terrain and the density of traffic congestion. Steep grades produce extra strain on the motor and power–train, and frequent stopping and starting wear the brakes, the engine, and the drive train. However, major "surgery" often fixes component breakdowns, via brake transplant or electrical bypass, resulting from the various strains on the visceral bus system. Disintegration of the bus skin, however, is irreparable and often forces vehicle replacement; one response to this problem is to build rust–proof buses of stainless steel that resist corrosion from road and airborne salt. This change in material could extend bus life, thereby presenting transit authorities, in adversely affected climatic regions, with an opportunity to build healthier, more efficient bus fleets.

The major contribution of this work is to derive measures of climatic conditions that can be used in the analysis of several factors related to vehicle performance. This exploits the "Potential Data Applications" suggested in the Fourth Annual Section 15 Report of National Urban Mass Transportation Statistics that "Peer groups could be formed based on mode, fleet size, annual operating expenses, and/or such other factors not contained in this report as climate and collective bargaining agreements. Comparisons can be made to the individual transit systems in the group, or to overall group averages" [1]. These climate peer groups are then used to show how an increased understanding of other factors, such as age profile and performance data on bus fleets, might result.

CLIMATE PEER GROUPS

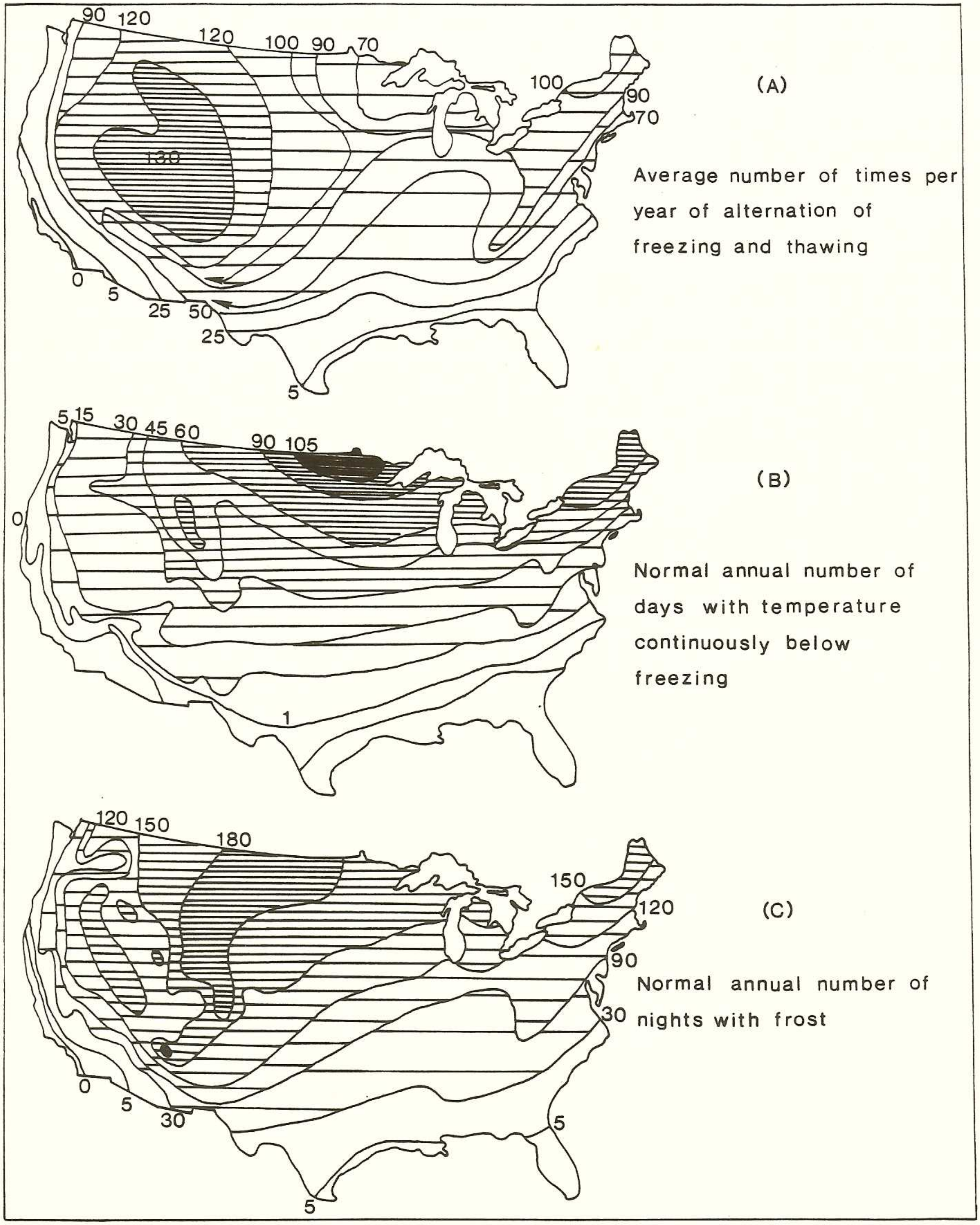
The mechanics of constructing climate peer groups involve incorporating material from climatic atlases into the Section 15 data and using the resulting climatic indicators to sort transit authorities into "harsh," "intermediate," or "benign" climatic peer groups. These peer groups are determined first according to a simple numerical procedure based only on climatic indicators above, below, or equal to a mean value, and are checked with an approach using linear algebra to associate a climate vector with each transit authority. The latter approach also generates a rank–ordering of transit authorities in each climate peer group. It does so using the lengths of climate vectors (vector norms) measured in a coordinate system with the national average as the origin.

Peer Groups Formed by a Simple Numerical Procedure

It is assumed that when road salt is used as an aid in snow removal, it speeds bus body corrosion; it is not assumed that all corrosion is caused by road salt, however, nor is it assumed that all communities employ road salt in snow removal. Thus, the measures that follow include transit authorities in which airborne salt in warm, humid climates promotes corrosion of buses that travel coastal routes, as well as transit authorities in agricultural states that do not use road salt in snow removal. Inclusion of these transit authorities provides a broad spectrum of positions for data points to partition into peer groups on relatively unchanging, purely climatic, bases. Changes in policy, involving decisions to salt, or changes in bus route position, involving nearness to salt water, are more closely spaced in time than are changes in climate. Although these are issues that could be superimposed on the results of this Chapter, they are beyond its scope as they do not contribute, at the fundamental level, to sorting transit authorities by climatic type; it is the typology that is dominant here.

The following climatic indicators will be used to link snow to road salt. First, the "total amount of annual snowfall" is significant as a rough measure of total volume of road salt to which bus bodies are subjected in a single winter. Second, the "mean number of days of one inch or more of snow and sleet" uses frequency of snow events to measure the extent to which bus bodies are exposed to road salt on a continuing basis. Third, the "average number of times per year of an alternation of freezing and thawing" gives a general indication of the number of days that are optimal for applying salt to melt snow and accumulated ice. These factors are assumed to have roughly the same weight in describing winter adversity at the national scale, as suggested by groupings of variables of this sort to describe national climate patterns in climate atlases; however, individual transit authorities may see one factor as more significant than another. Further, these climatic indicators measure trends over time and may thus differ from local weather patterns in any single year. Therefore, individual transit authorities should exercise caution in using current weather statistics. To understand the range of possible weather patterns, it is necessary to supplement current weather observations with a longer view of the climatic history of the region.

Data for the first two climatic indicators is available on a city–by–city basis in the tables of "Normals, Means, and Extremes" in Climates of the States [2]. These tables report data only from locations with complete weather stations. Only data from those weather stations in cities with bus systems were included. Cities with bus systems, but not with reporting weather stations, were grouped with the weather station in their climatic zone as shown in maps of "Climatic Zones" in Climates of the States. Data for the third variable come from the maps in Figures 1A, B, and C, that appeared originally in Stephen Visher's


(A)

Average number of times per year of alternation of freezing and thawing

(B)

Normal annual number of days with temperature continuously below freezing

(C)

Normal annual number of nights with frost

FIGURE 1.1. Visher maps; see Acknowledgment.

Climatic Atlas of the United States [3]. To form the isolines in this map, Figure 1.1A, Visher used the differences found by subtracting "Normal annual number of days with temperature continuously below freezing" (Figure 1.1B) from "Normal annual number of nights with frost (minimum of 32 deg F or lower)" (Figure 1.1C). For example, Detroit, Michigan, has about 135 nights with frost in a year. Of those, about 45 are associated with days where the temperature is already below freezing; on these days, little benefit comes from applying salt to the roads. That leaves $135 - 45 = 90$ times per year with frost at night when the day temperature is not continuously below freezing; hence, an alternation occurs across the freeze line. Locations between isolines were assigned the value of the lower of the two isolines. Interpolation was not employed because these climate values generally do not vary linearly between isolines. Numerical values for this climatic indicator range from 0 to 130 days. High values of the Visher index should be expected in alpine areas, due to daily temperature fluctuation. Low values should appear in southern cities, and these values will increase more rapidly away from large bodies of water because the land temperature responds more quickly than does the water temperature to changes in the surrounding air temperature.

The three climatic indicators were calculated for each of 193 cities associated with 203 transit authorities of more than 25 buses that filed Section 15 reports for at least two of the four years under study. The national mean for these indicators, rounded to the nearest integer and expressed as an ordered triple (number of inches of snow per year, number of snow events per year, and number of alternations of freeze–thaw per year), was $(23, 7, 50)$. An ordered triple that represents the climatic indicators for a particular city has entries of positive sign to represent deviation above the mean, of negative sign to represent deviation below the mean, or of 0 to represent no deviation from the mean. The following Table classifies the 193 cities according to the signs of their ordered triples (Table 1.1). No city received a score of $(0, 0, 0)$, the national mean. Cities in which all three climatic indicators are above the mean are represented by triples with sign $(+, +, +)$. These cities are grouped in the "harsh" climate class in the list (ordered by longitude). Similarly, cities in which all three climatic indicators are below the mean are represented by ordered triples with sign $(-, -, -)$. These are grouped as the "benign" climate class of entries in the list (ordered by longitude). The cities associated with the remaining sign possibilities are grouped in the "intermediate" climate class of the list (ordered by longitude).

Note that some cities may have more than one transit authority associated with them. Also note that the cities with the harshest climates are as follows (ordered by longitude): Portland ME; Manchester NH; Springfield MA; Albany, Utica, Binghamton, Syracuse, Rochester, and Buffalo, NY; Erie PA; Duluth MN; Colorado Springs and Denver CO; Salt Lake City UT; and Spokane WA. The cities whose climate was closest to the average were as

TABLE 1.1. CITIES BY CLIMATE CLASS: ORDERED FROM EAST TO WEST BY LONGITUDE.
(SOME CITIES MAY HAVE MORE THAN ONE TRANSIT AUTHORITY ASSOCIATED WITH THEM.)

HARSH

Portland ME
Haverhill MA
Boston MA
Lowell MA
Manchester NH
Worcester MA
Springfield MA
Hartford CT
New Haven CT
White Plains NY
Albany NY
Yonkers NY
Newark NJ
Utica NY
Allentown PA
Scranton PA
Kingston PA
Binghamton NY
Syracuse NY
Harrisburg PA
Rochester NY
Altoona PA
Johnstown PA
Buffalo NY
Pittsburgh PA
Erie PA
Youngstown OH
Kent OH
Canton OH
Akron OH
Cleveland OH
Detroit MI
Toledo OH
Saginaw MI
Ann Arbor MI
Flint MI
Bay City MI
Jackson MI
Fort Wayne IN
Kalamazoo MI
South Bend IN
Gary IN
Chicago IL
Racine WI
Kenosha WI
Waukegan IL
Des Plaines IL
Milwaukee WI
Joliet IL
Elgin IL
Aurora IL
Appleton WI
Oshkosh WI
Rockford IL
Madison WI
Rock Island IL
Davenport IA
Dubuque IA
La Crosse WI
Cedar Rapids IA
Duluth MN
Waterloo IA
St. Paul MN
Des Moines IA
St. Cloud MN
Sioux City IA
Lincoln NB
Fargo ND
Omaha NB
Colorado Springs CO
Denver CO
Salt Lake City UT
Spokane WA

INTERMEDIATE

Class (-,-,+)
Philadelphia PA
Wilmington DE
Lancaster PA
Washington DC
Lynchburg VA
Columbus OH
Knoxville TN
Chattanooga TN
Kansas City MO
Topeka KS
Tulsa OK
Wichita KS
Oklahoma City OK
Amarillo TX
Lubbock TX
Albuquerque NM

Class (-,-,0)
Richmond VA
Winston-Salem NC
Charlotte NC
Dayton OH
Atlanta GA
Cincinnati OH
Newport KY
Lexington KY
Nashville TN
Birmingham AL
Memphis TN
St. Louis MO
Little Rock AK

Class (+,+,0)
New Bedford MA
Brockton MA
Providence RI
Flushing NY
Jamaica NY
Jackson Heights NY
New York NY
East Meadow NY
Brooklyn NY
West Coxsackie NY
Louisville KY

Class (-,0,0)
Indianapolis IN
Urbana IL
Decatur IL
Peoria IL
Springfield IL

Class (+,-,+)
Bridgeport CT
Stamford CT
Asheville NC

Class (-,0,+)
Huntington WV
Charleston WV

Class (0,-,+)
Baltimore MD

Class (+,0,+)
Roanoke VA

Class (-,+,+)
Boise ID

BENIGN

Norfolk VA
Hampton VA
Raleigh NC
Fayetteville NC
West Palm Beach FL
Fort Lauderdale FL
Miami FL
South Daytona FL
Savannah GA
Orlando FL
Jacksonville FL
Augusta GA
Gainesville FL
Tampa FL
St. Petersburg FL
Bradenton FL
Clearwater FL
Tallahassee FL
Columbus GA
Montgomery AL
Pensacola FL
Mobile AL
Harahan LA
Gretna LA
New Orleans LA
Jackson MS
Baton Rouge LA
Shreveport LA
Houston TX
Dallas TX
San Antonio TX
Fort Worth TX
Corpus Christi TX
Austin TX
Laredo TX
El Paso TX
Tucson AZ
Phoenix AZ
San Diego CA
San Bernardino CA
Riverside CA
Oceanside CA
Garden Grove CA
Norwalk CA
Montebello CA
Long Beach CA
Los Angeles CA
Santa Monica CA
Gardena CA
Torrance CA
Bakersfield CA
Ventura CA
Santa Barbara CA
Fresno CA
Stockton CA
Sacramento CA
Monterey CA
San Jose CA
Santa Cruz CA
Oakland CA
Seattle WA
San Mateo CA
San Francisco CA
Tacoma WA
Salem OR
Eugene OR
Portland OR

HARSHEST PLACES: Portland ME, Manchester NH, Springfield MA, Albany, Utica, Binghamton, Syracuse, Rochester, Buffalo, Erie, Duluth, Colorado Springs, Denver, Salt Lake City, Spokane.

CITIES CLOSEST TO AVERAGE: Indianapolis IN, Urbana, Decatur, Peoria, Springfield IL, Baltimore MD, Huntington, Charleston WV.

follows (ordered by longitude): Indianapolis IN; Urbana, Peoria, Springfield, and Decatur IL; Baltimore, MD; and Charleston and Huntington WV.

Figure 1.1 partitions the continental United States into harsh, benign, and intermediate climate peer groups of transit authorities. Peer group boundaries were drawn to separate transit authorities in, or near, cities of harsh climate (see the preceding list) from transit authorities in, or near, cities of intermediate climate (see the preceding list). The latter were separated, in turn, from transit authorities in, or near, cities of benign climate (see the preceding list). As is evident from the underlying scatter of dots in Figure 1.2, the accuracy with which these climate peer group boundaries were placed is greater in the east than in the west. In much of the western mountainous region, the boundary follows topographic features such as mountain ranges and river basins. Because the climatic indicators that formed the basis for delineating climate peer groups were chosen for their capability to link road salt to snow, Figure 1.2 also shows the position of the Salina Basin, a major subsurface rock salt deposit near many of the transit authorities in the Great Lakes portion of the harsh climate peer group.

The Distribution of Climate Vectors

The three climate peer groups shown in Figure 1.2 exhibit a great deal of variation within each group; this section shows how to determine the peers most closely related, in both climatic and geographic position, to an arbitrarily chosen transit authority. The map in Figure 1.3 displays the grid generally employed for the polar case of an azimuthal equidistant map projection (on which distances measured from the center are true). In maps of this sort, the radials generally represent longitude and the arcs represent latitude. Because latitude and climate are related, climate is substituted for latitude; the column "climate vector norms" in Table 1.2 gives single climate values, based on all three climatic indicators, used in place of latitude in the map of Figure 1.3. Then, dots on that map that are close have both climatic and geographic position (longitude) that are close. Hence, the nearest neighbors within a semi–circular band of a given point are its geographically proximate climate peers. Table 1.3 gives the names of each transit authority represented in Figure 1.2 and its nearest climate peers. For example, there is no transit authority with winters as severe as those in Duluth, Minnesota, nearer than Springfield, Massachusetts, on the east, or than Denver, Colorado, on the west. Thus, Springfield and Denver are Duluth's geographically nearest climate peers.

The detail of constructing this map and these tables rests in viewing the ordered triples of climate indicators as vectors in three–dimensional space. The components of the vectors are numerical measures of different ranges, but are of equal weight in describing severity of winter (as previously explained). Thus, to compare vectors, adjustment is required of the set

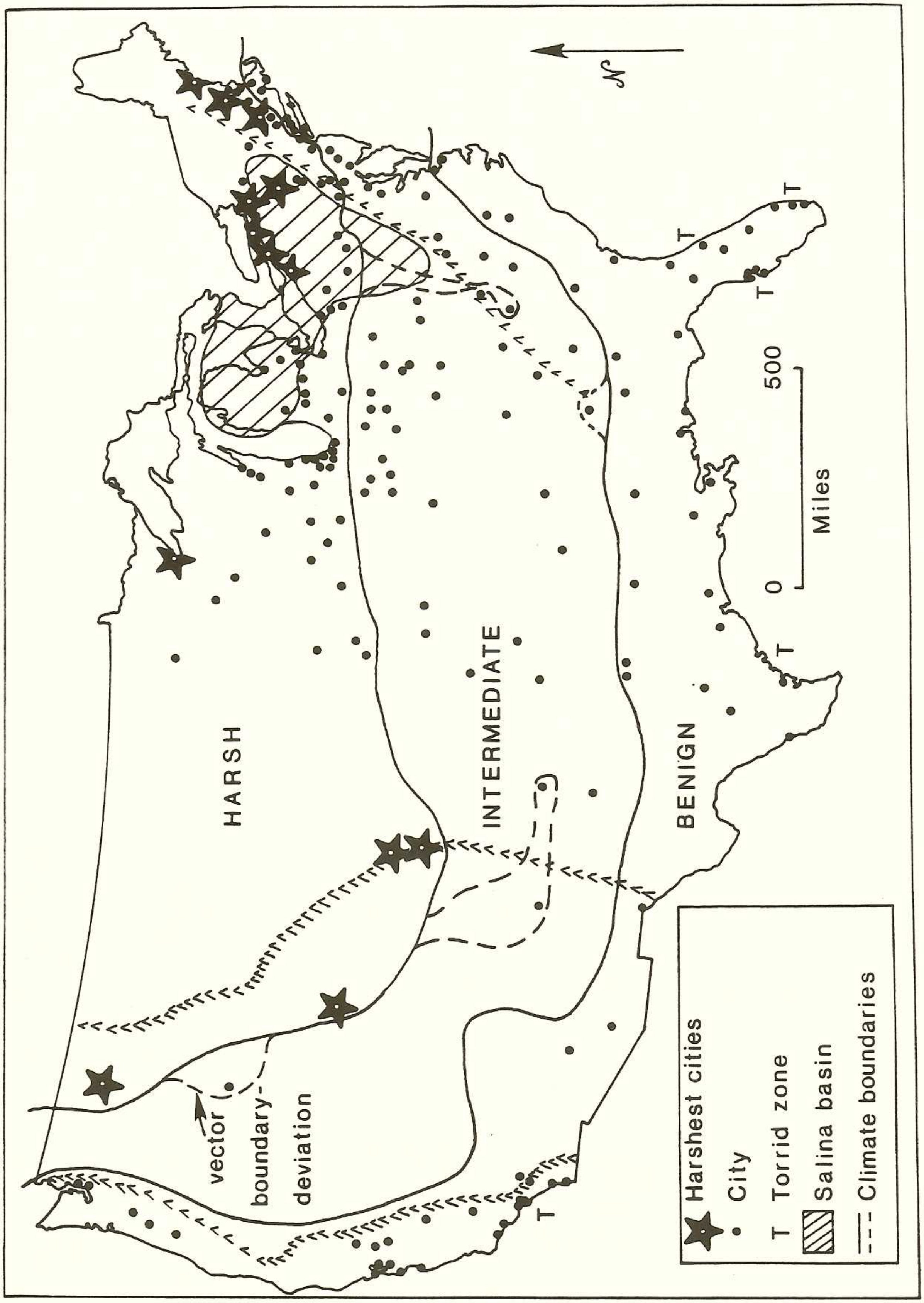


FIGURE 1.2. Climate peer groups for buses

FIGURE 1.3. Bus climate vectors grouped by state. Euclidean distance from the center measures climatic deviation from the sample mean; rotational distance from the horizontal measures shift in longitude

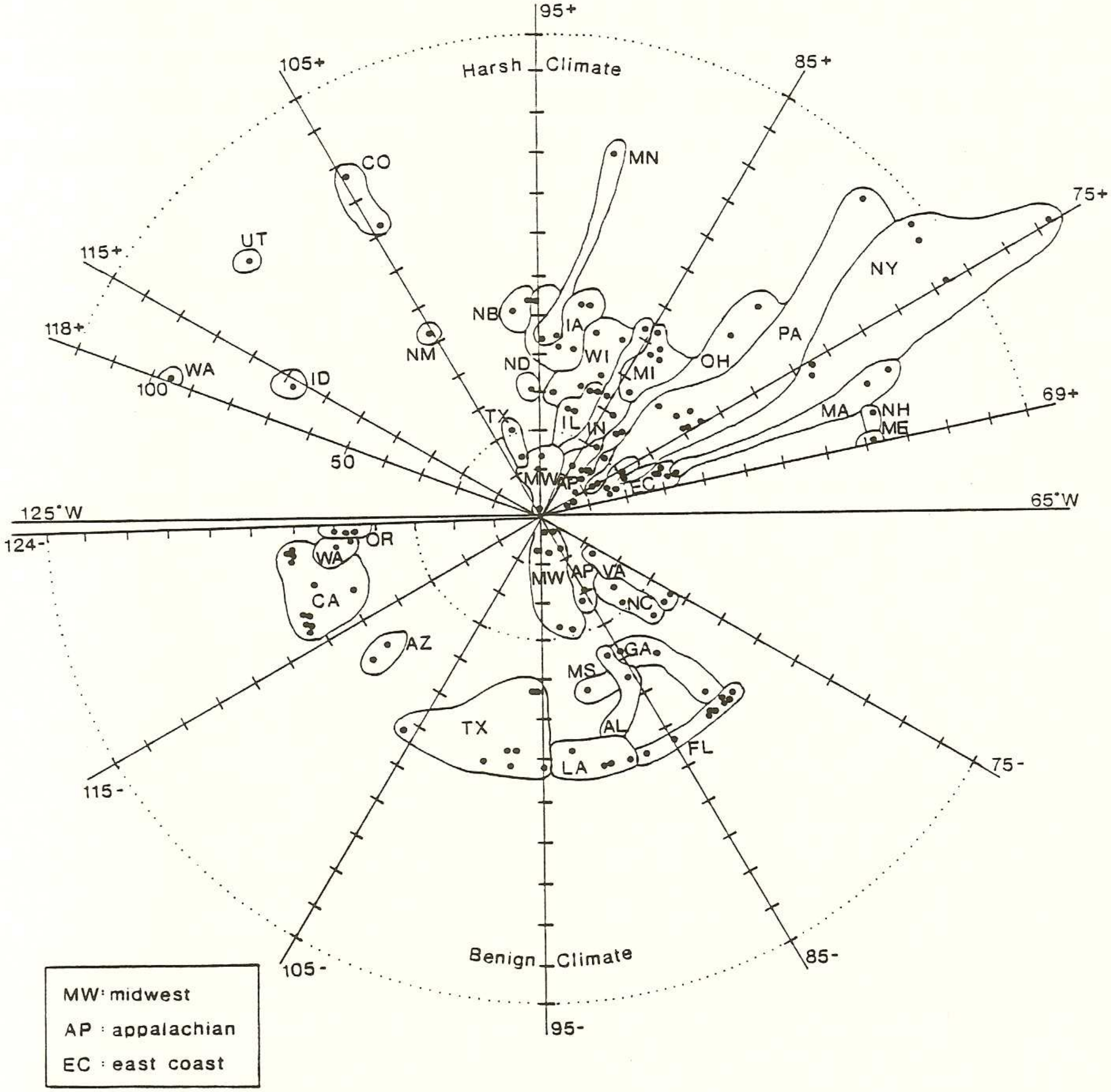


TABLE 1.2. CLIMATE VECTOR NORMS OF CITIES ARRANGED BY CLIMATE PEER GROUP;
"+" AND "-" INDICATE "ABOVE" OR "BELOW" AVERAGE NORM.

HARSH	NORM	LONGITUDE (deg. min.)	INTERMEDIATE	NORM	LONGITUDE (deg. min.)	BENIGN	NORM	LONGITUDE (deg. min.)
Portland	82.4	70 16	Philadelphia	15.7+	75 13	Norfolk	37.4	76 15
Haverhill	33.6	71 05	Wilmington	9.9+	75 33	Hampton	37.4	76 21
Boston	33.6	71 07	Lancaster	15.7+	76 20	Raleigh	37.4	78 39
Lowell	33.6	71 18	Washington DC	9.9+	77 00	Fayetteville	37.4	78 54
Manchester	85.3	71 30	Lynchburg	13.7+	79 08	West Palm Beach	63.7	80 04
Worcester	85.1	71 49	Columbus	15.7+	83 00	Fort Lauderdale	63.7	80 09
Springfield MA	91.9	72 35	Knoxville	3.3-	83 55	Miami FL	63.7	80 11
Hartford	31.0	72 40	Chattanooga	1.9-	85 15	South Daytona	63.7	81 02
New Haven	31.0	72 55	Kansas City	14.5+	94 35	Savannah	60.0	81 07
White Plains	22.0	73 47	Topeka	12.7+	95 41	Orlando	63.7	81 22
Albany	74.6	73 50	Tulsa	0.3-	95 58	Jacksonville	63.7	81 40
Yonkers	22.0	73 54	Wichita	7.1-	97 21	Augusta	46.0	82 00
Newark	22.0	74 10	Oklahoma City	3.3+	97 32	Gainesville	63.7	82 20
Utica	74.7	75 10	Amarillo	23.0+	101 49	Tampa	63.7	82 25
Allentown	42.9	75 30	Lubbock	16.7+	101 50	Bradenton	63.7	82 35
Scranton	60.0	75 45	St. Petersburg	63.7	82 45	Albuquerque	50.3+	106 40
Kingston	42.9	75 50	Richmond	15.5	77 30	Clearwater	63.7	82 45
Binghamton	113.8	75 55	Winston-Salem	26.3	80 15	Tallahassee	63.7	84 17
Syracuse	149.9	76 10	Charlotte	29.6	80 50	Columbus GA	39.5	84 56
Harrisburg	45.0	76 50	Dayton	4.8	84 15	Montgomery	46.0	86 17
Rochester	114.1	77 35	Atlanta	21.8	84 23	Pensacola	63.7	87 13
Altoona	45.0	78 25	Cincinnati	8.3	84 30	Mobile	63.7	88 03
Johnstown	42.0	78 50	Newport	8.3	84 30	Harahan	63.7	90 00
Buffalo	116.5	78 51	Lexington	6.3	84 30	Gretna	63.7	90 00
Pittsburgh	41.9	80 01	Nashville	24.2	86 48	New Orleans	63.7	90 05
Erie	111.9	80 05	Birmingham	38.0	86 49	Jackson MS	45.3	90 10
Youngstown	64.3	80 40	Memphis	29.6	90 03	Baton Rouge	63.7	91 10
Kent	28.1	81 20	St. Louis	8.3	90 15	Shreveport	60.0	93 46
Canton	28.1	81 25	Little Rock	28.7	92 16	Houston	63.7	95 21
Akron	28.1	81 30	New Bedford	17.0	70 55	Dallas	43.0	96 48
Cleveland	75.3	81 42	Brockton	17.0	71 01	San Antonio	59.9	97 08
Detroit	49.6	83 10	Providence	17.0	71 23	Fort Worth	42.3	97 20
Toledo	31.0	83 35	Flushing	8.3	73 50	Corpus Christi	63.7	97 24
Saginaw	38.2	83 40	Jamaica	8.3	73 50	Austin	59.3	97 42
Ann Arbor	49.6	83 45	Jackson Heights	8.3	73 50	Laredo	63.7	99 29
Flint	51.6	83 45	New York	6.3	73 58	El Paso	63.7	106 27
Bay City	38.2	83 55	East Meadow	6.3	73 58	Tucson	56.9	111 00
Jackson MI	55.6	84 25	Brooklyn	6.3	73 58	Phoenix	50.7	112 00
Fort Wayne	22.7	85 10	West Coxsackie	6.3	73 58	San Diego	63.7	117 10
Kalamazoo	43.5	85 40	Louisville	17.0	85 45	San Bernardino	63.7	117 19
South Bend	53.4	86 20	Indianapolis	6.0	86 08	Riverside	63.7	117 21
Gary	33.7	87 21	Urbana	1.0	88 15	Oceanside	63.7	117 22
Chicago	33.7	87 37	Decatur	2.0	88 59	Garden Grove	63.7	117 56
Racine	48.8	87 49	Peoria	1.0	89 35	Norwalk	63.7	118 05
Kenosha	48.8	87 50	Springfield IL	2.0	89 37	Montebello	63.7	118 06
Waukegan	33.7	87 51	Bridgeport	16.5+	73 12	Long Beach	63.7	118 12
Des Plaines	33.7	87 54	Stamford	16.5+	73 32	Los Angeles	63.7	118 15
Milwaukee	48.8	87 55	Asheville	15.9+	82 35	Santa Monica	63.7	118 19
Joliet	33.7	88 05	Charleston	12.8+	81 35	Gardena	63.7	118 19
Elgin	28.4	88 16	Huntington	12.8+	81 35	Torrance	63.7	118 20
Aurora	28.4	88 18	Baltimore	15.9+	76 38	Bakersfield	59.9	119 00
Appleton	32.0	88 27	Roanoke	20.3	79 55	Ventura	63.7	119 18
Oshkosh	32.0	88 35	Boise	67.7+	116 12	Santa Barbara	63.7	119 43
Rockford	28.4	89 07				Fresno	59.9	119 47
Madison	48.3	89 23				Stockton	63.7	121 16
Rock Island	28.0	90 37				Sacramento	50.7	121 30
Davenport	28.0	90 38				Monterey	63.7	121 53
Dubuque	54.1	90 43				San Jose	63.7	121 54
La Crosse	33.6	91 14				Santa Cruz	63.7	122 02
Cedar Rapids	54.1	91 43				Oakland	63.7	122 16
Duluth	91.7	92 07				Seattle	51.1	122 20
Waterloo	41.9	92 22				San Mateo	63.7	122 20
St. Paul	43.5	93 05				San Francisco	63.7	122 21
Des Moines	44.8	93 37				Tacoma	47.0	122 27
St. Cloud	43.5	94 08				Salem	53.4	123 03
Sioux City	53.7	96 25				Eugene	51.1	123 06
Lincoln	54.2	96 43				Portland	50.7	123 41
Fargo	31.9	96 48						
Omaha	52.3	97 57						
Colorado Sprngs	83.6	104 48						
Denver	97.4	104 59						
Salt Lake City	96.2	111 52						
Spokane	95.0	117 25						

TABLE 1.3. VECTOR RANK-ORDERING OF TRANSIT AUTHORITIES WITHIN CLIMATE PEER GROUPS. Transit authorities are listed by semi-circular bands from Figure 1.3 and ordered from east to west within a semi-circular band.

NORM	CITIES
100 +	Binghamton, Syracuse, Rochester, Buffalo, Erie.
90-99.9	Springfield MA, Duluth, Denver, Salt Lake City, Spokane.
80-89.9	Portland ME, Manchester, Worcester, Colorado Springs.
70-79.9	Albany, Utica, Cleveland.
60-69.9	Scranton, Youngstown, Boise.
50-59.9	Flint, Jackson MI, Kalamazoo, Dubuque, Waterloo, Sioux City, Lincoln, Omaha, Albuquerque
40-49.9	Allentown, Kingston, Altoona, Johnstown, Pittsburgh, Detroit, Ann Arbor, Milwaukee, Madison, St. Paul, Des Moines, St. Cloud.
30-39.9	Boston, Hartford, New Haven, Toledo, Chicago, Appleton, La Crosse, Fargo.
20-29.9	White Plains, Yonkers, Roanoke, Kent, Canton, Akron, Fort Wayne, Rock Island, Davenport, Amarillo.
10-19.9	New Bedford, Brockton, Providence, Bridgeport, Stamford, Philadelphia, Lancaster, Baltimore, Lynchburg, Asheville, Charleston, Huntington, Columbus, Louisville, Topeka, Kansas City, Lubbock.
0-9.9	New York City and suburbs, Wilmington, Washington D.C., Oklahoma City.
(-10)-(-0.1)	Knoxville, Cincinnati, Newport, Lexington, Dayton, Chattanooga, Indianapolis, Urbana, Decatur, Peoria, Springfield IL, St. Louis, Tulsa, Wichita.
(-20)-(-10.1)	Richmond.
(-30)-(-20.1)	Winston-Salem, Charlotte, Atlanta, Nashville, Memphis, Little Rock.
(-40)-(-30.1)	Norfolk, Hampton, Raleigh, Fayetteville, Birmingham, Columbus GA.
(-50)-(-40.1)	Augusta, Mongomery, Jackson MS, Dallas, Fort Worth, Tacoma.
(-60)-(-50.1)	Savannah, Shreveport, San Antonio, Austin, Tucson, Phoenix, Bakersfield, Fresno, Sacramento, Seattle, Salem, Eugene, Portland OR.
below (-60)	All of Florida, New Orleans, Baton Rouge, Houston, Corpus Christi, Laredo, El Paso, Los Angeles and suburbs, San Francisco and suburbs.

of values over which individual components may range. A variety of strategies is available for this purpose, and each could lead to the means for determining climate peer groups based on the climate vectors associated with individual transit authorities.

Suppose that the ordered triples are referenced to three mutually orthogonal axes. The x–axis measures the number of inches of snow, and values along it range from -23 inches below to 86 inches above the national mean; the y–axis measures the number of events, and values on it range from -7 events below to 25 events above the national mean, and the z–axis measures the Visher index, and values on it range from -50 alternations below to 80 alternations above the national mean. The origin $(0, 0, 0)$ represents the national mean. To standardize the units, any arbitrary scale, including those already on the axes, might have been used. Because the Visher scale has the finest mesh of the three scales already present, we chose, for ease in matching units, to convert each of the scales on the x and y axes to the 130–part Visher scale of the z–axis. Thus, the unit vector on the x–axis becomes $(1.1926606, 0, 0)$ because $x/130 = 1/109$; the unit vector on the y–axis stretches to $(0, 4.0625, 0)$ because $y/130 = 1/32$; and the unit vector on the z–axis remains fixed. Then, a climate vector may be associated with each transit authority by multiplying the number of inches of snow for that authority by 1.1926606, and the number of events by 4.0625. Table 1.2 gives the lengths (norms) of the climate vectors measured from $(0, 0, 0)$ for each transit authority for which both climatic and Section 15 data were available.

Figure 1.3 employs an azimuthal equidistant projection centered at the national mean of $(0, 0, 0)$ to show, using climate vectors, how much each transit authority lies above or below the average vector of $(0, 0, 0)$. On this projection, distances measured from the center are true. The horizontal line, as a base line in Figure 1.3, represents a meridian of 65 degrees west longitude to the right of the map center and a meridian of 125 degrees west longitude to the left of the map center. These choices of longitude correspond roughly to the east–west longitudinal extremes in the United States. The meridians that interrupt the projection, at 69 degrees and 118 degrees in the above average zone, and at 75 degrees and 124 degrees in the below average zone, show more precise positions for the transit authorities that are farthest east and west in each of the above and below average zones (i.e., Portland, Maine, and Spokane, Washington, in the above average zone, and Norfolk, Virginia, and Portland, Oregon, in the below average zone). A set of five evenly–spaced lines concurrent with the base line at $(0, 0, 0)$ partitions the map into wedges. These radials are assigned values of 75, 85, 95, 105, and 115 to represent longitude, and are followed by a "+" symbol when they lie above the origin and by a "–" symbol when they lie below it. The evenly–spaced set of concentric circles, that might generally suggest latitude on a projection of this sort, represents instead the length of the climate vector—the interval measuring the spacing is 10 units of climate vector length. Climate vectors all have positive length measured from the map center. Vector heads associated with triples containing only positive or zero entries were placed at an appropriate distance in the above average zone, and those with only negative or zero entries were located in the below average zone. The distance $||v||$ of a vector $v = (p, q, r)$ from the origin $(0, 0, 0)$ is computed as $||v|| = (p^2 + q^2 + r^2)^{1/2}$ [4]. However, vectors with both positive and negative entries could be misplaced using this norm. For example, a high positive Visher value coupled with negative indices far below zero on "frequency of storm" and "total snowfall amount" would represent a city with a norm larger than seems reasonable.

The degree of exaggeration depends directly on the size of the spread between positive and negative values; frequent freezing and thawing may be irrelevant if there is no snow, and will be if there is no rain. To overcome this, we computed the distance from the origin $||w||$ of a vector $w = (-s, -t, u)$, $s, t, u > 0$ as $||w|| = \left|(s^2 + t^2)^{1/2} - (u^2)^{1/2}\right|$; this procedure reduced the distortion in the norm of "mixed" vectors by preserving the difference in sign between entries of opposite sign. Corresponding calculations were used for $w = (-s, t, -u)$, $w = (s, t, -u)$, and for all of the other possibilities. The vector head of a mixed vector was placed in the above average zone of Figure 1.3 if the difference inside the absolute value sign was positive, and in the below average zone if that difference was negative. Entries in Table 1.2 that are followed by arrows suggesting "above" or "below" in the column displaying climate vector length, represent positions for "mixed" vectors that are not classified in the natural manner.

Thus, Figure 1.3 shows the entries in Table 1.2 positioned by longitude and by climate vector norm. Grouping these vector heads by state produces a political subdivision of the United States based on climate and longitude. In this map, distortion of the state boundaries away from the standard subdivision, based on latitude and longitude, is due entirely to climatic effects. For example, Washington is fragmented into two parts: coastal Washington, with a mild climate, lying between 115− and 125 degrees west in the below average zone, and mountainous Washington, with a harsh climate, lying between 115+ and 125 degrees west in the above average zone. In a similar manner, cities in Ohio south of Columbus lie below the center between 75− and 85−, and lie in the region labeled MW in Figure 1.3, while those in northern Ohio fall above the center between 75+ and 85+. The elongation away from the map center between 75+ and 85+ represents the presence of lake effect snow in Cleveland and Youngstown. Indiana is fragmented in the same way as Ohio, with Indianapolis, Muncie, and others south of the map center, Fort Wayne above the map center, and elongation away from the center out to South Bend. Further, southern Pennsylvania cities near the coast (e.g., Philadelphia and Lancaster) have vector heads lying just above the map center although those in mountainous Pennsylvania lie away from it. Again, this boundary stretches out from the center to pick up lake effect snows in Erie. Finally, New York exhibits the most extreme form of this sort of climatic distortion; a coastal section above, but close to, the map center includes New York City and suburbs, and an upstate section, that contains a number of lake effect cities, exhibits climatic indices for buses that are in the harshest climates in the nation.

What this suggests, or course, is that a transit manager in a given city should not necessarily look to another in his own state for a climatic peer; Erie is better advised to examine the climatic problems of Buffalo or Rochester than those of Philadelphia. Thus, the semicircular bands in the above and the below average zones of Figure 1.3 suggest rank ordering for transit authorities within climate peer groups (Table 1.3). Extremes in the longitudinal spacing within such bands show nearest and remotest peer, and it is on account of this that entries in Tables 1.2 and 1.3 are ordered by longitude.

Based on this more technically precise vector approach, Figure 1.3 and Tables 1.2 and 1.3 were used to generate vector boundaries separating harsh, intermediate, and benign climate peer groups. To find these boundaries, note that in Figure 1.3, cities that are close to the center (whether above or below the center) have a climate vector length close to the national mean. Consequently, the transit authorities associated with these vectors lie in an intermediate climate. One place to separate the intermediate positions from the harsh positions in the above average zone, that appeared to be reasonable in terms of the climatic data, was along the semicircle 20 units from the center. In the below average zone, the semicircle 30 units below the center appeared to be a natural choice. When these vector boundaries were superimposed on the map in Figure 1.2, they were coincident with the simple boundaries, determined in the first part of this Chapter, in all but five locations.

In particular, Boise, Roanoke, Albuquerque, and Amarillo belonged in the intermediate climate peer group according to the simple partition, but shifted to the harsh climate peer group in the vector partition. At the other extreme, Birmingham was classified as intermediate initially but as benign in the vector approach (Figure 1.2). The content of the climate vectors suggests reasons for these transit authorities to be climatic "boundary dwellers" [5]. In all cases, the Visher index had by far the greatest numerical value, often because of the presence of mountains, suggesting that in a rainstorm or snowstorm, the frequent freezing and thawing might cause difficulties for buses. Thus, in mild winters, these cities might be classified in the more benign of the two peer groups because there would be little need for salt (although in severe winters, the more frequent use of salt would push them into the harsher of the two peer groups). Cities in this position certainly appear to have the potential for a significant problem that may arise only every few years. The indices associated with

Birmingham show it to have the slightest such potential and those linked to Boise indicate that it has the greatest. Other than these boundary dwellers, the harsh, intermediate, and benign climate peer groups that were formed using the simple procedure correspond identically to those generated by the vector approach. Thus, the vector approach serves not only to pinpoint nearest climate peers but also to verify the more broadly based scheme displayed in Figure 1.2, within which the next consideration is of other factors such as age profiles and performance.

AGE STRUCTURE BY CLIMATE PEER GROUP OF THE U.S. BUS POPULATION

The application of these climate peer groups to the Section 15 indicator, "Age Distribution of Revenue Vehicle Inventory," produces evidence to support the hypothesis that harsh climates speed bus deterioration. The "Stratification Charts by Climate Peer Group" of Figure 1.4 show the expected, versus the actual, annual and aggregate age stratification of the bus population by climate peer group. For example, in 1978–1979, 35.8 percent of 0- to 5-year-old buses, 35.8 percent of 6- to 10-year-old buses, 35.8 percent of 11- to 15-year-old buses, and so forth, would lie in the harsh class in 1978–1979. The position of the horizontal line in Figure 1.4.A represents this expected value. In fact, however, this harsh class contained 38.7 percent of 0–5 year olds, 34.7 percent of 6–10 year olds, 36.8 percent of the 11–15 year olds, 29.8 percent of the 16–20 year olds, 23.0 percent of the 21–25 year olds, and 21.3 percent of the 25+ group (Figure 1.4.A.i). The remaining frames in Figure 1.4 display similar breakdowns of data on bus age across climate peer groups; frames ii, iii, and iv (Figure 1.4) show age stratification in the harsh class for the remaining three years while frame 1.4.A.v displays the aggregate of frames i–iv. Figure 1.4.B shows five frames depicting, in chronological sequence, the annual and aggregate age stratification of the bus population in the intermediate climate peer groups and Figure 1.4.C represents the same sequence for the benign climate peer group.

Of particular note is the distribution of the oldest buses across these peer groups. The harsh group has 23.8 percent of the oldest buses, rather than the expected 34.8 percent (Figure 1.4.A.v); the intermediate group has 12.4 percent rather than the expected 38.1 percent (Figure 1.4.B.v); and the benign group has 63.8 percent rather than the expected 28.9 percent (Figure 1.4.C.v). The fact that the intermediate peer group has a smaller percentage of old buses than does even the harsh peer group, might suggest the (a) lack of expenditure in maintaining intermediate- climate buses, or (b) small size of many transit authorities in this peer group 20 to 30 years ago. The benign climates have far more than their share of old buses; we suspect that the graphic distinctions already evident in Figure 1.3 might become even more apparent if buses could be identified and eliminated subject to

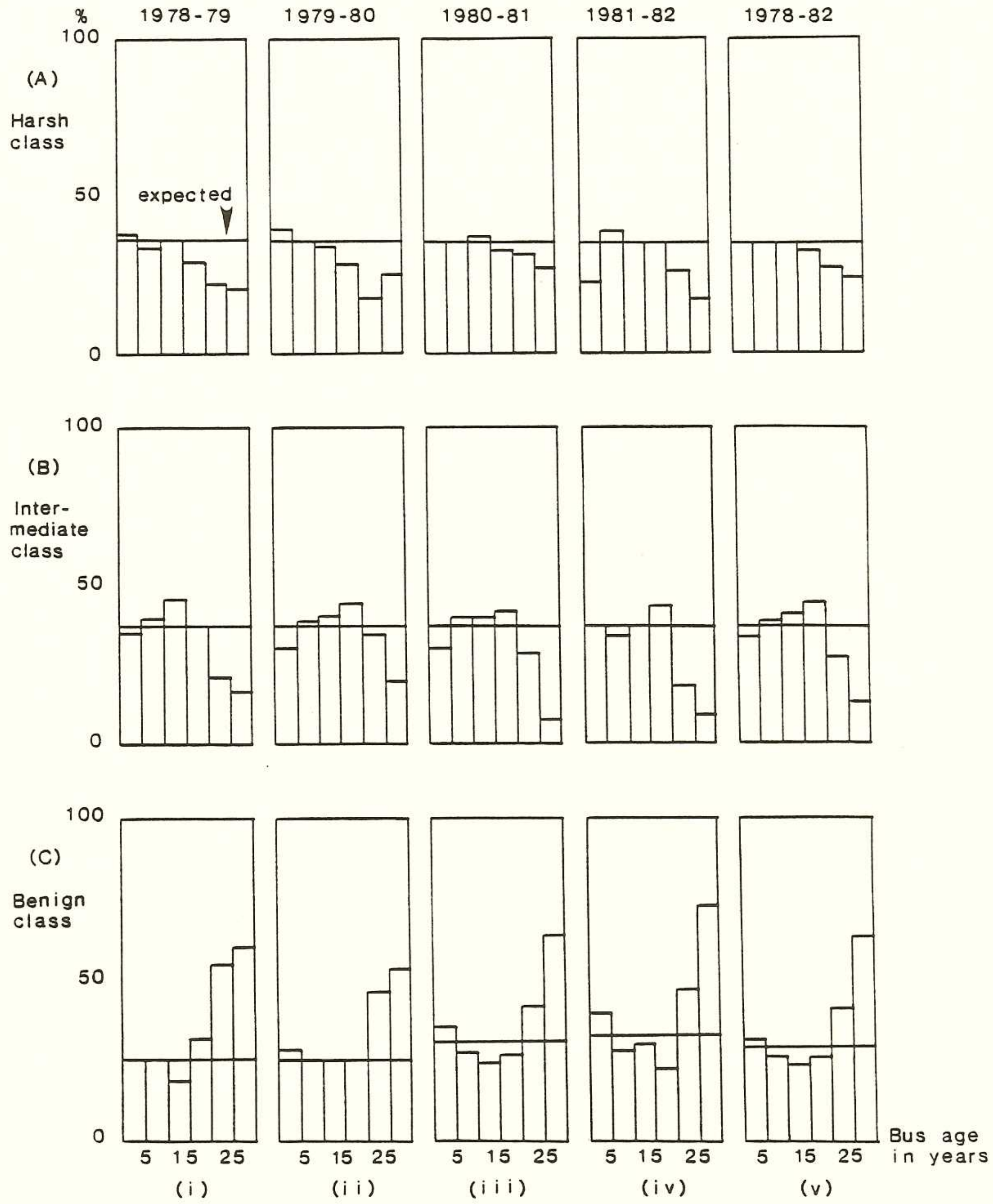


FIGURE 1.4. Time–series and aggregate stratification charts by climate peer group. The intermediate climate class has a relatively small percentage of very old buses, while the benign climate class has a relatively large percentage of very old buses.

airborne salt in warm, humid climates. Figure 1.4.C also shows bus fleets growing through time in sun–belt cities through the rise in the left–hand (0–5) column across the series of Figures. As these recently enlarged fleets age, it will be significant, in evaluating climatic effects on bus durability, to see if the trend continues toward high percentages of old buses in benign climates.

MAINTENANCE INDICATORS IN CLIMATE PEER GROUPS

Figure 1.4 serves to show differences in age profiles between climate peer groups; reasons for these differences might be related to climate, but might be related to other factors as well, such as tightness of maintenance budget. In establishing climate peer groups, size of transit authority was deemed unimportant; general climatic patterns are not a function of number of buses, and climate, unlike maintenance budgets, varies continuously across the map. Thus with maintenance data, economies of scale and increased labor costs in large cities forced partitioning of maintenance indicators by size within each climate peer group. We looked at the maintenance indicators, "vehicle miles per road call" and "total vehicle miles per dollar spent on maintenance." The former indicator appeared less reliable than the latter, on an annual basis, because any single transit authority might have a cluster of road calls toward the end of one year followed by few in the next year. Many entries were missing, especially in the first year, but were filled in, where possible, for "distance between road calls," using data from "total vehicle miles" divided by "total road calls," and for "miles per maintenance dollar" by dividing "total vehicle miles" by the product of "total operating expenses" and "percent of operating budget spent on maintenance." Two outliers were removed, and only entries reporting data in all categories for more than two years were included. The total sample for these indicators ranged in size from 138 to 178 authorities.

Table 1.4 gives distances between road calls over the entire 4–year span for the national bus population and for the bus population in the three climate peer groups. The breakdown into size peer group uses boundaries that appear, from hand–sorting of the data, to record positions of sharp change in indicator values and to separate data along boundaries already present in the tabular data. Table 1.5 gives miles per maintenance dollar on an annual basis for the bus population by size peer group within each climate peer group. All three climate peer groups show declining mileage per maintenance dollar from 1978–1979 to 1981–1982 (Table 1.5), suggesting that inflation has eaten into the mileage figures as a result of higher labor and parts costs.

Various interpretations of the patterns in the data in Tables 1.4 and 1.5 are available. This is a first effort to analyze the relationship between maintenance and climate; thus, a significant function of these data is to suggest directions in which this climatic partition

TABLE 1.4. DISTANCE BETWEEN ROADCALLS BY SIZE AND CLIMATE PEER GROUPS

NUMBER OF BUSES PER	YEAR OF SECTION 15 REPORT					NUMBER OF ENTRIES			
TRANSIT AUTHORITY	1981-82	1980-81	1979-80	1978-79	1978-82	1982	1981	1980	1979
HARSH	2665.2	2487.1	2547.7	2993.0	2652.1	64	64	62	50
Large--500+	2789.4	2688.1	2829.9	2991.9	2818.2	9	9	9	9
Mid-sized--100-499	2066.2	1876.6	1896.6	3439.9	2119.9	15	15	13	13
Small--25-99	3008.9	2548.7	2233.4	2558.1	2559.9	40	40	40	28
INTERMEDIATE	1104.3	929.5	953.1	1872.6	1118.2	52	52	51	48
Large--500+	981.6	756.9	796.9	2059.3	979.2	7	6	6	6
Mid-sized--100-499	1398.2	1423.9	1418.3	1427.7	1417.2	21	22	19	19
Small--25-99	1824.9	2208.6	2229.6	2427.8	2153.8	24	24	26	23
BENIGN	1596.8	1445.8	1551.1	2072.4	1621.7	62	62	57	49
Large--500+	1396.4	1250.2	1259.6	2525.1	1464.1	12	12	8	6
Mid-sized--100-499	2305.2	2006.7	2374.3	1245.6	1902.6	14	14	16	18
Small--25-99	2488.9	2514.5	2269.0	2567.9	2448.5	36	36	33	25
NATIONAL	1618.1	1403.0	1457.3	2230.0	1611.9	178	178	170	147
Large--500+	1503.5	1250.9	1293.8	2490.2	1509.2	28	27	23	21
Mid-sized--100-499	1791.6	1685.2	1822.6	1564.6	1716.6	50	51	48	50
Small--25-99	2446.2	2443.9	2245.6	2521.2	2404.6	100	100	99	76

TABLE 1.5. VEHICLE MILES PER MAINTENANCE DOLLAR BY SIZE AND CLIMATE PEER GROUPS. Entries marked with an asterisk include data from New York City; without it, they become: 1.41, 1.65, 1.84, 2.21.

NUMBER OF BUSES PER	YEAR OF SECTION 15 REPORT					NUMBER OF ENTRIES			
TRANSIT AUTHORITY	1981-82	1980-81	1979-80	1978-79	1978-82	1982	1981	1980	1979
HARSH	1.57	1.71	1.92	2.61	1.84	63	64	58	49
Large--500+	1.44	1.55	1.74	2.45	1.69	9	9	9	8
Mid-sized--100-499	2.00	2.25	2.72	3.36	2.41	15	15	13	11
Small--25-99	2.21	2.36	2.62	3.22	2.52	39	40	36	30
INTERMEDIATE	1.17	1.32	1.50	1.64	1.39	48	48	46	44
Large--500+	1.01*	1.11*	1.28*	1.41*	1.18	7	6	6	6
Mid-sized--100-499	1.70	2.00	2.18	1.40	2.03	19	20	17	17
Small--25-99	2.55	2.73	3.35	3.66	3.00	22	22	23	21
BENIGN	1.65	1.81	2.29	2.80	1.99	61	62	55	45
Large--500+	1.46	1.56	2.05	2.59	1.73	12	12	8	4
Mid-sized--100-499	2.09	2.58	2.44	2.90	2.50	14	14	16	17
Small--25-99	2.90	3.08	3.99	3.98	3.33	35	36	31	24
NATIONAL	1.34	1.59	1.85	2.19	1.71	172	174	159	138
Large--500+	1.29	1.39	1.62	1.94	1.50	28	27	23	18
Mid-sized--100-499	1.91	2.21	2.41	2.76	2.28	48	49	46	45
Small--25-99	2.53	2.70	3.26	3.55	2.91	96	98	90	75

might aid in controlling for other factors. For example, in both tables, the climate groupings suggest that the poorest performance rests in the intermediate climate class. Is this borne out by actual maintenance practices, by tightness of maintenance budget in these regions, or by the general economic environment in most transit authorities in the intermediate climate peer group? Further, both tables indicate that despite general climatic adversity, the large cities in the harsh climate peer group of transit authorities do relatively well on these indicators. Perhaps these transit authorities are more sensitive to maintenance, and to transit problems in general, than are a number of their counterparts in the more automobile–oriented cities in the benign climate group. Finally, Table 1.5 gives an improvement in vehicle miles per maintenance dollar as one moves from the small transit authorities in the north to those in the south. This effect might be due in part to climate, or it might be a function of how the indicator itself was constructed (e.g., low wage rates in small southern fleets might make aggregate vehicle miles per maintenance dollar appear higher if they constitute a relatively small percentage of the total benign maintenance budget). Thus, Tables 1.4 and 1.5 provide yet another means of identifying different subclasses within the Section 15 data.

CONCLUSION

The primary contribution of this Chapter is to classify transit authorities according to climate. The typology has two layers. First, it sorts transit authorities into the three general categories of harsh, intermediate, and benign climates. Second, it pinpoints the nearest climatic peers of transit authorities within each of the broader categories.

In addition, an indication was given as to how these climate peer groups might be used to increase understanding of other factors, such as age profiles and performance. Beyond these, the broad categories might be employed in, for example, a regression analysis context involving several factors related to vehicle performance, while the nearest neighbor map (Figure 1.3) might be used to run corresponding studies on more narrowly defined climate subgroupings. Ultimately, however, the utility of these peer groups will likely be judged in conjunction with other factors, as they do, or do not, permit distinctions to be made among variables that are significant in the implementation of transit policy.

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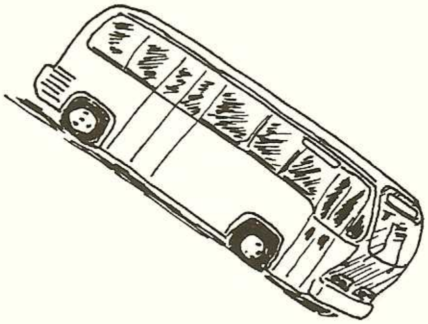
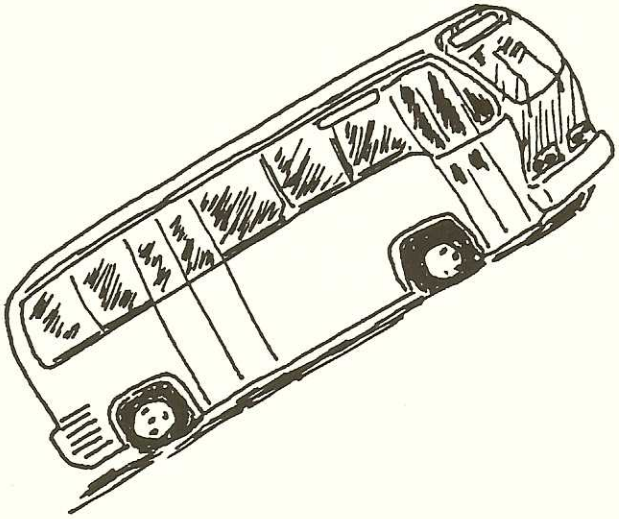




CHAPTER 2: TERRAIN EFFECTS

INTRODUCTION

An arbitrary abstract bus–route network, superimposed on the undulating surface of a city, would logically follow lines of lowest topographic gradient when minimal terrain–imposed stress on equipment was a factor. The resultant routing strategy would fail to provide effective service to the population, because bus–route networks should also follow service gradients. The key issue centers on how to thread routes through an urban area so that they touch a set of high–demand locations like places of employment and then connect with areally spread residential zones. Another way to pose the question is how can the linear form of a bus route get as close as possible to an area, or how can a one–dimensional linear form be routed along a winding path to fill a portion of a two–dimensional market area?

We begin to answer this question by displaying a general procedure to classify city terrain at the $1:250,000$ scale. Steep grades in bus routes create strain on the motor and power train of a bus, and frequent alternation between uphill and downhill operations on the bus creates further stress on its internal system. Terrain "peer" groups for buses, formed from a set of transit authorities participating in the Section 15 reporting system of the Urban Mass Transportation Administration (UMTA), assist in understanding the impact terrain might have on bus maintenance performance. The application of a simple terrain template permits either transit managers or the UMTA to place an arbitrary transit authority into a flat, intermediate, or steep terrain peer group. A set of 181 transit authorities was classified according to terrain type, and graphic displays were used to supplement the tabular display format of the classification.

To illustrate one way to employ the taxonomy, Section 15 indicators were used to consider the effect terrain might have on bus maintenance performance. Miles–per–gallon indicators were stratified into subclasses according to terrain and maintenance quality type. With other independent variables, such as climate [1] and congestion, introduced into the analysis, a more comprehensive view of bus maintenance performance as a function of environmental, as well as of routing and economic, considerations will follow.

Although this terrain peer group classification is useful to make broad terrain comparisons among cities, it does not permit identification of variations in elevation that result from residential–service needs to be made at the city level. Therefore this Chapter proceeds with a comprehensive analysis of the terrain in Ann Arbor at a scale of $1:24,000$, based on vertical profiles of local bus routes. Bus–route vertical profiles were viewed as wiggly lines, attempting to fill some sector of the market area. To understand how these routes might fill space, we developed a procedure to measure the displacement of a bus–route vertical profile from a topographic baselevel. This base was established as a slope between adjacent "critical" points, such as river crossings, on the profile. This discrete set of critical points forced changes in elevation of the route the bus travels from origin to terminus, thereby partitioning the route into continuous intervals over which route–elevation displacement from a baselevel is measured. Routes along paths that maintain baselevel are analogous to an arbitrary net dropped on a city. Displacement of all others from this net, as a minimal routing response, is a function of the need to serve distinct points with high demands for service as well as areally spread residential markets with different demands for service.

The broad contribution of this research is to introduce methodology to classify sets of transit authorities according to terrain type. As the scale of an arbitrary research study ranges from local to global, modifications suited to scale demands might be superimposed on this basic methodology to reflect the needs of the project at hand. To illustrate how to do this, we examined the network of Ann Arbor bus routes and suggested the implications that such a geography of terrain based on bus routes might have for transit managers. At the nationwide as well as at the citywide scale, the goal was to present ideas in their broadest form to suggest the range of uses for these procedures to a variety of researchers.

TERRAIN CLASSIFICATION

The mechanics of classifying terrain involves constructing a template to be used to standardize differences in elevation on U.S. Geological Survey topographic maps as applied, in this case, to the map series of scale $1 : 250,000$. The construction consists of two parts: first, the approximation of the boundary of each transit authority, and second, the determination within this boundary of the terrain as predominantly steep, intermediate, or flat.

To achieve the former goal, allometry with standard techniques [2, 3] was used to represent the city as a circle centered in most cases on city hall, with radius proportional to total population. Because each city was then represented with a circular boundary, visual comparisons of topographic evidence within the set of cities under study were facilitated. To create these circular cities, census data pertaining to the city itself, rather than to a larger metropolitan region or urbanized area, were used because bus routes run predominantly across terrain interior to the city. Total population figures rather than population density data were used because density figures, that do reflect directly the likely extent of wear and tear on buses, do not reflect variation at the city scale in terrain. As a pure terrain measure is sought, allometry appears well suited to the task; there is no additional input from phenomena unrelated to terrain such as density to confound the terrain data.

To determine terrain type within the circular boundaries, sets of evenly spaced lines were used to sample the unevenly spaced contour lines within the allometric circle and to classify the underlying terrain as steep, intermediate, or flat. The details of these procedures are described next.

To construct a set of circles representing cities of various sizes, the law of allometric growth was used to determine circle radius corresponding to city population as given in the 1980 census. Biologists use allometry to predict the size of an entire individual within a given species from the size of one of its parts; pediatricians apply this idea to predict adult heights of children [2]. Nordbeck and Tobler [3] used allometry to represent city size as a circle proportional to the size of the built–up area and to population inhabiting the built–up area. It was found from empirical studies that the area of a U.S. city can be estimated by $A = 0.00151P^{0.8757}$, where A is area in square miles and P is total city population [2, 3]. Using $A = \pi R^2$ with R the radius of a circle of area A associates a radius R with each city given its population as $R = 0.0219237P^{0.43785}$ [3]. Calculations were then made to determine population sizes that corresponded to radii of $0.5, 1.0, 1.5, 2.0, 2.5, \ldots, 23.0$ miles. Population intervals were centered on integral mile values for radii R, and these radii were converted to the scale of a $1 : 250,000$ map. Table 2.1 presents these values of radii, that include all cities in the study. A set of circles of radii $0.25, 0.51, 0.76, 1.01, \ldots, 5.58$ inches were drawn on transparent plastic; when superimposed on a topographic map of scale $1 : 250,000$ and centered on a central point distinguished on the map, the circumference served as the city boundary.

In Table 2.1, transit authorities were rank–ordered from the 1980 census within terrain classes by total city population [4, 5]. The numbers used to partition each terrain class represented the size of the radius of the associated allometric circle in inches at a scale of $1 : 250,000$. Within an allometric subclass, cities were ordered from large to small. No cities fell into the population intervals represented by the allometric radii $5.32, 5.07, 4.82, 4.56, 4.31, 4.06, 3.55$. Consequently, these values were not included in this table.

The mechanics of analyzing the terrain within a circle required sampling the spacing between the line pattern of contour lines. Hammond [6] commented that terrain steeper than about an 8 percent grade causes problems for virtually any sort of vehicle, while Ullman [7] noted that most railroad tracks run across terrain of less than 1.5 percent grade. Thus, a city with a significant percentage of 8 percent grade was characterized as steep, one with terrain of grade largely less than 2 percent as flat, and all others as intermediate; using other percentages would not alter the general procedure. Evenly spaced lines were used to sample the unevenly spaced contour lines within the allometric circle and to classify the underlying terrain as steep, intermediate, or flat.

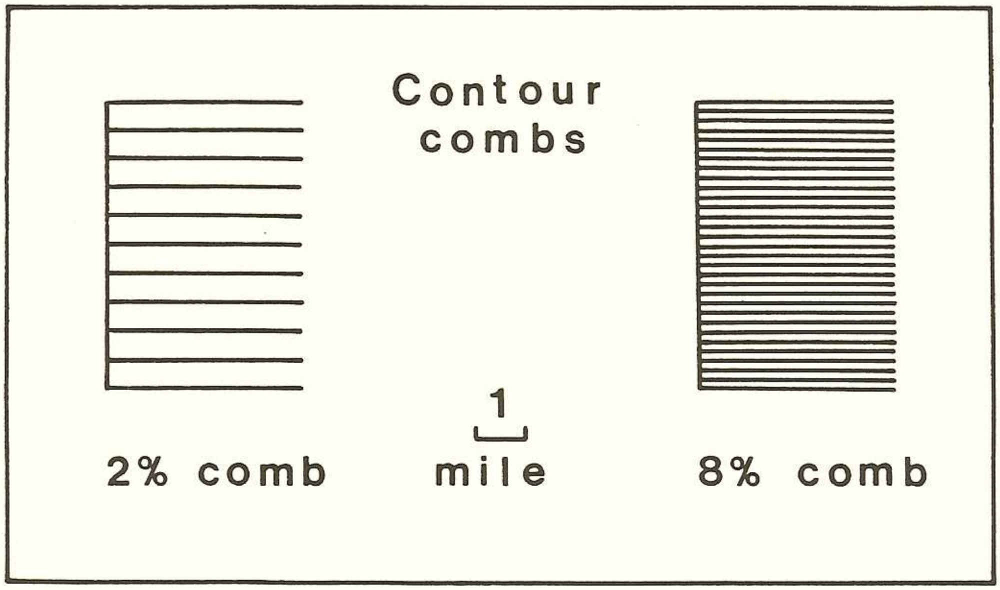


FIGURE 2.1. 2 percent and 8 percent contour combs.

TABLE 2.1. TERRAIN TYPE AND ALLOMETRIC RADII OF 181 TRANSIT AUTHORITIES.
(NUMBERS ARE RANK-ORDERED BY ALLOMETRIC RADIUS AND ARE PROPORTIONAL TO CITY SIZE.)

	STEEP TERRAIN: 20 Transit Authorities.	INTERMEDIATE TERRAIN: 80 Transit Authorities.	FLAT TERRAIN: 81 Transit Authorities.
5.58	No entries	No entries	New York City NY
3.80	Los Angeles CA	No entries	Chicago IL
3.30	No entries	No entries	Brooklyn NY
3.04	No entries	Philadelphia PA	No entries
2.79	No entries	No entries	Houston TX
2.53	No entries	No entries	Detroit MI
2.28	San Diego CA	Dallas, TX	No entries
2.03	San Francisco CA; Washington DC	Baltimore MD; San Antonio TX Memphis TN; Minn./St. Paul MN; Milwaukee WI; San Jose CA	Phoenix AZ; Indianapolis IN
1.77	Boston, MA; Seattle WA; Kansas City MO	Cleveland OH; Denver CO; Nashville TN; St. Louis MO	New Orleans LA; Columbus OH Jacksonville FL
1.52	Pittsburgh PA; Cincinnati OH/ Newport KY; Oakland CA Omaha NB	El Paso TX; Atlanta GA; Fort Worth TX; Portland OR; Austin TX; Charlotte NC	Long Beach CA; Buffalo NY; Toledo OH; Miami FL; Oklahoma City OK; Tulsa OK; Albuquerque, NM; Tucson AZ
1.27	Yonkers, NY	Birmingham AL; Akron OH; Colorado Springs CO; Jackson MS; Mobile AL; Dayton OH	Louisville KY; Wichita KS: Sacramento CA; Tampa FL; Norfolk VA; Rochester NY; Corpus Christi TX; St. Petersburg FL; Baton Rouge LA; Richmond VA; Fresno CA; Shreveport LA; Lexington KY
1.01	Worcester MA	Des Moines IA; Montgomery AL; Knoxville TN; Lincoln NB; Madison WI; Riverside CA; Syracuse NY; Chattanooga TN; Columbus GA; Salt Lake City UT; Flint, MI; Little Rock AK; Springfield MA; Raleigh NC; Rockford IL; Hartford CT; Winston-Salem NC; New Haven CT; Peoria IL; Erie PA; Topeka KS; Youngstown OH; Cedar Rapids IA; Ann Arbor MI	Lubbock TX; Fort Wayne IN; Spokane WA; Tacoma WA; Providence RI; Fort Lauderdale FL; Gary IN; Stockton CA; Amarillo TX; Bridgeport CT; Savannah GA; Torrance CA; Orlando FL; Garden Grove CA; Hampton VA; San Bernardino CA; South Bend IN
0.76	Duluth MN; San Mateo CA; Ventura CA; Charleston WV; Dubuque IA	Eugene OR; Davenport IA; Stamford CT; Boise ID; Albany NY; Roanoke VA; Brockton MA; Canton OH; Lowell MA; Laredo TX; Manchester NH; Salem MA; Scranton PA; Sioux City IA; Tallahassee FL; Kalamazoo MI; Oceanside CA; Waterloo IA; Utica NY; Wilmington DE; Huntington WV; Appleton WI; Lynchburg VA; Fayetteville NC; Altoona PA; Binghamton NY; Asheville NC; Harrisburg PA	Bakersfield CA; Allentown PA; Springfield IL; New Bedford MA; Urbana-Champaign IL; Decatur IL; Clearwater FL; Norwalk CA; Gainesville FL; Kenosha WI; Saginaw MI; Waukegan IL; West Palm Beach FL; Portland ME; Pensacola FL; Lancaster PA; Daytona FL; Des Plaines IL; Montebello CA
0.51	Johnstown PA	Augusta GA; Haverhill MA; Jackson MI; Kent OH	Oshkosh WI; La Crosse WI; Rock Island IL; Gardena CA; St. Cloud MN; Bay City MI; Santa Cruz CA; Bradenton FL; Gretna LA Kingston PA
0.25	No entries	No entries	Harahan LA

Generally, contour lines are wiggly; locally, however, all are topologically equivalent to short straight-line segments. Thus, a sequence of parallel short straight-line segments became a "contour comb" to disentangle contour lines (Figure 2.1). When the segments were spaced to represent 2 percent and 8 percent grades on a $1 : 250,000$ topographical map with a 50-foot contour interval, they were in a form suitable for use with a topographic map of the same scale [6]. A 2 percent slope at a scale of $1 : 250,000$ is represented by a comb with teeth spaced 0.12 inches apart; an 8 percent slope at $1 : 250,000$ is represented by a comb with teeth spaced 0.03 inches apart. (Adjustments may be made easily for 100-foot and 200-foot contour intervals.) Each contour comb is then transferred to a transparency. When either comb is superimposed on both the allometric circle and the topographic map so that the horizontal line perpendicular to the teeth (comb "handle") passes through the center of the circle, the "handle" carries the teeth through a sample of contour lines. Rotating the handle about the center produces a scan of the city using the contour comb. Use of the allometric circle and the contour comb as a template of transparencies applied to USGS maps permitted rapid (under one minute each) determination of the general terrain of most cities as steep, intermediate, or flat. Table 2.1 presents the results of applying the template to a set of 181 transit authorities; in Table 2.1 this set of transit authorities is partitioned into steep, intermediate, and flat terrain classes.

Of course, some cities did not fall clearly into one terrain type or another. These were included in the steeper of the two categories if more than just a single hill or ridge or small group of them was of the steeper type; they were included in the flatter of the two categories if the relatively steep parts appeared from the road pattern or from shading on the map not to lie in regions likely to be served by buses. To make these decisions, it was useful to make supplementary maps by tracing both the drainage pattern and rail pattern onto the allometric circle. Figure 2.2 includes maps of this sort for selected transit authorities that did not fall clearly into a particular terrain type. It also includes maps of terrain in transit authorities typical of each terrain type. The river and rail networks partitioned these circles into a number of regions, within each of which it was determined using the contour combs whether they were flat, intermediate, or steep, and they were shaded accordingly (Figure 2.2) shows an Ann Arbor topographic map and its corresponding shaded region as a pair, in order to illustrate this point). In flat cities it appeared that rails were often straight and that no topographic advantage was gained by running rails in river valleys. Thus, rail lines in flat cities as well as those in substantially flat coastal areas of nonflat cities (e.g., Oakland) were omitted in Figure 2.2. In nonflat cities, both river and rail patterns were shown; in fact, curviness in railnet generally suggested nonflat cities.

Within the flat group of cities shown in Figure 2.2, Detroit, Indianapolis, Sacramento,

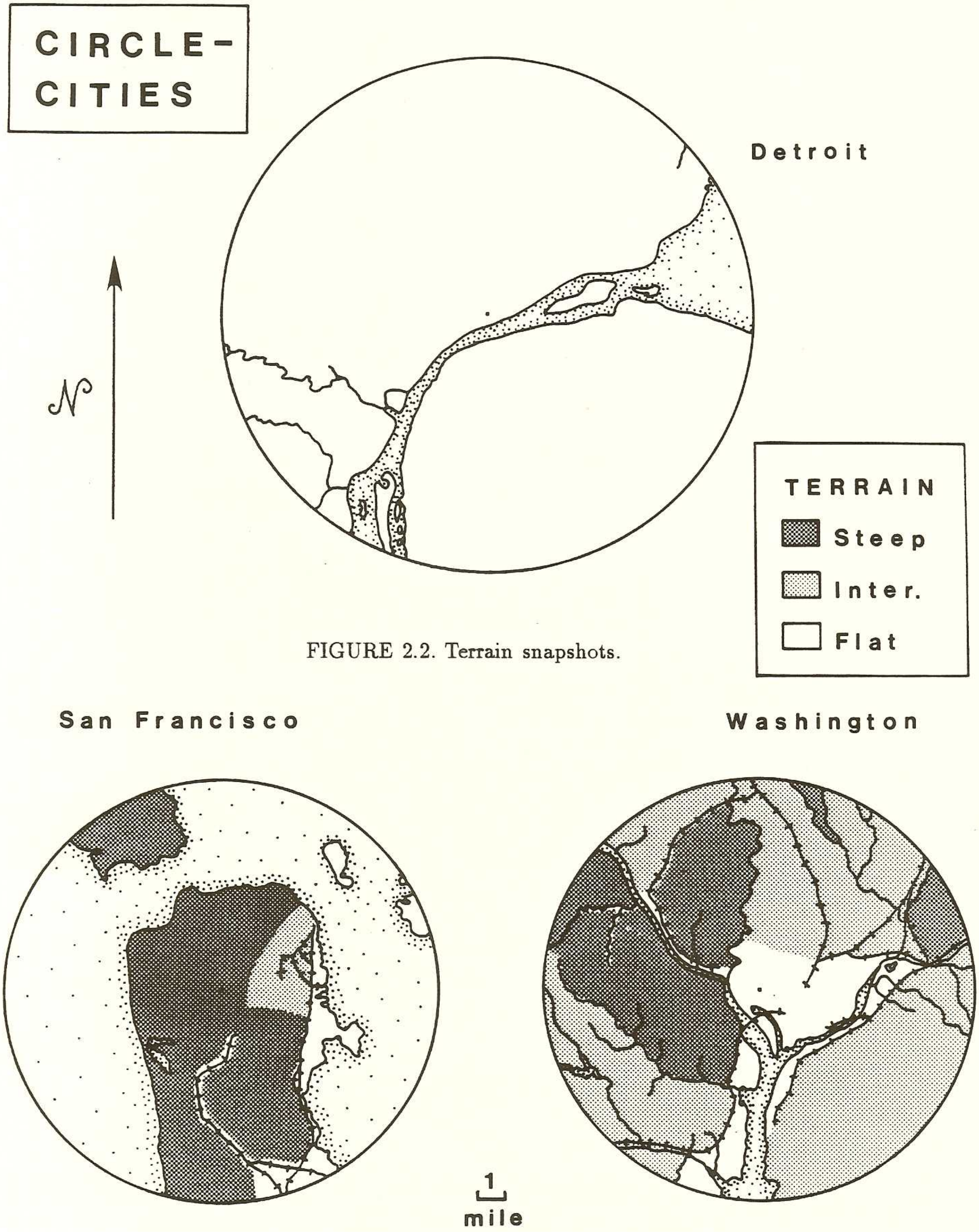
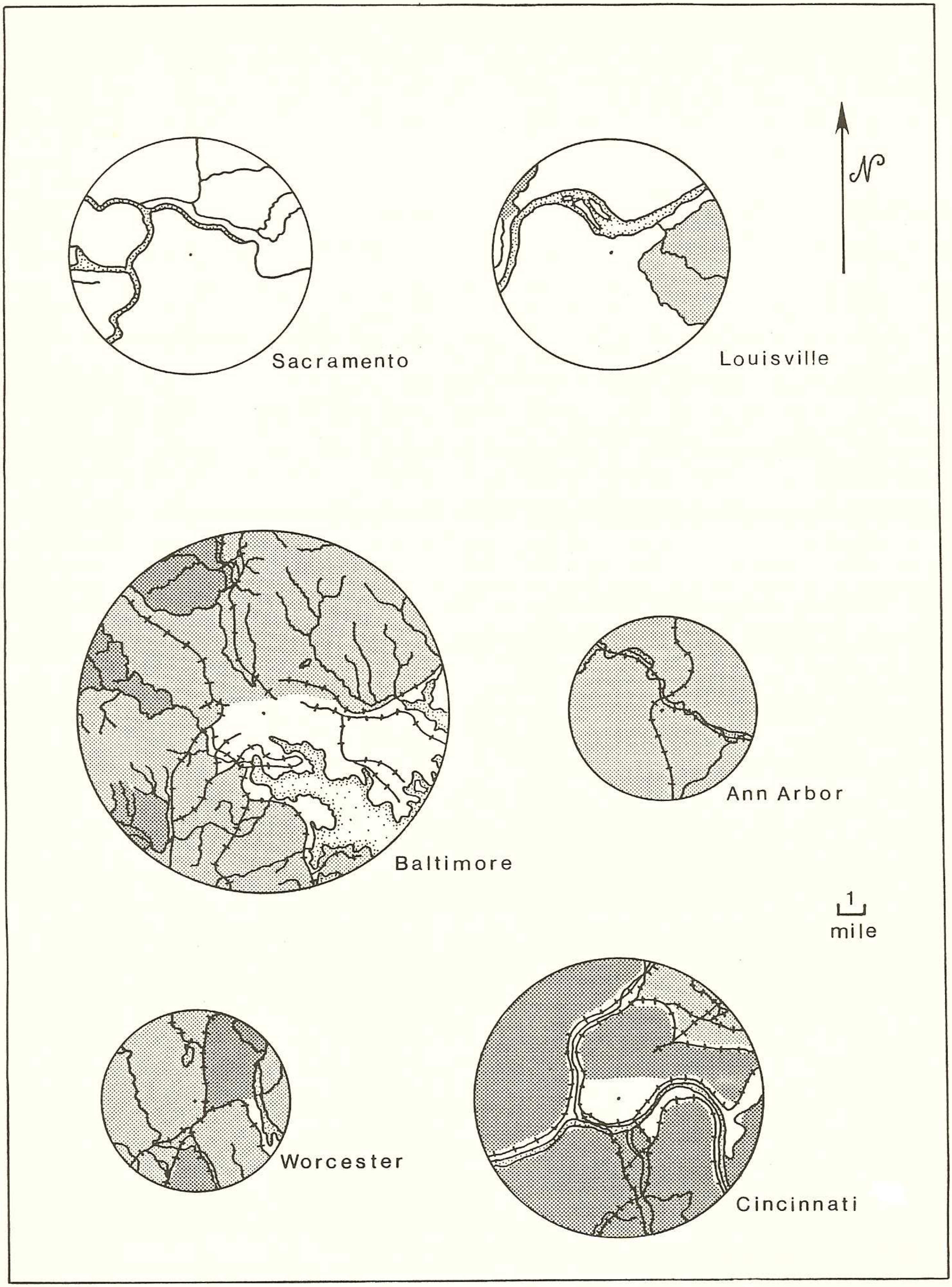


FIGURE 2.2. Terrain snapshots.


N
Sacramento
Louisville
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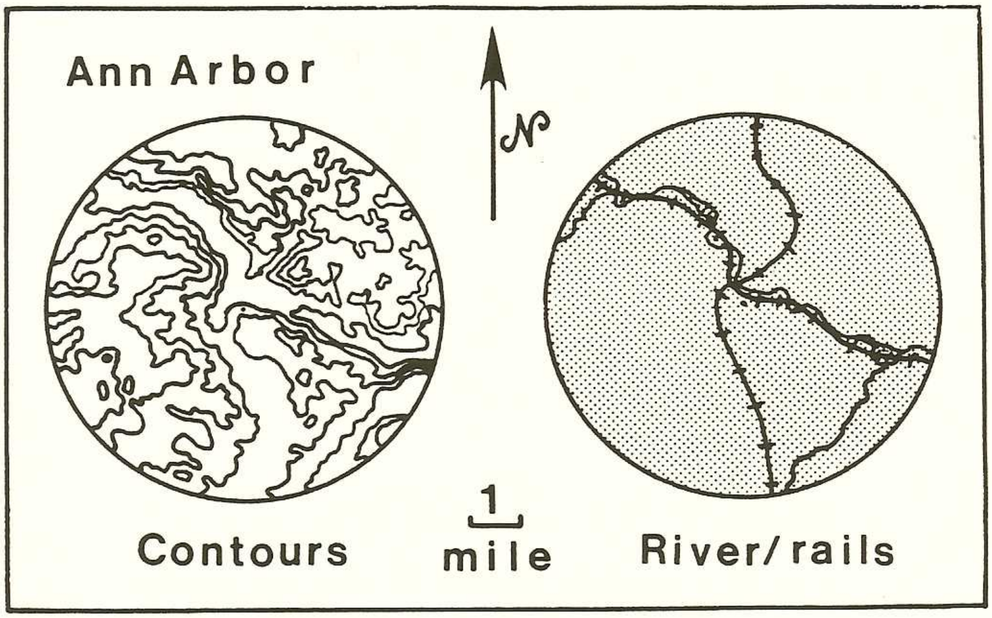

Ann Arbor: Contour lines within the allometric circle (left); river and railroad lines in intermediate terrain (right). *Source:* U. S. Geological Survey topographic maps 1 : 250, 000, 50–foot contour interval.

and Stockton are all clearly flat; however, the drainage pattern in Indianapolis suggests a more undulating surface, and a corresponding increase in expected wear on bus brakes and power train, than does that of Detroit. Sacramento and Stockton both appear to have surfaces that show more topographic variation (resulting from the need to cross the river) than does Detroit, but less than does Indianapolis. River width also helps to determine the extent of undulation; narrow streams may be bridged at grade level whereas wider streams, not easily bridged in that fashion, force change in elevation. Judging from local Ann Arbor field evidence, streams that appear on maps at a scale of 1 : 250, 000 are wide enough to be of the latter sort.

Louisville and San Jose are both predominantly flat. An eastern section of Louisville near a stream feeding into the Ohio River is somewhat hilly; the general pattern of contour lines suggests a clearly flat region elsewhere. On the other hand, San Jose might have been classed as intermediate, or even as steep, if the road pattern suggested that people lived in the hills to the northeast of the center. No evidence suggests this distribution and thus San Jose is classed as flat because it appears that most bus routes cross flat terrain.

In the intermediate class, the flattest city is Jackson, Michigan, and the steepest is Baltimore. Jackson and Brockton are the least steep; however, both maps display curvy railnets, at least one line in each of which runs along the river next to terrain classed as intermediate, suggesting topographic advantage from such placement. Dayton, Minneapolis–St. Paul, and Kalamazoo show a mixture of flat and intermediate regions but appear on the whole to be predominantly intermediate. Ann Arbor, Lowell, and Haverhill are all intermediate as determined both from contour combs and from the shape of rail lines. Baltimore has a few steep areas; as these occur mainly in parklands, the city is placed in the intermediate class.

In the steep class, Boston and Washington contained a fairly even mixture of flat, intermediate, and steep regions. In both cases, a substantial amount of the steep terrain appeared to be in residential areas, requiring buses to shift through the entire spectrum of terrain types; thus, these were classified as steep. The remaining four cities (Worcester, San Francisco, Oakland, and Cincinnati) appeared clearly steep, although each in a different way.

NATIONWIDE TERRAIN PEER GROUPS

In Table 2.1, all transit authorities that are steep are grouped in one terrain class or peer group, all transit authorities that are intermediate are grouped in another terrain peer group, and all transit authorities that are flat are grouped in a third terrain peer group. The point of the procedure developed in the previous sections was to come to such a classification of transit authorities by terrain type; the terrain snapshots graphically supplement the numerical classification.

As with any taxonomy, the underlying decisions on which it is formed involve a certain degree of arbitrariness. In this case, a finer partition of terrain type into more than three classes would permit finer distinctions among transit authorities. Although this notion has some merit, there may be considerable sacrifice in grasping the broad terrain picture when partitioning is extended. Further, it appears undesirable to claim that some number of categories is best; any reasonable number will have advantages and drawbacks. It is for this reason that the supplementary evidence shown in the terrain snapshots is useful. These snapshots show the whole picture at a single glance in a way that refinement in data partitioning cannot. An additional advantage to choosing three as the number of classes in this taxonomy is the retention of classificatory structure that parallels the form underlying the research in Chapter 1, thereby facilitating cross-class comparisons between corresponding climate and terrain peer groups.

The material that follows, that shows one application of this classification, is presented to illustrate possible uses for this sort of methodology. In it, maintenance data expressed in terms of dependent variables selected for illustrative purposes were extracted from Section 15 data and were examined within each of these nationwide terrain peer groups.

MAINTENANCE DATA IN TERRAIN PEER GROUPS

In this application, maintenance performance is measured with two indicators: maintenance value and maintenance efficiency, where maintenance value equals total vehicle-miles per dollar of maintenance expenses, and maintenance efficiency equals total vehicle-miles per maintenance employee. Data for the first indicator appear directly in the *National Urban Mass Transportation Statistics* [8]; data for the second indicator were calculated as total vehicle-miles divided by the number of maintenance employees per vehicle in maximum scheduled service where such an employee is assumed to work $2,000$ hours per year. For both indicators, higher values reflect higher quality in maintenance. When both maintenance value and efficiency indicators are calculated for each of the 181 transit authorities, and these data are partitioned by quartiles, 16 mutually exclusive subclasses based on maintenance quality appear in the data.

When the set of transit authorities is also partitioned by quartiles according to the miles-per-gallon indicator, bars placed in each maintenance subclass of Figure 2.3 showed (a) by their length, the percentage of the set of 181 transit authorities within each; (b) by their internal partitioning, the percentage of entries ranked by the miles-per-gallon indicator within that subclass coming from the top, second, third, and bottom quarters of the set. The result is that Figure 2.3 compresses four dimensions of data (maintenance value, maintenance efficiency, percentage per quarter of the miles-per-gallon indicator, and percentage of transit

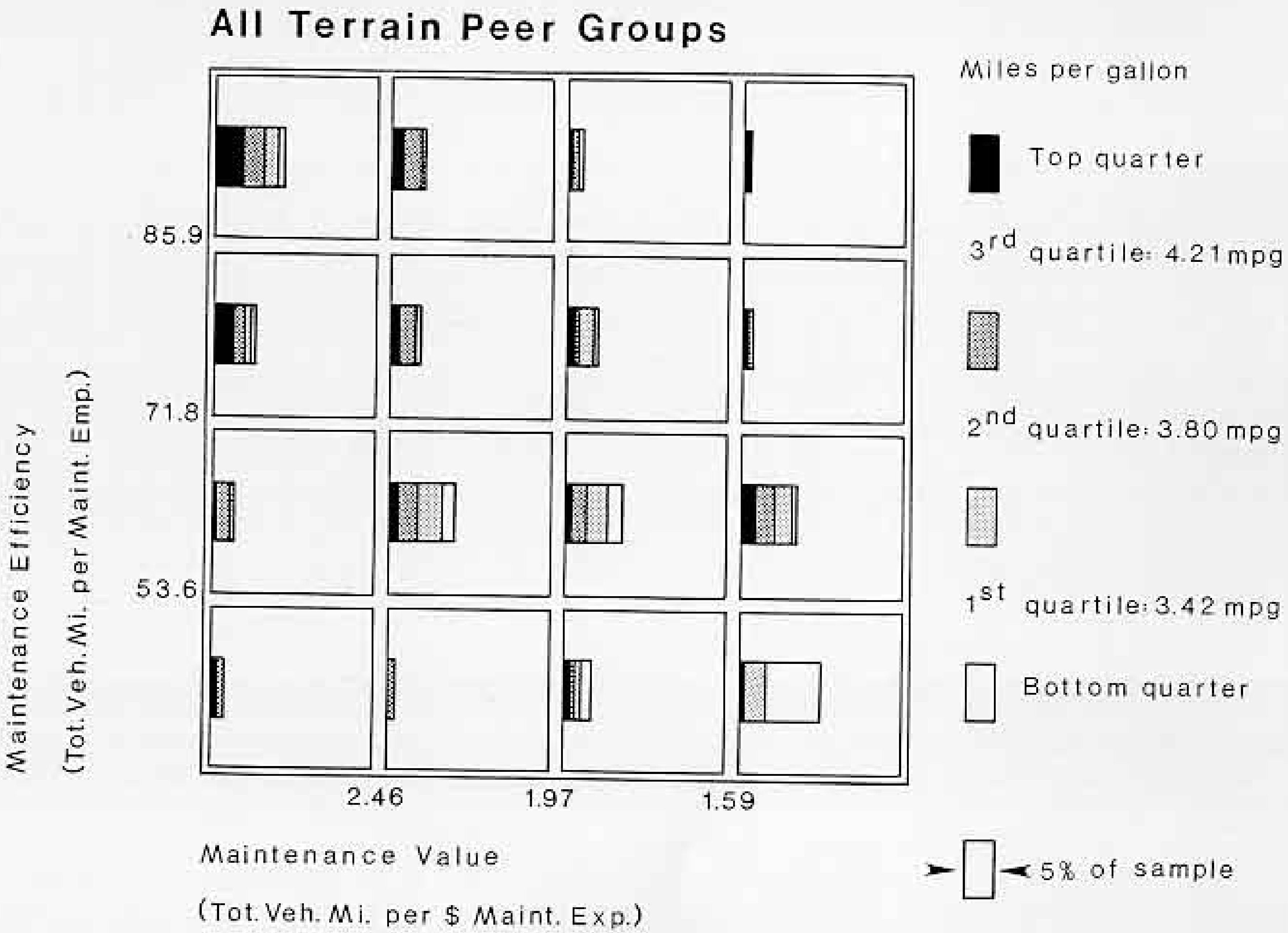

FIGURE 2.3. Miles-per-gallon indicator within maintenance subclasses (sample size: 181 transit authorities).

authorities per maintenance subclass) into two geometric dimensions. For example, the bar in the upper-left-hand corner of Figure 2.3 is between two and three times as long as the 5 percent box in the legend. This length demonstrates, graphically, that about 12 percent of the 181 transit authorities fall into this "best" subclass. The partitioning internal to this bar shows by shading that, of the transit authorities in this subclass, about 46 percent fall into the top quarter of the miles-per-gallon indicator, about 32 percent fall into the second quarter of the miles-per-gallon indicator, about 18 percent fall into the third quarter of the miles-per-gallon indicator, and 4 percent lie in the bottom quarter of that indicator. Good maintenance efficiency and maintenance value and good fuel economy graphically correspond across the entire sample in Figure 2.3. The subclass in the lower-right-hand corner has the poorest value and efficiency. The shading internal to the bar shows that almost all transit authorities achieve mileage worse than the median and that a substantial majority score in the bottom quarter, indicating that bad mileage corresponds to bad maintenance as well. Because Figure 2.3 provides graphic support for the natural notion that transit authorities achieving the highest maintenance value and efficiency achieve higher miles-per-gallon figures than do those reporting poor maintenance, it serves as a graphic standard against which to test the same sort of chart when these data are also stratified according to terrain class.

When the data from Figure 2.3 were sorted using a fifth data dimension according to terrain peer group, Figures 2.4—2.6 emerged. Abstractly these Figures represent two-dimensional portraits of miles-per-gallon data within maintenance subclasses for the steep, intermediate, and flat terrain peer groups, respectively. Figure 2.4 graphically suggests that the ties between maintenance value and efficiency and miles-per-gallon are stronger in steeper environments than they are in the whole sample in Figure 2.3; in flatter surroundings other factors apparently overshadow the effects of terrain on the miles-per-gallon indicator (Figures 2.5 and 2.6).

The distinctions among maintenance subclasses within a Figure fade increasingly from steep terrain (Figure 2.4) to flat terrain (Figure 2.6). This result suggests that, in the steep-terrain peer group, transit authorities with low miles-per-gallon are more likely to have lower maintenance and efficiency values than are corresponding properties in the intermediate-terrain peer group; and, that those in the intermediate-terrain peer group with low miles-per-gallon are more likely to fall into lower maintenance and efficiency value subclasses than are corresponding properties in the flat-terrain peer group. In addition, there is a greater proportion of transit authorities in the upper-left-hand square subset or the four small boxes of Figure 2.6 than there is in the corresponding position in Figure 2.5, suggesting better performance in flat terrain.

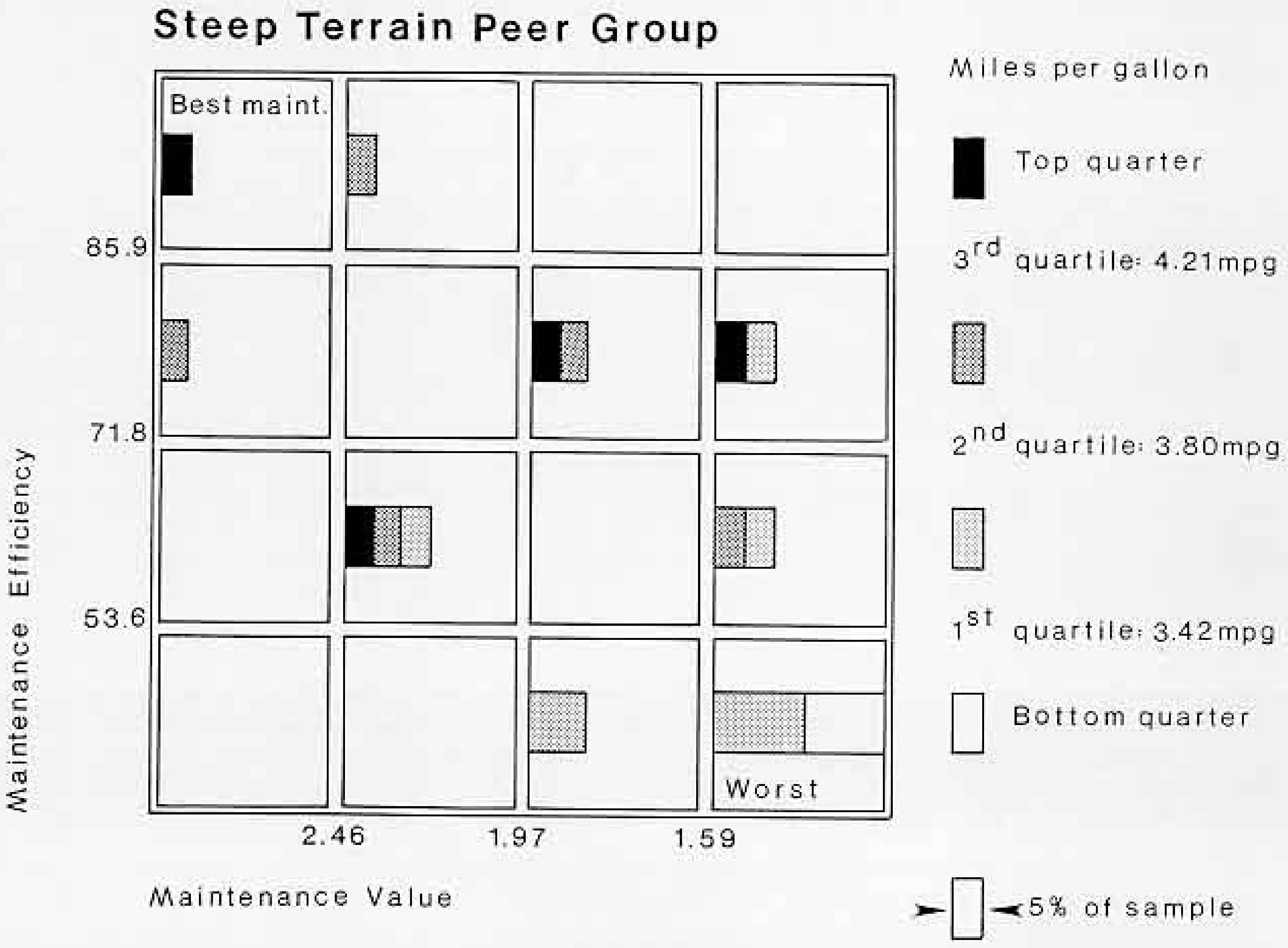

FIGURE 2.4. Miles–per–gallon indicator within maintenance subclasses measured across the steep–terrain peer group (sample size: 20 transit authorities).

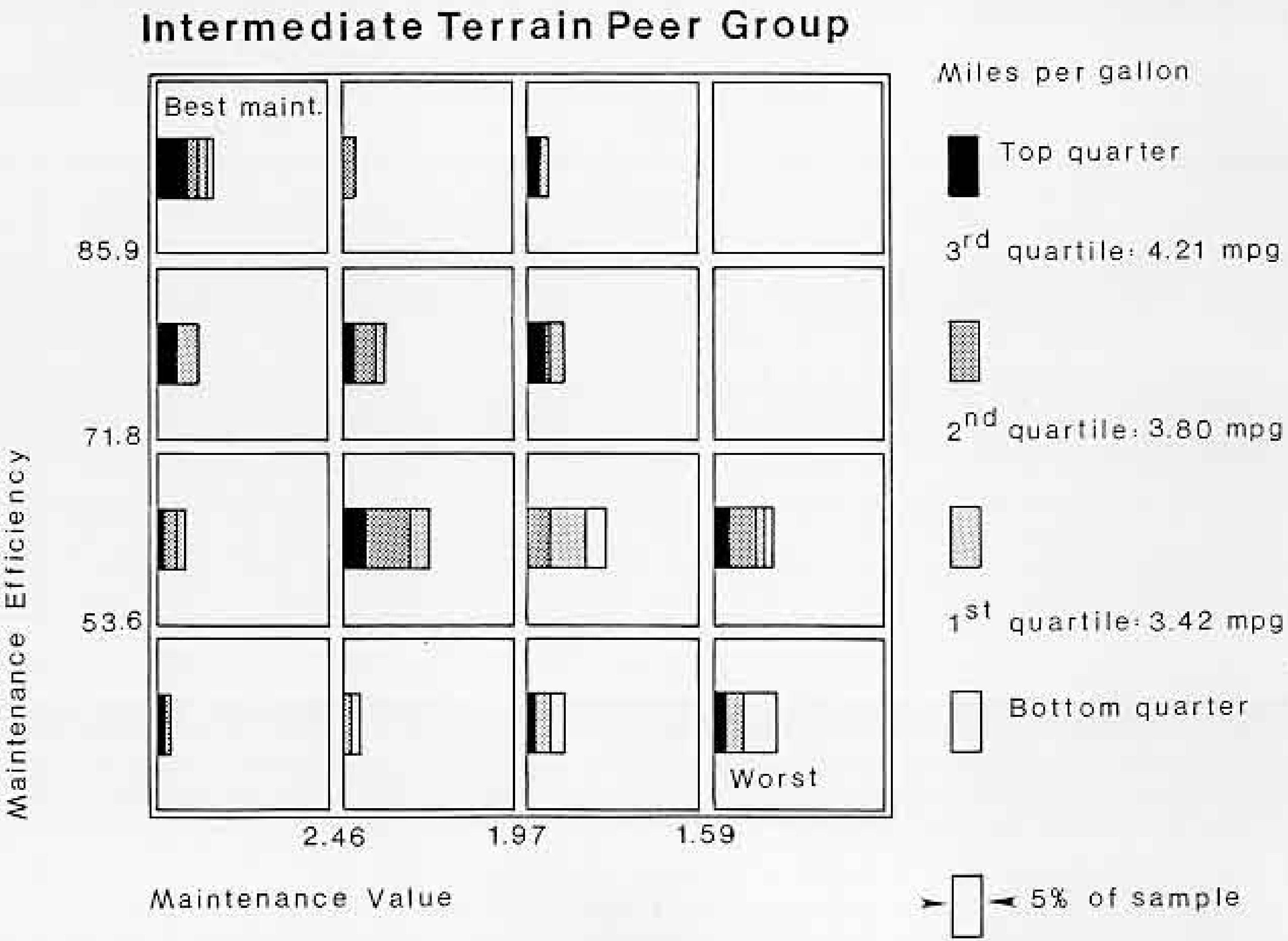

FIGURE 2.5. **Miles-per-gallon** indicator within maintenance subclasses measured across the intermediate-terrain peer group (sample size: 80 transit authorities).

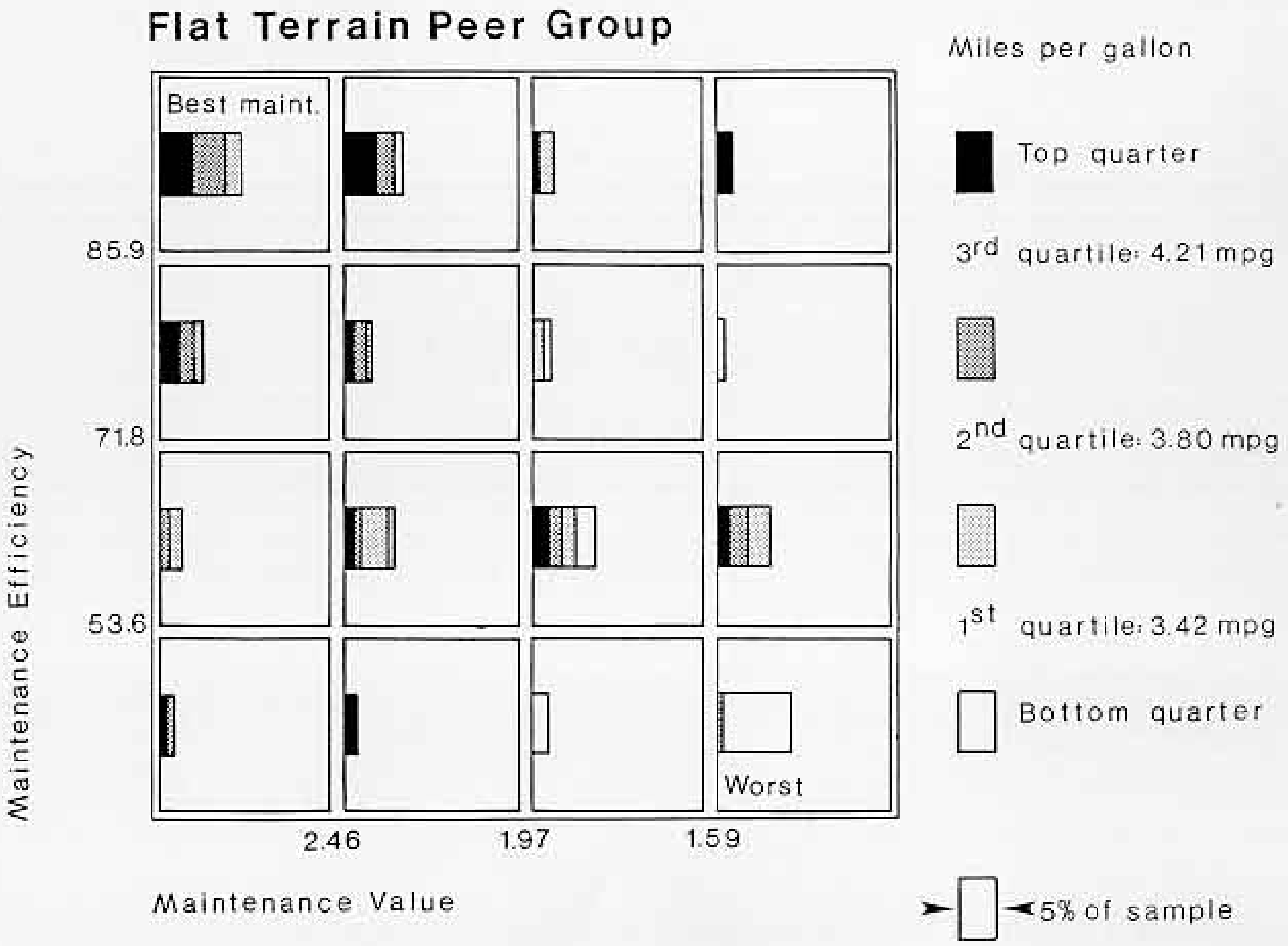

FIGURE 2.6. Miles-per-gallon indicator within maintenance subclasses measured across the flat-terrain peer group (sample size: 81 transit authorities).

One implication of this sort of approach is that any transit authority might classify itself according to terrain type and then use charts such as these as constructive guidelines to focus the direction of its maintenance effort. On the other hand, UMTA might use them to evaluate the quality of the maintenance effort of a particular transit authority as compared to its peers in conjunction with other factors mentioned previously. In either application, (a) the guidelines suggested by these charts are general, and (b) the numerical figures associated with these graphical displays are based on data that vary from year to year.

BUS-ROUTE TERRAIN IN ANN ARBOR

A general measure of terrain, based on topographic evidence at the city scale, may fail to correspond with the gradient stresses along individual routes. Traffic engineers may adjust routes along favorable terrain, while demand for service may force buses to routes that have uncharacteristically steep gradients. The application of a taxonomy, based on small-scale topographic evidence, allows placement of an arbitrary city into one of the three general categories of steepness. This taxonomy is not sensitive to local variations in terrain along individual bus routes.

Ann Arbor, the site of a major state university, had a 1980 population of 107,966. The city has eighteen distinct bus routes to serve this population as well as the substantially fewer number of people (24,031) in nearby Ypsilanti, which is approximately three miles away [9]. The bus garage is a facility located south of the central business district (CBD) in Ann Arbor. A central stop in each downtown serves as the terminus for all routes. Both CBDs are located approximately one-half mile from the Huron River. Except to the southeast, the CBD in Ann Arbor is higher in elevation than the zones immediately around it. Farther from the CBD, glacial features like moraines and hogbacks dominate the landscape and provide a generally rolling surface over which buses travel [10].

The eighteen bus routes were mapped, and the average percentage of slope was calculated for each of them. The mechanics of this procedure involved determining total relief and length for each route. To obtain resolution of topography finer than that on a $1:250,000$ scale, maps at a scale of $1:24,000$ were used [11]. Measurement of total length, L, was straightforward. Using the map scale to determine lengths of the linear segments that compose the route, their sum is L. Measurement of total relief for a route, R, was more complicated. We counted the number, N, of contour lines crossed by a route; multiplied N by the value, C, of feet in the contour interval, and added to this total a small amount, E, sufficient to accommodate the ends of a route. Thus the equation $R = (N \times C) + E$. Then the quotient of total route relief divided by total route length gave an average percentage of slope, S, along a route as $S = (R/L) \times 100\%$. The percentage of slope, S, derived from topographic analysis for each

TABLE 2.2. TOPOGRAPHIC ANALYSIS OF ANN ARBOR BUS ROUTES.

ROUTE		CONTOUR CROSSINGS (N)	LENGTH (L) (in feet)	% SLOPE (S) S=(R/L) × 100%
1	in	41	14,000	3.0
	out	73	21,800	3.4
2	in	84	42,000	2.0
	out	82	40,600	2.0
3	in	119	56,400	2.0
	out	119	56,400	2.0
4	in	82	44,000	1.8
	out	82	44,000	1.8
5	in	77	56,600	1.3
	out	77	56,600	1.3
6	in	92	61,000	1.5
	out	92	61,000	1.5
7	in	159	64,800	2.5
	out	159	64,800	2.5
8	in	32	14,600	2.3
	out	28	11,400	2.5
9	in	28	13,800	2.1
	out	28	13,800	2.1
10	in	42	19,600	1.1
	out	64	31,600	1.0
11	in	34	13,200	1.3
	out	57	13,000	2.2
12	in	109	56,200	2.0
	out	109	56,200	2.0
13	in	56	20,000	2.9
	out	52	18,600	2.9
14	in	59	20,000	3.0
	out	50	17,400	2.9
15	in	65	25,400	2.2
	out	62	24,800	2.1
16	in	24	17,200	1.5
	out	24	17,200	1.5
17	in	35	16,000	2.3
	out	35	16,000	2.3
18	in	29	19,000	1.3
	out	29	19,000	1.3

of the eighteen routes, ranged from a low of 1 percent along route 10 outbound to a high of 3.4 percent along route 1 outbound (Table 2.2). Not all routes differed in length of inbound and outbound paths.

At the city-wide scale, the average of the values for percentage of slope along all routes was 2.039, and the average percentage of slope across the eighteen routes was 1.953 percent. As expected, both proportions are close to the 2 percent figure of the general classification and demonstrate the validity of its results. They suggest by implication the utility of performing additional test cases as empirical support for the general terrain classification.

These results were used to chart a vertical profile for each route at a scale of $1:24,000$. Both inbound and outbound profiles along a route were included only if they appeared dissimilar (Figure 2.7). The vertical scale of these profiles is 1 inch to 50 feet, and the horizontal scale is 1 inch to $2,000$ feet. The corresponding vertical exaggeration of the profiles is 40 times that which appears in the landscape. These profiles appear to be quite bumpy; however, the general trend of some is a relatively smooth climb or drop toward the terminus in a CBD. Some of the topographic variation in the profiles is a consequence of landscape features like rivers or dales that cause a drop in elevation along a route. The remainder of the topographic variation arises from demand for bus service and the response of transit engineers to bus-stop placement as well as from various political, economic, and other pressures on the local transit authority.

A critical value along a bus-route vertical profile is a point around which the slope changes sign, that is, from uphill to downhill. To be called a critical value, this point must arise from the rivers or dales that account for shifts of elevation. Streams that appear on a 1:250,000 map produce critical values in the vertical profiles of bus routes crossing them, independent of the steepness of the underlying terrain. In intermediate and steep terrain, railroad lines on a map of the same scale may yield additional critical values in the vertical profiles of bus routes that cross them. The railroad lines paralleling rivers contribute little, while ones in valleys with no streams contribute much. We assume that railroad lines are map features that are sensitive to slope. In flat terrain the choice of a route can essentially be a straight line. In steep terrain, railroad lines curve to follow the path of low grades in the direction of travel; slopes normal to the direction of travel tend to be much steeper. Curved railroad lines are often surrogates for dales that define critical values in the absence of streams wide enough to be displayed on the maps.

TERRAIN PARTITIONING OF INDIVIDUAL ROUTES

Identification of critical values as a means to partition variations in elevation prompted the notion of viewing the continuous intervals between critical values as domains that are

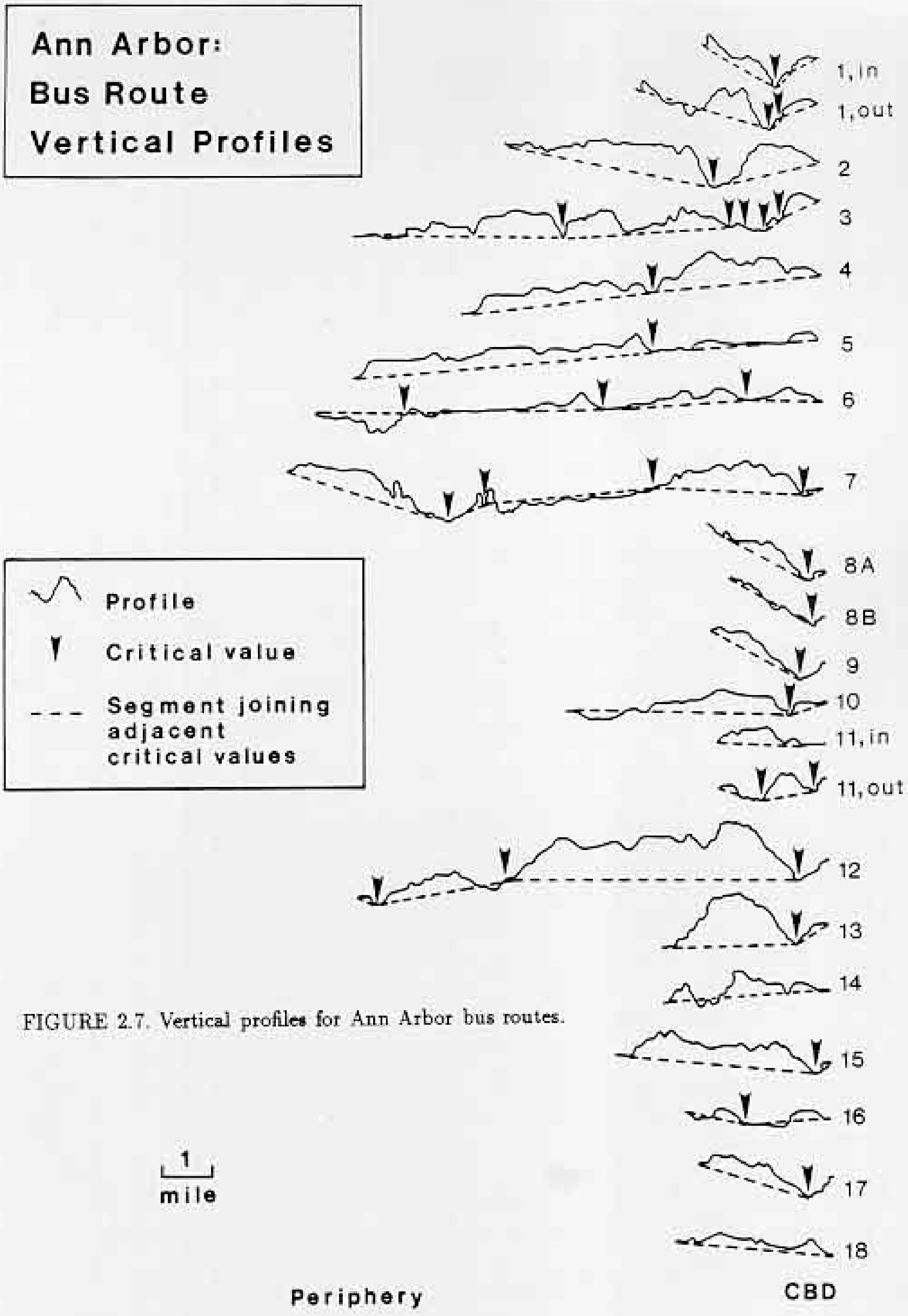

FIGURE 2.7. Vertical profiles for Ann Arbor bus routes.

well suited to a fine measurement of trends in these variations. Between critical values, route location depends on the social and political needs of various sectors of the population. Decisions about routing in these continuous intervals involve the notion of a service gradient that bridges the need to provide service to important locations and to areally spread residential zones. Reasons for responding to one demand and not to another might be based on historical evidence, gathered from patterns of accidents or congestion, or other issues of local importance.

With the topographic variation along a bus route partitioned into continuous intervals by a set of critical values, the objective here becomes three-fold: to develop a procedure to measure bus-route steepness within an interval between adjacent critical values, to apply this procedure to actual bus routes, and to map bus-route intervals according to steepness to delineate a geography of city terrain at a local scale that was not possible with the general classification of city sectors bounded by rivers and railroad lines.

MEASUREMENT BETWEEN CRITICAL VALUES

To characterize the variation in elevation caused by rivers and dales, a route was partitioned into intervals marked by route ends and intervening critical values. The percentage of slope was calculated along each straight-line segment joining these values and was displayed graphically as the slope of a dashed-line segment that linked adjacent critical values. These segments, viewed in route sequence, approximate the shape of the corresponding bus-route vertical profile. They represent the amount of steepness, caused by critical values in the underlying terrain, that a bus must overcome along its route from origin to end, independent of demands for service. This pattern is a minimal representation of city terrain.

In a set of the eighteen actual bus routes, the percentage of slope of each segment linking critical values was calculated within the allometric circle. These slopes ranged in value from 0.0 percent to 2.9 percent, with most values near the intermediate level of 1.5–2 percent, as expected. These values measure absolute steepness and are directly comparable to the percentages used to classify the city as intermediate. The steepest intervals occurred along routes north of the CBD that led toward the river, along routes north of the river, along routes west of the CBD, and along routes in the CBD going west toward the railroad tracks. Routes to the southeast of the CBD were largely flat.

To characterize the variation in demands for service within bus-route intervals between adjacent critical values, a route was divided into a sequence on n intervals, $I1, \ldots, In$ with In in the CBD, marked by route ends and intervening critical values. Within a given interval, between adjacent critical values, D represents the vertical displacement of the actual vertical profile from the dashed line (Figure 2.8). This displacement is measured at each point on

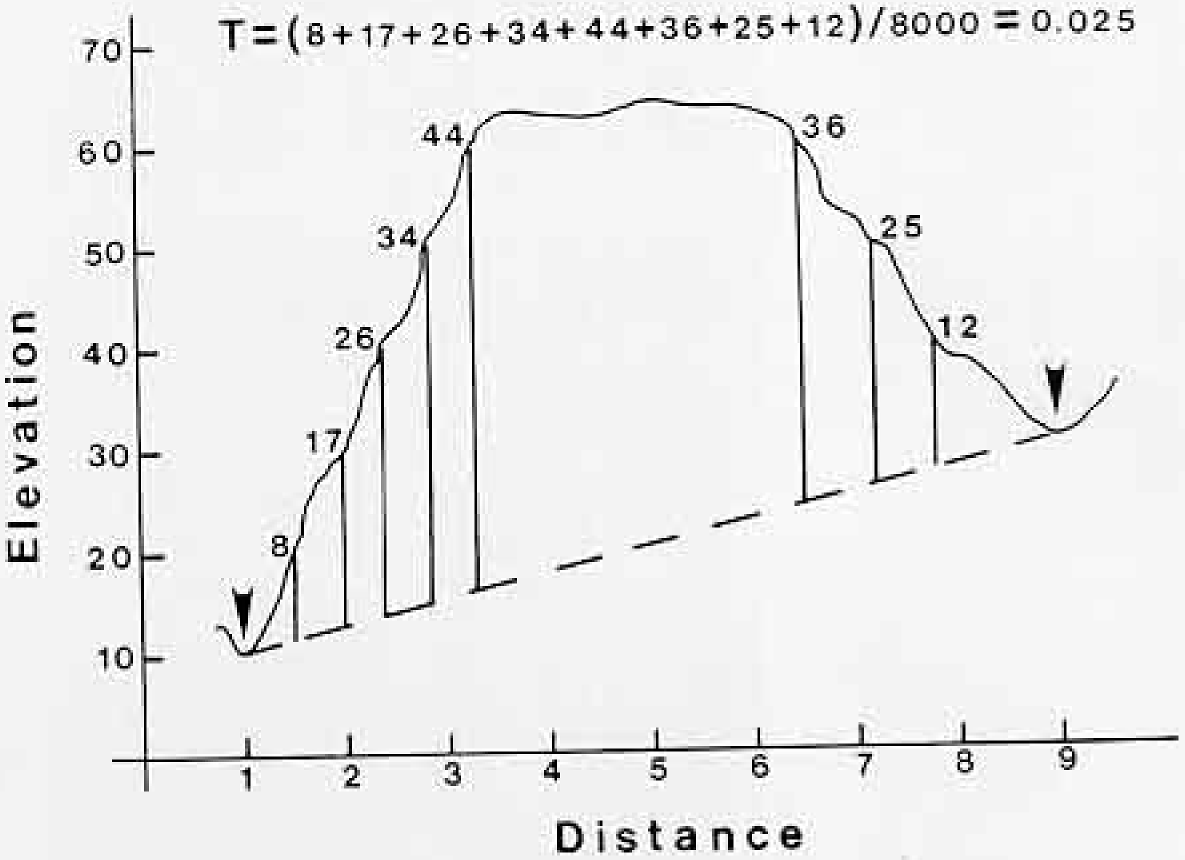

FIGURE 2.8. Sample calculation of topographic variation T between adjacent critical values along a hypothetical bus-route vertical profile. The horizontal axis measures surface distance in thousands of feet between adjacent critical values. The vertical axis measures elevation in feet above some base, spaced to correspond to the contour spacing on suitable U. S. Geological Survey maps. Numerical values along the profile measure the displacement of the bus-route profile from the dashed line.

the profile where a bus route crosses contour lines to produce i values of $D(1), \ldots, D(i)$ for each of i contour crossings. The topographic variation T between critical values may then be calculated as a displacement measure, T, the sum of the i values $D(1), \ldots, D(i)$ divided by the length of segment joining adjacent critical values. This variation between critical values represents the topography that a bus must overcome as a result of the transit authority's response to passenger demands and to political pressures; it is one response to finding a service gradient across the urban surface.

Because contour crossings rather than an evenly spaced net of points were used as references for measuring displacement, steepness was reflected directly in T: steeper segments were sampled more frequently than smooth segments.

APPLICATION OF DISPLACEMENT MEASURE

For actual bus routes in Ann Arbor, the topographic variation T was measured along intervals, I, between adjacent critical values. When T was multiplied by 100 to facilitate comparisons, the value of this relative measure ranged from a high of 25.3 for the first interval, $I1$ of route 13 remote from the CBD, to a low of 0.4 along $I2$ of route 9. The pattern reflected directly the relative steepness along these route segments (Table 2.3).

When these values of $T \times 100$ were mapped along generalized bus routes, based on actual route locations, a detailed geography of city terrain emerged (Figure 2.9). When the rank-ordered values for $T \times 100$ were roughly partitioned into thirds, at the 8 percent and the 2 percent levels, one–third contained bus routes with steep topographic variation between critical values. Another third contained routes with intermediate topographic variation between critical values (between 2 percent (inclusive) and 8 percent (exclusive)), and the remaining one–third comprised bus routes with flat topographic variation between critical values.

The values for $T \times 100$ were mapped along generalized bus routes. Dotted lines represented flat intervals, dashed lines delineated intermediate intervals, and solid lines marked steep intervals. Bus routes were characterized abstractly as radial or circular within the allometric circle for Ann Arbor. Routes 1, 4, 5, 8, 9, 13, 14, 15, 16, and 17 were radial, while routes 2, 3, 6, 7, and 12 were circular. Routes 10, 11, and 18 were outside this circle and not included in the analysis. Along these intervals, relative steepness is a direct consequence of service demands on the local transit authority in routing policy rather than underlying terrain variation due to critical values.

When this relative steepness along intervals is evaluated in the context of the general notion that routes to the north and west have steep intervals and those to the southeast are mainly flat, several implications emerge for routing buses across Ann Arbor city terrain. Firstly, radial route intervals at the western edge of the CBD have minor displacement from

TABLE 2.3. TOPOGRAPHIC VARIATION BETWEEN CRITICAL VALUES FROM TRANSIT AUTHORITY DEMANDS.
R denotes route number; I indicates interval number.

RANK ORDERING		SEQUENTIAL ORDERING	
T x 100	R & I	T x 100	R & I
25.3	I1 of R3	6.8	I1 of R1 in
21.8	I3 of R12	2.0	I2 of R1 in
15.1	I4 of R7	2.4	I3 of R1 in
14.0	I1 of R1 out	14.0	I1 of R1 out
12.8	I1 of R2	2.5	I2 of R1 out
11.5	I2 of R4	4.0	I3 of R1 out
11.3	I1 of R15	12.8	I1 of R2
10.3	I2 of R3	7.5	I2 of R2
9.6	I1 of R17	10.3	I2 of R3
9.4	I1 of R7	1.5	I3 of R3
8.2	I6 of R3	0.6	I4 of R3
8.0	I2 of R7	4.7	I5 of R3
7.7	I1 of R14	8.2	I6 of R3
7.5	I2 of R2	11.5	I2 of R4
6.8	I1 of R1 in	0.9	I2 of R5
5.3	I1 of R9	2.0	I2 of R6
4.9	I2 of R12	4.0	I3 of R6
4.7	I5 of R3	2.5	I4 of R6
4.0	I3 of R1 out	9.4	I1 of R7
4.0	I3 of R6	8.0	I2 of R7
3.8	I1 of R8A	3.3	I3 of R7
3.3	I3 of R7	15.1	I4 of R7
2.5	I2 of R1 out	0.8	I5 of R7
2.5	I4 of R6	3.8	I1 of R8A
2.4	I3 of R1 in	0.9	I2 of R8A
2.4	I1 of R16	1.7	I1 of R8B
2.0	I2 of R1 in	0.6	I2 of R8B
2.0	I2 of R6	5.3	I1 of R9
1.7	I1 of R8B	0.4	I2 of R9
1.5	I3 of R3	0.8	I1 of R12
1.4	I2 of R13	4.9	I2 of R12
1.2	I2 of R16	21.8	I3 of R12
1.0	I2 of R15	0.6	I4 of R12
0.9	I2 of R5	25.3	I1 of R13
0.9	I2 of R8A	1.4	I2 of R13
0.9	I2 of R17	7.7	I1 of R14
0.8	I5 of R7	11.3	I1 of R15
0.8	I1 of R12	1.0	I2 of R15
0.6	I4 of R3	2.4	I1 of R16
0.6	I2 of R8B	1.2	I2 of R16
0.6	I4 of R12	9.6	I1 of R17
0.4	I2 of R9	0.9	I2 of R17

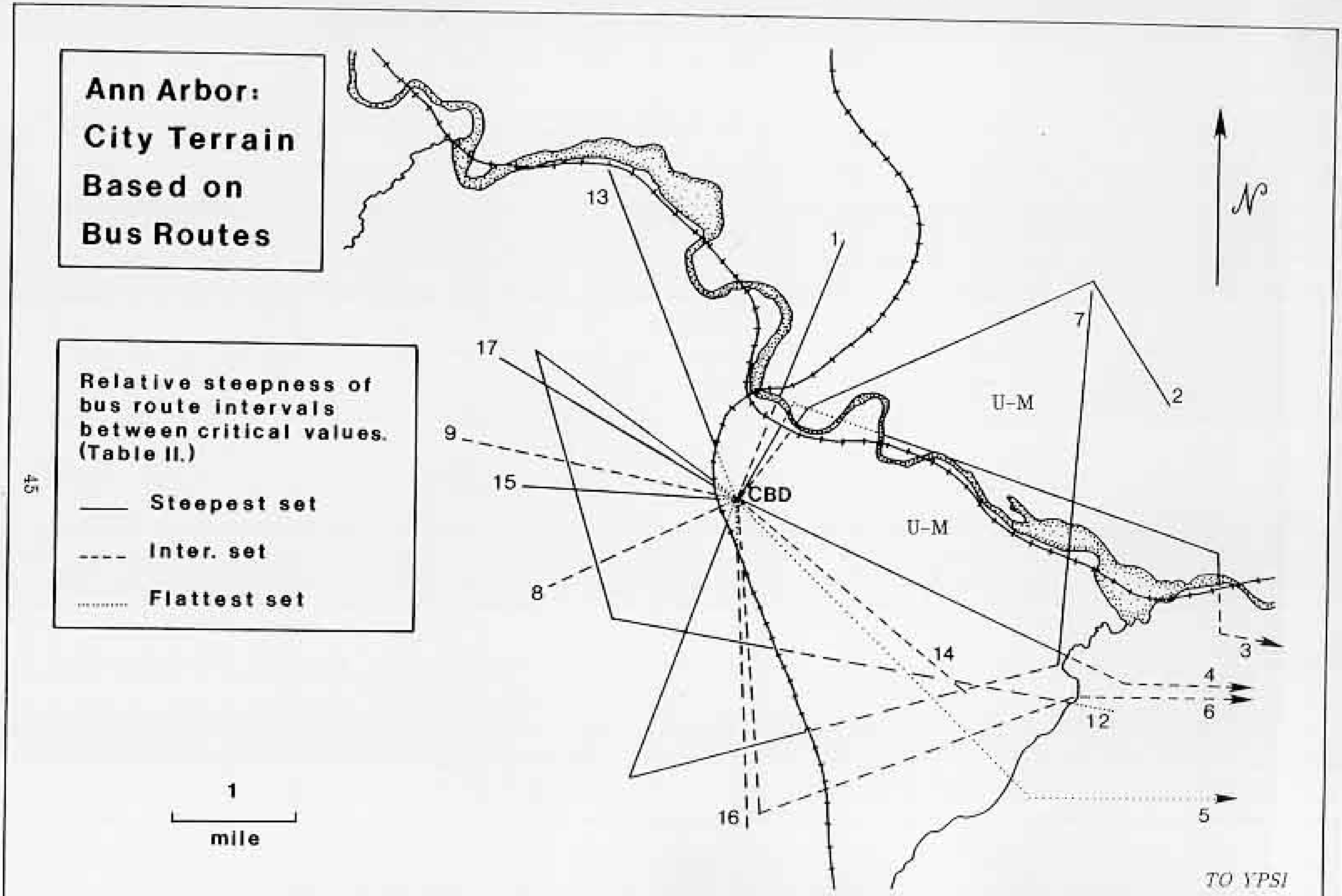

FIGURE 2.9. City terrain based on Ann Arbor bus routes. *Source:* Values from Table 2.2 for classification of data as steep, intermediate, or flat.

the topographic baselevel linking critical values. These intervals have low values for $T \times 100$. However, the underlying terrain in this region is fairly steep. Variation in a profile cutting across it is forced largely by topographic features rather than by service–demand responses. This aspect suggested that the routing of buses across this terrain is effective in making the service gradient coincide with the terrain one. In other words, the routing is "good."

Secondly, route 7 has relatively little variation in elevation caused by critical values, but it displays high values for $T \times 100$ that result from response to service demands. Routes with this pattern experience more terrain stress than required by critical values. Review of service demand, relative importance of locations that are served, and bus-stop positions in zones of dispersed housing might be in order. Issues of this sort do not appear to be a widespread concern of transit managers, except in cities like Seattle or San Francisco, where response has been to run trolley buses or cable cars on steep slopes. Current cuts in funding for UMTA might suggest that all transit managers should consider the long-term consequences for maintenance of sometimes subtle environmental factors that affect bus durability.

Route 1 experiences steep variations caused by both critical values and service demands. This consistency suggests that the quality of steepness might be invariant with a shift of scales. The abstract tools of self-similarity and of fractal geometry might be used to investigate steepness along such routes. Insofar as roadbed and water-table levels are a function of steepness, they might be applied locally to predict routes likely to become riddled with potholes [12].

When values that measure the relative steepness of bus-route intervals between adjacent critical values are coupled with the general trend in terrain dictated by those values, a geography of city terrain is created to suggest which segments of the routes are effectively designed in terms of gradients and which are not. By combining these data with local economic and political issues, transit managers could produce policies that reflect spatial as well as other values.

The principal direct contribution of the Ann Arbor case study is to demonstrate how to extend a small-scale terrain classification (steep, intermediate, or flat) to a large scale that is sensitive enough to include terrain variation along bus routes. Because a shift in scale is involved, use of the notion of self-similarity to represent the scale changes along bus routes outward from a CBD or to characterize scale changes with movement from the physiographic province inward to the city might result in terrain fractals.

The geography of city terrain based on Ann Arbor bus routes was crafted to provide insight about general problems in measuring variation of steepness that results from terrain and service demands. At the pragmatic level, implications for transit-authority budgets and local transit policy stem from maintenance associated with steepness of routes. At an abstract level, the ideas in this Chapter might be applied to a broad group of cities. Use of an automatic counter to tabulate contour crossings and to create a data set to produce computer-generated maps could present a static portrait of city terrain based on bus routes, which in turn might lead to a study of the dynamics of bus-route changes.

CONCLUSION

One contribution of this Chapter is to classify transit authorities according to terrain type into steep, intermediate, or flat peer groups. The typology is formed on the basis of empirical topographic evidence accumulated at the $1:250,000$ scale using a terrain template. Nationwide terrain peer groups established using this terrain template are displayed in Table 2.1. When the variables miles-per-gallon, maintenance efficiency, and maintenance value, quantified by Section 15 indicators, are introduced into these terrain peer groups, connections are found between maintenance value and efficiency and miles-per-gallon in steeper environments.

These broad terrain categories might be used in an analysis involving several factors in addition to terrain, related to vehicle performance (e.g., frequency between stops and passenger load). Or, they might be used to restructure this classification, using different percentage slopes to correspond to steep or intermediate terrain. However, an arbitrary attempt to balance the numerical size of terrain peer groups would result in misclassification because there are few steep cities.

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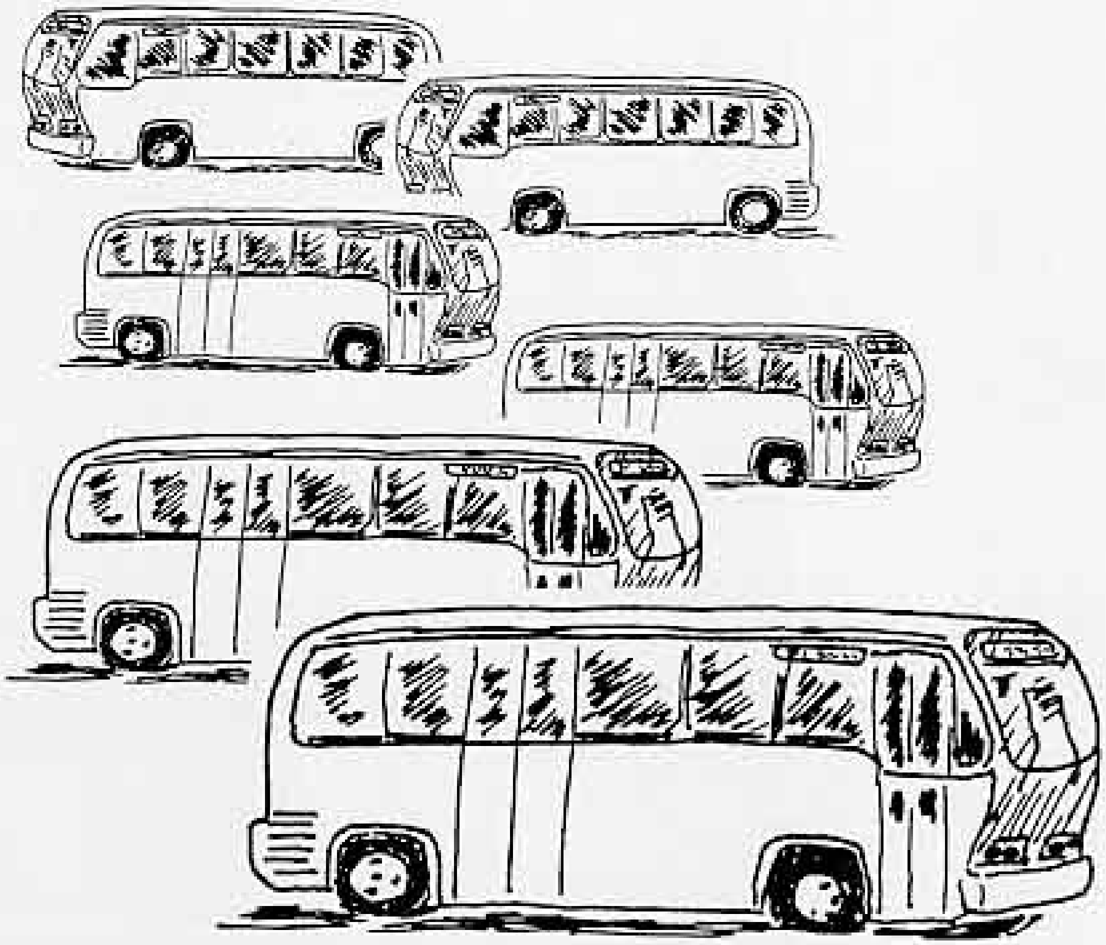


CHAPTER 3: CONGESTION EFFECTS

INTRODUCTION

The human element, in addition to climate and terrain, contributes to environmental effects on bus durability; the weight of the bus-passenger load contributes to bus wear-out, as do route congestion along densely populated metropolitan arterials that forces frequent stopping and starting, and high levels of passenger loading. Because terrain and climate patterns change along a geological time-scale, while human patterns often fluctuate on a diurnal cycle (with rush-hours), the problems associated with the mapping of congestion data are different from those associated with the mapping of terrain and of climate data.

Three indices, derived from Census data and from Section 15 data, are used to sort data concerning sets of transit authorities into classes of "dense," "intermediate," and "sparse" congestion, in parallel to comparable climate and terrain classes of previous chapters. We employ the device of shifting the scale of the study to see if what is "sensible" information about the "dense" (or other) class at one scale, is also sensible at a different scale. The emphasis in this study is to see how the transformation of scale change is reflected in the data set to which it is applied (rather than to discuss the merits of using one style of analysis of population data instead of another, although we do hope that the selected indices capture some elements of the complex human connections underlying issues involving mass transit). Fractal geometry offers vivid, visual evidence that pattern of all sort, when subjected to scale change, can form constant, predictable structure. The advantages to an approach that considers scale transformation therefore include, but are not limited to, an increased capability to regularize difficult data sets, and to pinpoint significant concerns visible at the local, but not at the global, scale.

CONGESTION INDICES BY TRANSIT-UZAs

The transit-UZA: definition

The broadest geographic scale at which we consider demographic data concerning bus mass transit is at the "urbanized area" (UZA, as defined by the U. S. Bureau of the Census [1]) scale. We chose UZAs as nationwide analysis units because they are the foundation for the Section 9 apportionment scheme of the Urban Mass Transportation Administration (UMTA) by which funding is allocated to transit authorities [1, 2]. A transit-UZA is a unit formed from Census data and Section 15 data as follows.

1. Record the names and addresses of all the transit authorities in a given UZA in Section 15 data [2].
2. Record corresponding population data, from the Census, for each city or town associated with each transit authority.

The result is a "transit–UZA": a demographic analysis unit that focuses specifically on bus transportation. It is skewed from the more broadly defined census UZAs because it excludes regions lacking bus service (such as small wealthy communities or rural enclaves).

To measure congestion associated with bus transit, three indices are used: one based on population density (as a general "external" measure of urban congestion), one based on bus passengers per bus mile (as an "internal" measure of load on a bus), and one based on bus passenger miles per person residing in an UZA (as an "external" measure suggesting how much use the entire bus system receives within the urbanized area). Initially, these indices are used to form broad congestion peer-groups; when the scale is transformed to apply one of these indices to sets of individual transit authorities composing a single transit UZA, and then to a single transit authority, the level of sensibility of this index remains about the same throughout.

Population density index

Cities with a large total population might experience traffic congestion greater than do those with small populations; however, what seems more important than sheer number of people in an UZA is the density of its population, possibly reflected in the density of traffic and of crowds demanding space on buses. Thus, small cities might suffer congestion problems directly comparable to larger ones; gridlock can occur anywhere.

Table 3.1 contains a listof transit–UZAs. The first set of data–columns rank–orders 101 Urbanized Areas according to total transit–UZA population. This Table also shows, in the next column, the population density of each transit–UZA (Table 3.4, in Appendix 3.A, shows the set of transit–UZAs rank–ordered according to transit–UZA population density). This population density index is also compiled from the 1980 Census; it measures the number of people per square mile in each transit UZA.

The notion that smaller cities may have relatively high densities stands out: Miami is third in density, behind New York City and Los Angeles and ahead of Chicago and Philadelphia, but eighteenth in total population; Ann Arbor is sixteenth in density, ahead of Boston and Denver, but ninety–ninth in total population. The "sensibility" of the former might be a function of the geographic layout of Miami relative to the ocean and of the percentage of its population that are recent immigrants (without access to an automobile), while that of the latter might be a function of the concentrated dormitory populations at the University of Michigan. High values of this index mean that the population is relatively dense in regions with access to bus service; it does not address the extent to which the bus service is actually used. It is a measure of one aspect of the potential for congestion within the bus system, but external to the buses themselves.

TABLE 3.1: THREE INDICES USED TO FORM CONGESTION PEER GROUPS:
UZA POPULATION DENSITY, BUS LOAD, AND BUS USE.
(List is rank-ordered on Total UZA Population.)

UZA #	UZA STATE & CITY NAME (# of transit authorities shown in parentheses.)	TOTAL POPULATION BY TRANSIT UZA (1980 Census).	POPULATION DENSITY (1980 pop. per sq. mi.)	BUS LOAD (Annual pass. mi. per bus mi.)	BUS USE (Bus pass. mi. per UZA resident.)
1	NY NEW YORK (22)	15,590,274	5552	14.73	261.02
2	CA LOS ANGELES (11)	9,479,436	5189	17.04	217.79
3	IL CHICAGO (15)	6,779,799	4526	14.13	189.49
4	PA PHILADELPHIA (3)	4,112,933	4052	13.10	151.21
5	MI DETROIT (1)	3,809,327	3649	13.02	114.30
6	CA SAN FRANCISCO (6)	3,190,698	4008	17.51	343.81
7	DC WASHINGTON (2)	2,763,105	3424	15.10	238.53
8	MA BOSTON (5)	2,678,762	3126	10.33	81.19
9	TX DALLAS (3)	2,451,390	1915	11.84	86.84
10	TX HOUSTON (2)	2,412,664	2300	15.42	141.81
11	MO ST. LOUIS (1)	1,848,590	3099	10.24	107.33
12	PA PITTSBURGH (5)	1,810,038	2539	13.91	244.43
13	MN MINN.-ST.PAUL (1)	1,787,564	1824	11.72	131.75
14	MD BALTIMORE (2)	1,755,477	3357	17.17	206.46
15	OH CLEVELAND (1)	1,752,424	2786	18.72	210.20
16	CA SAN DIEGO (3)	1,704,352	2789	10.18	112.29
17	GA ATLANTA (1)	1,613,357	1783	13.76	215.85
18	FL MIAMI (1)	1,608,159	4730	13.88	180.24
19	AZ PHOENIX (1)	1,409,279	2199	13.03	68.05
20	WA SEATTLE (3)	1,391,535	2869	15.89	306.61
21	CO DENVER (1)	1,352,070	3080	12.90	174.96
22	CA SAN JOSE (1)	1,243,952	3816	6.45	119.99
23	WI MILWAUKEE (3)	1,207,008	2433	10.48	178.31
24	OH CINCINNATI (2)	1,123,412	2675	12.72	144.77
25	KS KANSAS CITY (1)	1,097,793	1864	11.19	73.28
26	LA NEW ORLEANS (4)	1,078,299	4688	14.62	175.03
27	OR PORTLAND (1)	1,026,144	2940	9.94	207.02
28	FL FT. LAUDERDALE (2)	1,008,526	3490	12.00	77.13
29	NY BUFFALO (1)	1,002,285	2768	11.86	113.00
30	TX SAN ANTONIO (1)	944,893	2669	11.83	156.89
31	IN INDIANAPOLIS (1)	836,472	1932	11.32	83.61
32	OH COLUMBUS (1)	833,648	2733	12.44	132.46
33	FL ST. PETERSBURG (2)	833,337	2615	9.42	49.41
34	CA SACRAMENTO (2)	796,266	2864	13.78	121.12
35	RI PROVIDENCE (2)	796,250	2824	21.15	139.35
36	TN MEMPHIS (1)	774,551	2617	6.88	53.09
37	VA NORFOLK (1)	770,784	1844	19.16	119.86
38	KY LOUISVILLE (1)	761,002	2916	11.39	116.92
39	CA SAN BERNARDINO (2)	705,175	1964	8.10	58.93
40	OK OKLAHOMA CITY (1)	674,322	1502	4.60	16.58
41	UT SALT LAKE CITY (1)	674,201	2225	7.53	96.79
42	AL BIRMINGHAM (1)	606,065	1777	14.94	62.82
43	NY ROCHESTER (1)	606,070	3015	10.83	100.85
44	FL JACKSONVILLE (1)	598,015	1388	10.11	93.89
45	OH DAYTON (2)	595,059	2399	13.90	113.07
46	FL ORLANDO (1)	577,235	1890	7.86	36.86
47	TN NASHVILLE (1)	518,325	1255	8.53	66.76
48	OH AKRON (2)	515,720	2388	5.54	34.85
49	NB OMAHA (1)	512,438	2785	5.82	63.42
50	CT HARTFORD (2)	510,034	2452	12.60	162.07
51	MA SPRINGFIELD (1)	505,822	1787	8.46	70.32
52	VA RICHMOND (1)	491,627	1959	12.94	117.78
53	NY ALBANY (1)	490,015	2475	9.45	110.54
54	FL W. PALM BEACH (1)	487,044	2605	4.36	19.91
55	OH TOLEDO (1)	485,440	2758	8.71	109.63
56	TX EL PASO (1)	454,158	2703	16.18	137.84
57	AZ TUCSON (1)	450,059	2601	7.90	81.65
58	OK TULSA (1)	443,350	1648	8.12	51.80
59	NM ALBUQUERQUE (1)	418,206	2446	6.25	63.84
60	CT BRIDGEPORT (2)	410,998	2491	8.04	74.91
61	PA SCRANTON (4)	406,517	2064	9.37	65.27
62	DE WILMINGTON (3)	406,112	2375	9.18	55.07
63	WA TACOMA (1)	402,077	2150	9.56	125.43
64	OH YOUNGSTOWN (1)	383,398	2573	4.07	10.23
65	PA ALLENTOWN (1)	381,734	3006	7.44	33.95
66	TX AUSTIN (1)	379,560	2692	6.76	42.57
67	NY SYRACUSE (3)	379,284	2963	6.90	109.19
68	CT NEW HAVEN (2)	368,061	2375	11.65	123.62

69	NC	CHARLOTTE (1)	350,715	1846	9.97	83.85
70	LA	BATON ROUGE (1)	350,657	2100	9.53	47.28
71	MI	FLINT (1)	331,931	2274	7.84	42.22
72	CA	FRESNO (1)	331,551	3251	7.44	65.35
73	VA	HAMPTON (1)	328,576	1676	9.18	64.73
74	KS	WICHITA (1)	305,752	2446	4.04	25.36
75	FL	BRADENTON (2)	305,431	2036	8.96	38.48
76	TN	CHATTANOOGA (1)	301,515	1216	8.51	44.25
77	AL	MOBILE (1)	295,493	1500	8.52	33.16
78	AK	LITTLE ROCK (1)	295,133	1800	7.26	44.79
79	IL	ROCK ISLAND (3)	285,024	2007	4.85	22.82
80	TN	KNOXVILLE (1)	284,706	1445	19.96	131.02
81	PA	HARRISBURG (1)	278,296	2031	20.42	124.57
82	CO	COL. SPRINGS (1)	276,872	1950	7.73	56.06
83	MA	WORCESTER (1)	276,022	2339	6.40	45.74
84	IA	DES MOINES (1)	267,192	2190	6.02	44.85
85	WA	SPOKANE (1)	266,709	2493	8.24	136.02
86	MS	JACKSON (1)	265,051	1541	9.16	33.22
87	LA	SHREVEPORT (1)	263,827	2199	8.68	66.26
88	IL	PEORIA (1)	261,418	2125	6.51	39.32
89	GA	AUGUSTA (1)	251,250	1611	6.81	25.03
90	TX	CORPUS CHRISTI (1)	245,854	1756	3.94	18.75
91	OH	CANTON (1)	244,888	2633	5.00	22.37
92	IN	FORT WAYNE (1)	236,479	2718	4.30	33.60
93	IN	SOUTH BEND (1)	226,331	2408	7.36	55.35
94	CA	BAKERSFIELD (1)	222,236	3268	6.07	38.60
95	FL	PENSACOLA (1)	215,995	1577	6.00	23.30
96	NC	FAYETTEVILLE (1)	215,839	1741	6.89	17.59
97	GA	COLUMBUS (1)	214,591	1759	5.24	37.41
98	WI	MADISON (1)	213,675	2775	9.02	193.01
99	MI	ANN ARBOR (1)	208,782	3163	7.64	51.68
100	NC	RALEIGH (1)	206,597	2087	8.86	61.38
101	IL	ROCKFORD (2)	204,304	2653	8.29	53.11

Bus-load index

To find a rough measure of the load exerted on buses by the passengers, as congestion "internal" to the buses themselves, we calculated the ratio "passenger miles per bus mile" [Foerster, see Chapter Acknowledgment] using the Section 15 indicators of "Annual passenger miles" (by transit-UZA) and "Annual vehicle revenue miles" (by transit-UZA). This index, calculated for each of the 101 transit-UZAs, appears in the next column of Table 3.1 (Table 3.B, in Appendix 3.B, shows this set of transit-UZAs rank-ordered by this "bus load" index). Again, some of the smaller cities are at the top of the list; Providence, Harrisburg, Knoxville, and Norfolk (Table 3.*B*) head the ordering, and are followed closely by cities more likely "expected" at the top such as New York (Table 3.1).

Large values of this quotient are produced when the "passenger miles" value in the numerator greatly exceeds the "vehicle revenue miles" value in the denominator. Thus, relatively large numbers of passengers travel on a relatively small number of buses. In Providence, for example, one might expect, on average, to step on a bus carrying about 20 other people; in Los Angeles, on average, with about 16 others; in Detroit, with about 12 others; and, in Ann Arbor, with about 6 others. Values in this Table range from a high of 21.15 in Providence to a low of 3.94 in Corpus Christi: about a five-fold range from top to bottom.

High values on this indicator, when coupled with other factors involving vehicle stress resulting from heavy loading, might suggest an "excellent" transit system, as for example in the case of Seattle, or they might suggest a large percentage of automobile-deprived individuals. Also, a high value in a large city (coupled, again, with other indicators) is likely to suggest a load more stressful to a bus than would that value in a smaller city (all else being equal). Bus routes in a large city, that are not "express" routes, are likely to have more closely-spaced total stops over longer routes than are bus routes in smaller cities.

Bus-use index

To find a rough measure of the extent to which people actually use a bus system, another measure "external" to the buses themselves, we calculate the ratio of "Annual passenger miles per transit-UZA" divided by "1980 Total Population per transit-UZA" for each of the 101 UZA's. The final column of Table 3.1 shows these quotients for each transit-UZA (and Table 3.*C*, in Appendix 3.*C*, shows these transit-UZAs rank-ordered by this index). This index measures passenger miles, per person, in a year; a San Franciscan travels over 343 bus passenger miles per year, while a resident of Youngstown, Ohio travels a mere 10 bus passenger miles per year. No single indicator captures all of the complexity associated with congestion; some other indices which might work well with this one could be based on data concerning fleet size and average trip length in the region.

Because people use mass transit when they find it easier than driving or when they have no other alternative, this "bus-use" index also serves as a surrogate measure to general congestion external to the bus system itself. The extent to which people actually use the bus system is a reflection of underlying congestion and associated parking problems (as well as, of course, a number of other variables such as reliability of service, convenience to points of access, and comfort of ride).

This "bus-use" quotient measures a sort of average density of bus-use and therefore samples a bus system, in much the way the population density quotient samples a city area. Thus, as is the case for both San Francisco and Youngstown, one might suspect that a high (low) value on one suggests a high (low) value on the other (in which case there would be no point to having two indices). This is not the case, however, in all instances. The Detroit UZA which ranks relatively high on the population density index (10th), is considerably lower on the bus-use index (36th)—the "Motor City" is densely populated, but does not make extensive use of its bus system. San Francisco, on the other hand, ranks sixth on one index and first on the other; it is a densely-populated urban area that does make extensive use of its bus system. These two indices, when used together, therefore distinguish situations, in an apparently sensible manner, that would remain hidden using only one of the two.

CONGESTION PEER-GROUPS BY TRANSIT UZAs

Next, we use these three indices to partition the 101 transit-UZAs into congestion "peer-groups (terminology consistent with Section 15 usage)" of "dense," "intermediate," and "sparse" congestion. The main problem is to decide how to separate each list (Tables 3.*A*, 3.*B*, and 3.*C*) into classes. Values of the bus-use index are spread fairly symmetrically about the mean of the list; values of population density by transit-UZA, however, are skewed with respect to the mean of the list, due to the presence of a few UZA's with very large populations. Values of this index are compressed below the mean. Because we wish to compare values generated by bus-use density with those involving UZA population densities (Table 3.1), we simply partitioned the lists generated in Tables 3.*A*, 3.*B*, and 3.*C* into subsets of roughly even sizes (Appendices 3.*A*, 3.*B*, and 3.*C*) instead of partitioning them around the means of the lists. Breakpoints by variable, showing where the rank-ordered values for each index were partitioned, are shown in Table 3.2. Transit-UZAs falling in the top third of a given list are classified as "+;" those falling in the middle third as "0;" and, those falling in the bottom third as "−" (Table 3.2). Bus-load, for example, is therefore characterized as "heavy" when, on the average, more than 12 people would be expected to board at any stop, and "light" when fewer than 8 people would be expected to board at any stop.

TABLE 3.2. BREAKPOINTS BY VARIABLE FOR 101 TRANSIT UZAs

Classification	Number of UZAs	Breakpoints by variable		
		Population Density	Bus Load	Bus Use
+	33	>2750	>11.75	>118
0	34	2100-2750	8.24-11.75	56-118
-	34	<2100	<8.24	<56

Misclassification errors are likely near arbitrarily chosen lines of partition; thus, we might also have chosen to look for "natural" breaks in the data and used these to guide the choice for the lines of partition. However, as the bar charts associated with the rank-ordered lists for the first two indices suggest (Charts 3.A and 3.B, in Appendices 3.A and 3.B), there are few "obvious" breaks in the data associated with the population density and bus load variables. There appear to be sharper breaks in the bar chart associated with the rank-ordered bus-use values (Chart 3.C, in Appendix 3.C). For example, the disparity in bar height between UZAs 21 and 50, 11 and 43, and 77 and 74, is sharper than any found for the first two indices, but even these, when checked as to size of actual difference (Table 3.C), are of questionable sense.

Therefore, corresponding to the procedure of the previous chapter, each list of rank-ordered transit-UZAs is partitioned into three subsets; transit-UZAs are assigned ordered triples composed of "+," "0," or "−" according to relative positions on appropriate rank-ordered lists of population density, bus-load, and bus-use. Thus, for example, San Francisco is in the top third of all three lists and is assigned $(+,+,+)$; Detroit is in the top third on the population density and bus-load lists and in the middle third on the bus-use index and is assigned $(+,+,0)$; and, Youngstown is in the middle third on the population density index and in the bottom thirds of bus-load and bus-use and is assigned $(0,-,-)$.

Ordered triples are sorted, according to the number of triple-components of various types, into "dense," "intermediate," and "sparse" congestion peer-groups (Table 3.3). The densest class includes most of the largest (in total population) urbanized areas; however, it also includes some smaller places, such as Sacramento and El Paso reflecting the idea that gridlock can occur anywhere. The strictly intermediate class ($(0,0,0)$) and the sparsest class ($(-,-,-)$) contain no surprises.

The various hybrid intermediate classes might warrant a bit of reflection, but as a group seem sensible. The first component of the triple is the one which has least to do with the bus system, directly. Thus, a relatively high value of the first component followed by low values of the other two components would suggest an UZA in which the bus system is underutilized. The most extreme class of this sort would logically be that symbolized as $(+,-,-)$, comprising in this case, Allentown, Ann Arbor, and Bakersfield. Certainly in the case of Ann Arbor, the population density figure is high on account of the dormitory population at The University of Michigan; however, much of that population rides the free University of Michigan bus fleet (rather than the commercial Ann Arbor Transportation Authority bus fleet) when they ride a bus. The discrepancy in this case is not hard to explain. Reasons in other cases may well be more subtle, particularly in classes symbolized by $(+,0,0)$ (including Boston, Louisville, Rochester, San Diego, St. Louis, and Syracuse) and

TABLE 3.3. CONGESTION PEER GROUPS BY TRANSIT UZAs
(Entries are arranged alphabetically within each class)

DENSE CONGESTION:
32 Transit UZAs.

- Class (+,+,+):
  - Baltimore
  - Chicago
  - Cleveland
  - Denver
  - El Paso
  - Los Angeles
  - Miami
  - New Orleans
  - New York
  - Philadelphia
  - Providence
  - Sacramento
  - Seattle
  - San Francisco
  - Washington DC
- Class (+,+,0):
  - Buffalo
  - Detroit
  - Fort Lauderdale
- Class (+,0,+):
  - Madison
  - Portland OR
  - San Jose
- Class (0,+,+):
  - Cincinnati
  - Columbus
  - Hartford
  - Houston
  - New Haven
  - Pittsburgh
  - San Antonio
- Class (+,+,-):
  - No entries
- Class (+,-,+):
  - No entries
- Class (-,+,+):
  - Atlanta
  - Harrisburg
  - Knoxville
  - Norfolk

INTERMEDIATE CONGESTION:
27 Transit UZAs.

- Class (0,0,+):
  - Milwaukee
  - Tacoma
- Class (0,+,0):
  - Phoenix
  - Dayton
- Class (+,0,0):
  - Boston
  - St. Louis
  - San Diego
  - Louisville
  - Rochester
  - Toledo
  - Syracuse
- Class (0,0,0):
  - Albany
  - Albuquerque
  - Wilmington
- Class (0,0,-):
  - Rockford
- Class (0,-,0):
  - Bridgeport
  - Salt Lake City
  - Shreveport
  - South Bend
  - Tucson
- Class (-,0,0):
  - Charlotte
  - Hampton
  - Indianapolis
  - Jacksonville
  - Kansas City
  - Nashville
  - Raleigh
  - Scranton
  - Springfield MA
- Remaining intermediate classes:
  - Birmingham
  - Dallas
  - Fresno
  - Minn.-St. Paul
  - Omaha
  - Richmond
  - St. Petersburg
  - Spokane

SPARSE CONGESTION
32 Transit UZAs.

- Class (-,-,+):
  - No entries
- Class (-,+,-):
  - No entries
- Class (+,-,-):
  - Allentown
  - Ann Arbor
  - Bakersfield
- Class (-,-,0):
  - San Bernardino
  - Colorado Springs
- Class (-,0,-):
  - Baton Rouge
  - Bradenton
  - Chattanooga
  - Mobile
- Class (0,-,-):
  - Akron
  - Austin
  - Canton
  - Des Moines
  - Flint
  - Fort Wayne
  - Memphis
  - Peoria
  - West Palm Beach
  - Wichita
  - Worcester
  - Youngstown
- Class (-,-,-):
  - Augusta GA
  - Columbus GA
  - Corpus Christi
  - Fayetteville NC
  - Jackson MS
  - Little Rock
  - Oklahoma City
  - Orlando
  - Pensacola
  - Rock Island
  - Tulsa

by (0, −, −) (including Akron, Austin, Canton, Des Moines, Flint, Fort Wayne, Memphis, Peoria, West Palm Beach, Wichita, Worcester, and Youngstown). The class (−, −, 0), in which actual bus-use is higher than either density or bus-load, has Colorado Springs as an entry. This relatively heavy use might stem from the presence of the Air Force Academy and the resort trade, both drawing from non-resident populations without access to cars; this, however, is speculation based on the structure of the index rather than on direct knowledge of the situation. There are no entries in either the class (−, −, +) or in the class (−, +, −); this is not surprising. It is hard to conceive of situations in which transit-UZAs experience either bus-use or bus-load in the top third and yet have population densities in the bottom third; reality fits the conceptual context, confirming the value of this classification.

CONGESTION PEER-GROUPS BY TRANSIT AUTHORITY

Some transit-UZAs contain exactly one transit authority while others contain a number of distinct transit authorities: the transit-UZA for Detroit comprises one transit authority—that of New York City includes twenty-two transit authorities. This fact suggests that comparisons might sensibly be made between individual transit authorities rather than between transit-UZAs; looking at congestion at the scale of the transit authority is a natural scale transformation to consider.

On account of the complexity of dealing with 1980 census data sets by transit authority units we deal only with the index of bus-load, derived solely from Section 15 data, in assessing congestion by transit authority as a "dense," "intermediate," or "sparse" condition. The *style* of analysis would be similar, independent of the number of related indices employed.

Table 3.*D* (in Appendix 3.*D*) shows a rank-ordered list of values for the bus load index for all the transit authorities in each of the 101 transit-UZA's. Because we wish to see if this index is one that works in the same manner at the more local scale of the individual transit authority as it did at the more global scale of the transit-UZA, we apply the same numerical breakpoints to this list of transit authorities (Table 3.*D*) as we did to the list of transit-UZA's (Table 3.2). Thus, transit authorities with a bus-load of more than 11.75 are classed as dense, those with a load between 8.24 and 11.75 as intermediate, and those with a load less than 8.24 are classed as sparse. We need to evaluate whether or not this procedure is reasonable; that is, to evaluate whether or not the index is scale-free and stable over one or more transformations of scale as is the fractal concept of self-similarity.

Table 3.4 shows the set of all transit-UZAs composed of more than one transit authority. The left-hand column shows the name of the transit-UZA and the bus-load value associated with that transit-UZA (from Table 3.2). The row(s) corresponding to each transit-UZA show the names of the transit authorities composing the transit-UZA, their bus-load values, and whether they experience dense, intermediate, or sparse congestion as determined using

TABLE 3.4. TRANSIT AUTHORITIES FROM THE 32 UZAs WITH MORE THAN ONE TRANSIT AUTHORITY (TABLE 3.1) SEPARATED INTO CONGESTION CATEGORIES OF DENSE, INTERMEDIATE, AND SPARSE ACCORDING TO THE BUS-LOAD VARIABLE.
(As in Table 3.2, "dense" is greater than 11.75; "sparse" is less than 8.24; "intermediate" is between those two. Bus-load values are shown in brackets follwing the UZA or transit authority name. UZAs are rank--ordered by bus load value. Asterisk indicates suspect data.)

UZA NAME	TRANSIT AUTHORITY NAMES BY UZA		
	DENSE CONGESTION	INTERMEDIATE CONGESTION	SPARSE CONGESTION
[21.15] PROVIDENCE	[22.52] Providence	No entries	[3.85] Gr. Attleboro-Taunton
[17.51] SAN FRANCISCO	[23.17] San Francisco MUNI [21.60] San Fran. Golden Gate [17.63] San Mateo [14.55] Alameda Contra Costa	No entries	[6.01] Central Contra Costa [4.39] Vallejo Transit
[17.17] BALTIMORE	[17.68] Columbia TS [17.16] Baltimore MTA	No entries	No entries
[17.04] LOS ANGELES	[18.85] Los Angeles SCRTD [17.50] Santa Monica [12.13] Orange County	[11.11] City of Torrance [11.06] Long Beach [10.72] Culver City [9.04] Montebello	[7.31] City of Commerce [6.09] Gardena [5.51] Norwalk [3.54] Hermosa Beach Free Bus
[15.89] SEATTLE	[16.83] Seattle Metro	[11.65] City of Everett [10.06] Lynnwood	No entries
[15.42] HOUSTON	[117.49] Houston-Korrville * [14.06] Houston MTA	No entries	No entries
[15.10] WASHINGTON DC	[15.62] Washington-WMATA	No entries	[7.51] Rockville Ride-On
[14.73] NEW YORK CITY	[41.88] Putnam Area RT [28.96] Yonkers-Liberty Lines [28.39] Yonkers-Riverdale [25.56] East Meadow MSBA [24.39] Yonkers-Pelham Parkway [23.24] Brooklyn-Command [22.11] Queens Transit [21.09] New York CTA [18.55] Steinway Transit [17.30] Bergenfield-Rockland [16.14] Jamaica-Green [14.63] New York-Jamaica [13.89] Long Beach [12.09] Westchester County	[10.03] J'kson Heights-Triboro [9.58] Newark NJT [8.73] Pomona of Rockland [8.27] Huntington Area	[4.47] Nanuet, Clarkstown Mini [4.08] Houppage-Suffolk [3.67] Village of Spring Valley [2.63] Yonkers Airport
[14.62] NEW ORLEANS	[14.87] New Orleans [13.75] Gretna Westside [13.50] Harahan	No entries	[6.22] Chalmette-St. Bernard
[14.13] CHICAGO	[27.46] Harvey-Safeway [16.77] West Towns [16.58] East Chicago [14.59] Chicago CTA [12.56] Des Plaines N. Suburban	[9.79] Waukegan [9.14] Wilmette	[6.87] Elgin [6.13] Glen Ellyn [6.07] Naperville GNATS [5.06] Gary [3.38] Highland Park [3.09] Chicago RTA [2.64] Niles [2.39] Hammond
[13.81] PITTSBURGH	[14.08] Pittsburgh PAT [13.05] Beaver BCTA	[10.87] Westmoreland County	[7.62] Greater Aliquippe [3.21] Wash.-Cannonsburgh
[13.90] DAYTON	[14.36] Dayton Miami Valley	No entries	[7.25] Middletown
[13.78] SACRAMENTO	[13.86] Sacramento [12.70] Woodland-Yolobus		
[13.10] PHILADELPHIA	[15.42] Philadelphia SEPTA	No entries	[7.57] Newark NJT/Phil. [5.28] Pottstown

[12.72] CINCINNATI	[13.77] Cincinnati SORTA	No entries	[7.60] Fort Wright of No. Ky
[12.60] HARTFORD	[12.95] Hartford CT	No entries	[6.05] Middletown
[12.00] FORT LAUDERDALE	[12.21] Metro Dade-Broward	No entries	No entries
	[12.00] Ft. Lauderdale-Broward		
[11.84] DALLAS	[13.33] Dallas TS	No entries	[7.82] Fort Worth CITRAN
			[6.97] Dallas SURTRAN
[11.65] NEW HAVEN	[11.80] New Haven-CT	No entries	[4.13] Wallingford-NE
[10.48] MILWAUKEE	No entries	[10.80] Waukesha County	[3.02] Waukesha Metro
		[10.65] Milwaukee County	
[10.33] BOSTON	No entries	[10.99] Brockton Area	[6.84] Fitchburg, Montachusett
		[10.40] Boston MBTA	[3.84] Lowell
			[1.76] Gloucester-Cape Ann
[10.18] SAN DIEGO	[14.25] San Diego TS	No entries	[6.07] San Diego Regional TS
			[5.92] North San Diego TO
[9.42] ST. PETERSBURG	No entries	[9.99] St. Petersburg	No entries
		[8.68] Pinellas Suncoast	
[9.37] SCRANTON	No entries	[10.45] Kingston-Luzerne	[7.84] Scranton-Lackawanna
		[9.17] Nanticoke	[2.74] Wilkes Barre-Williams
[9.16] WILMINGTON	No entries	[9.52] Wilmington DART	[7.48] Dover, Delaware TA
			[5.37] Newark-NJT/Wilmington
[8.96] BRADENTON	No entries	[9.46] Bradenton-Manatee Cty	No entries
		[8.50] Sarasota County	
[8.90] SYRACUSE	No entries	[10.42] Auburn-Onondaga	[2.82] Syracuse and Oswego
		[9.51] Syracuse-CNY Centro	
[8.29] ROCKFORD	No entries	[8.42] Rockford MTD	[7.22] Loves Park
[8.10] SAN BERNARDINO	No entries	[8.67] San Bern. Omnitrans	[7.14] Riverside Transit
[8.04] BRIDGEPORT	[16.67] Greater Bridgeport	No entries	[2.23] Milford
[5.54] AKRON	No entries	No entries	[7.65] Kent Campus Bus
			[4.94] Akron Metro RTA
[4.85] ROCK ISLAND	No entries	No entries	[5.76] Rock Island IL
			[4.40] Davenport IA
			[2.11] Bettendorf IA

the transit–UZA breakpoints (Table 3.2). Thus, for example, Providence, as a transit–UZA has a dense bus-load value of 21.15 and is composed of two transit authorities, one serving "Providence" with a "dense" bus-load value of 22.52, and one serving Greater Attleboro and Taunton with a "sparse" bus-load value of 3.85.

A closer look at Table 3.4 shows that many of the transit–UZAs classed as "dense" (bus-load values greater than 11.75) have not only transit authorities of "dense" congestion, but also transit authorities experiencing lighter congestion (either "intermediate" or "sparse," or both). Typically, these transit–UZAs have one or more dominant transit authorities, likely serving the CBD or other regions of heavy population concentration, and one or more transit authorities serving suburban areas. Providence exhibits this pattern, as do the transit–UZAs for San Francisco, Los Angeles, Seattle, Washington D.C., New York City, New Orleans, Chicago, Pittsburgh, Dayton, Philadelphia, Cincinnati, Hartford, and Dallas. The only other logical possibility is that a transit–UZA with dense congestion might consist *only* of transit authorities with dense congestion (it cannot happen, in terms of numerical characteristics, that a "dense" transit–UZA fails to have a "dense" transit authority). Indeed, Baltimore and Houston are two such transit–UZAs.

Thus, there are logically two distinct configurations of transit authorities, as to congestion class, with "dense" transit–UZAs:

1. those with at least one "dense" transit authority and others of lighter congestion,
2. those with at least one "dense" transit authority and no others of lighter congestion.

In the "dense" class of transit–UZAs, the Law of the Excluded Middle, one of the fundamental, logical premises underlying commonly-used measurement systems, exhausts all possible cases.

One might expect that the Law of the Excluded Middle would not produce a corresponding structure for the exhaustion of the case for the "intermediate" transit–UZAs. For, it would be natural to consider that "intermediate" transit–UZAs might generally be composed of dense and sparse (and intermediate) transit authorities whose bus-load values average out in some way to an intermediate value describing the bus-load for the entire UZA. This is not generally the case, however. Table 3.4 shows that only the intermediate transit–UZAs of New Haven and San Diego exhibit this pattern. In all other cases, the congestion class (based on bus-load) of the transit–UZA serves as an upper bound on the set of congestion classes available to be assigned to the transit authorities composing that transit–UZA: transit–UZAs of intermediate congestion are composed of transit authorities experiencing, themselves, intermediate or sparse congestion (**not** dense congestion). The situation of dominant and subordinate transit authorities prevails, and the Law of the Excluded Middle does serve, for the most part, to exhaust all cases in the set of transit–UZAs experiencing intermediate congestion. Thus, the set of "intermediate" transit–UZAs is well-described by two logically distinct configurations of transit authorities:

1. those "intermediate" transit–UZAs with at least one "intermediate" transit authority and others of lighter congestion,
2. those "intermediate" transit–UZAs with at least one "intermediate" transit authority and no others of lighter congestion.

Milwaukee, Boston, Scranton, Wilmington, and Syracuse are of the first type; St. Petersburg and Bradenton are of the second type. New Haven is right at the boundary separating "dense" from "intermediate;" San Diego is an exception.

A similar situation holds in the case of the "sparse" transit–UZA (bus–load value less than 8.24). The transit–UZAs with bus–load values close to the breakpoint of 8.24, San Bernardino and Bridgeport, do not follow a corresponding pattern. Those transit–UZAs with bus–load values clearly in the "sparse" range (Akron and Rock Island) do follow the pattern suggested above: they have only "sparse" transit authorities. Here, the sample size is really too small to deal with in any sensible manner; however, that is not surprising. Why should transit–UZAs that experience only sparse congestion overall, be partitioned into a number of transit authorities?

What all this suggests is that there is some sort of "inheritance" of congestion type (as an upper bound with respect to density of congestion) from transit–UZA to transit authority; that using the breakpoints from the transit–UZA scale to partition data at the transit–authority scale produced sensible results. This "sensibility" might be expressed systematically, by saying that under this scale transformation (again from an Excluded Middle perspective), either

1. it is correct to assign only the congestion class of the transit–UZA itself, and those classes representing sparser congestion, to all transit authorities within the transit–UZA (as with Providence), or
2. it is correct to assign only the congestion class of the transit–UZA itself to all transit authorities within the transit–UZA (as with Baltimore).

From an analytical viewpoint, it is the logical Fallacy of Division [3] (the so–called Ecological Fallacy of sociology) that involves attributing *erroneously* the characteristics of the whole to each of its parts, that has been examined to determine the sensibility of the transformation of assigning breakpoints across different geographic scales. In light of this analysis, it appears that this index of bus–load is relatively free from scale effects under this transformation.

ANN ARBOR: CITY CONGESTION BASED ON BUS-ROUTES

Finally, we transform ideas concerning congestion, particularly those of "bus-load" to the scale of the individual transit authority. Here, Section 15 data is useless: the entire Ann Arbor Transit-UZA and the Ann Arbor Transportation Authority (AATA) are characterized as "sparse," on the bus-load index. Thus, before we can consider the sensibility of partitioning "bus-load" data using breakpoints of Table 3.2, or of forming classes of AATA route segments that have "dense," "intermediate," or "sparse" congestion, it is necessary to devise a way to refine the measures derived from Section 15 data so that they might incorporate data from the local transit authority.

The bus-load index, as calculated from Section 15 data, was figured as Annual Passenger Miles per Bus Mile. In the case of Ann Arbor, we therefore seek a similar figure; the difficulty with using exactly this index is that it would simply repeat values already obtained using the general Section 15 data. Thus, we look first to determine where the bus routes actually are in relation to the population: in the context of this study, this is done to illustrate that this bus system is not "sparsely" loaded as a result of being inaccessible to much of the population.

With this established, we then employ data from actual headcounts of passengers boarding and deboarding on inbound and outbound buses and partition them into quarters to come up with "dense," "intermediate," and "sparse" thirds (as do three edges linking four vertices, linearly) for bus-routes. Long-standing experience with this transit system and its routes suggests whether or not the transformation of "bus-load" to this scale is sensible.

The Urban Area Served by the Ann Arbor Transportation Authority

Ann Arbor-Ypsilanti is presently served by 20 distinct bus routes. At the time of writing, comprehensive data were available from AATA for 18 of the 20 routes [4]—the same 18 as in the previous Chapter, suggesting the possibility of overlays with maps from the last chapter (Figure 2.9) to determine "worst-possible" route segments. Generally, AATA bus routes fan out from central termini in the CBD's of Ann Arbor and Ypsilanti, across a loosely-defined combination grid and radial street pattern, to serve (from over 1100 bus stops) a population moving from home to workplace to schools to shopping centers and so forth.

Both Ann Arbor and Ypsilanti house major state universities. The University of Michigan, in Ann Arbor, has an enrollment of around 35,000 students, many of whom claim residence in Ann Arbor; these students are therefore included in the Census count of local population [5]. This University maintains its own separate bus system that effectively transports students, faculty, and staff from the Central Campus, just east of the CBD, to the North Campus, north east of the CBD and across the Huron River (Figure 2.9). In contrast to the commercial service provided by AATA, this bus service is free to qualified riders; interchange between free and commercial systems is easily accomplished at about six locations. Eastern Michigan University, in Ypsilanti, has an enrollment of around 25,000 students, many of whom commute and do not claim a residence in Ypsilanti; these students are therefore excluded from the Census count of the local population. This University does not have its own bus service; its students are reliant on public transportation, on car-pooling, or on individual use of private cars.

Population Concentrations: A Visual Approach

To provide access to bus routes, for the non-dormitory population in particular, the AATA has attempted to position routes in such a way that no member of that underlying population is more than 1/4 mile from a bus stop. Because bus-stop position can be changed more flexibly than can route position, we encased each route in an "envelope" of width one-quarter mile in order to evaluate proximity of the population to bus service (Figure 3.1). Service zones one-quarter mile on either side of the 20 distinct bus routes serving the Ann Arbor-Ypsilanti area leave 24 "islands" (or "peninsulas") of territory within city limits that are unserved (according to this criterion) by AATA bus routes (Figure 3.1). When we shaded these islands and peninsulas, the bus route envelope for the whole metro area stood out quite clearly, as do Mark Jefferson's rail net patterns in Europe [6], as do Nystuen's "boundary dwelling" regions along a coastline [7], and as do "buffers" in Geographic Information Systems that display (for example) the use of land parcels contiguous to roadways [8]. Areas served by bus routes, according to AATA's 1/4 mile specification, are thus separated from areas not served by bus routes (in a few instances a bus route travels outside the metropolitan boundaries–in such cases, the envelope is not included in Figure 3.1). In the case of Ann Arbor, the irregular street pattern creates islands of various shapes and makes difficult the filling in of the bus network coverage. In a city like Chicago, one might expect mostly rectangular islands (if any) with only a few angled cuts.

To estimate the percentage of the city's population within each island, a percentage dot map (Figure 3.2) was superimposed on the map showing regions served by bus routes (Figure 3.1). The percentage dot map was formed by placing evenly-spread dots within each "block" on a map of Census Tracts and Blocks [5; base map was from the Washtenaw County Planning Commission–see end of Chapter Acknowledgment] in such a way that each dot represents $1/10^{th}$ of 1% of the entire population of Ann Arbor-Ypsilanti, or, 132 individuals. Census data, corresponding to the map, was used to find the numbers of individuals per map unit (block). The positions of dots within each unit may deviate from an "evenly-spread" within-unit distribution, reflecting our knowledge of highly localized positions of

FIGURE 3.1.

ISLANDS OUTSIDE AN ENVELOPE OF RADIUS 1/4 MILE ENCASING EACH AATA BUS ROUTE (SHADED AREAS REPRESENT ISLANDS).

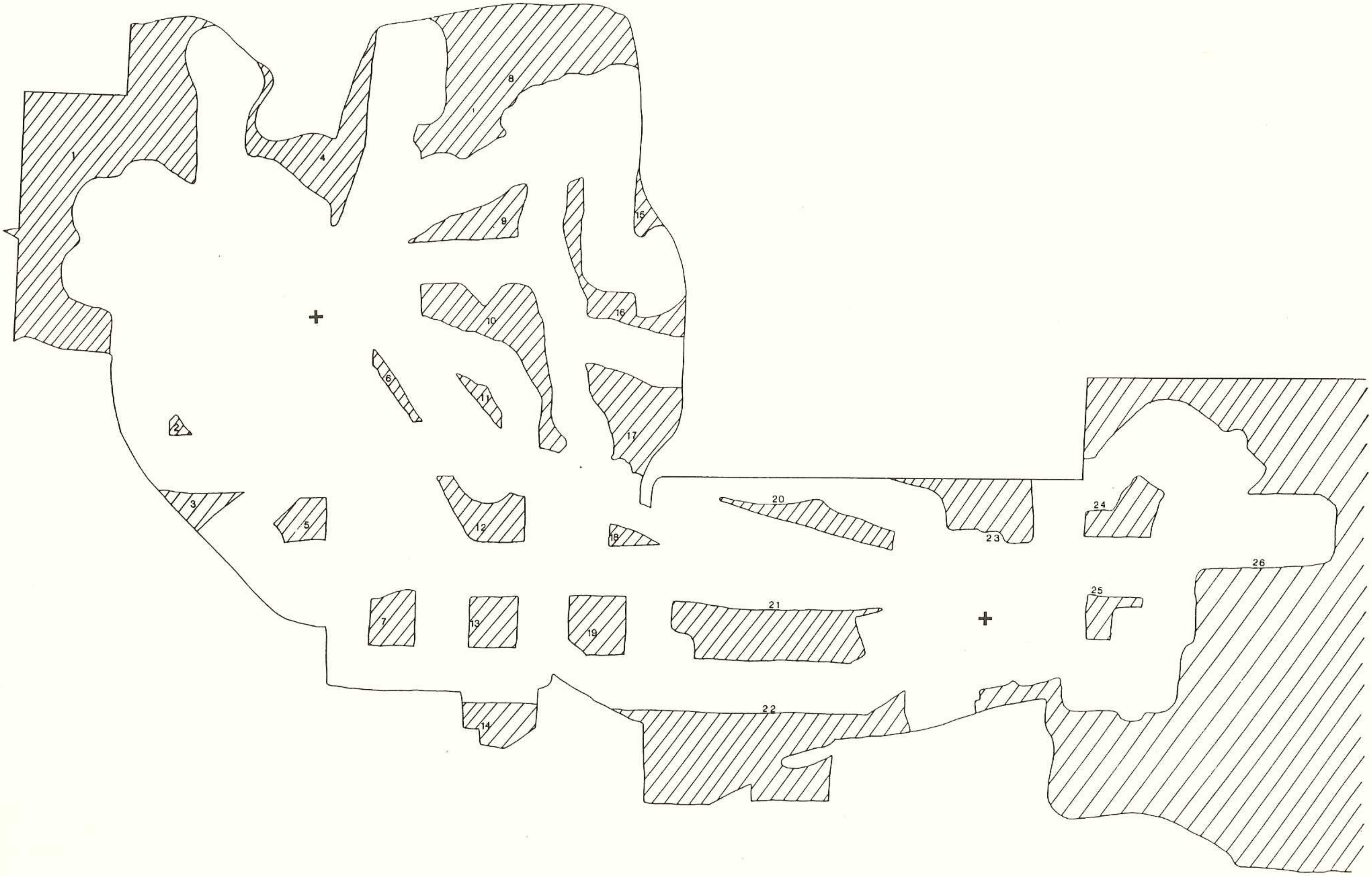
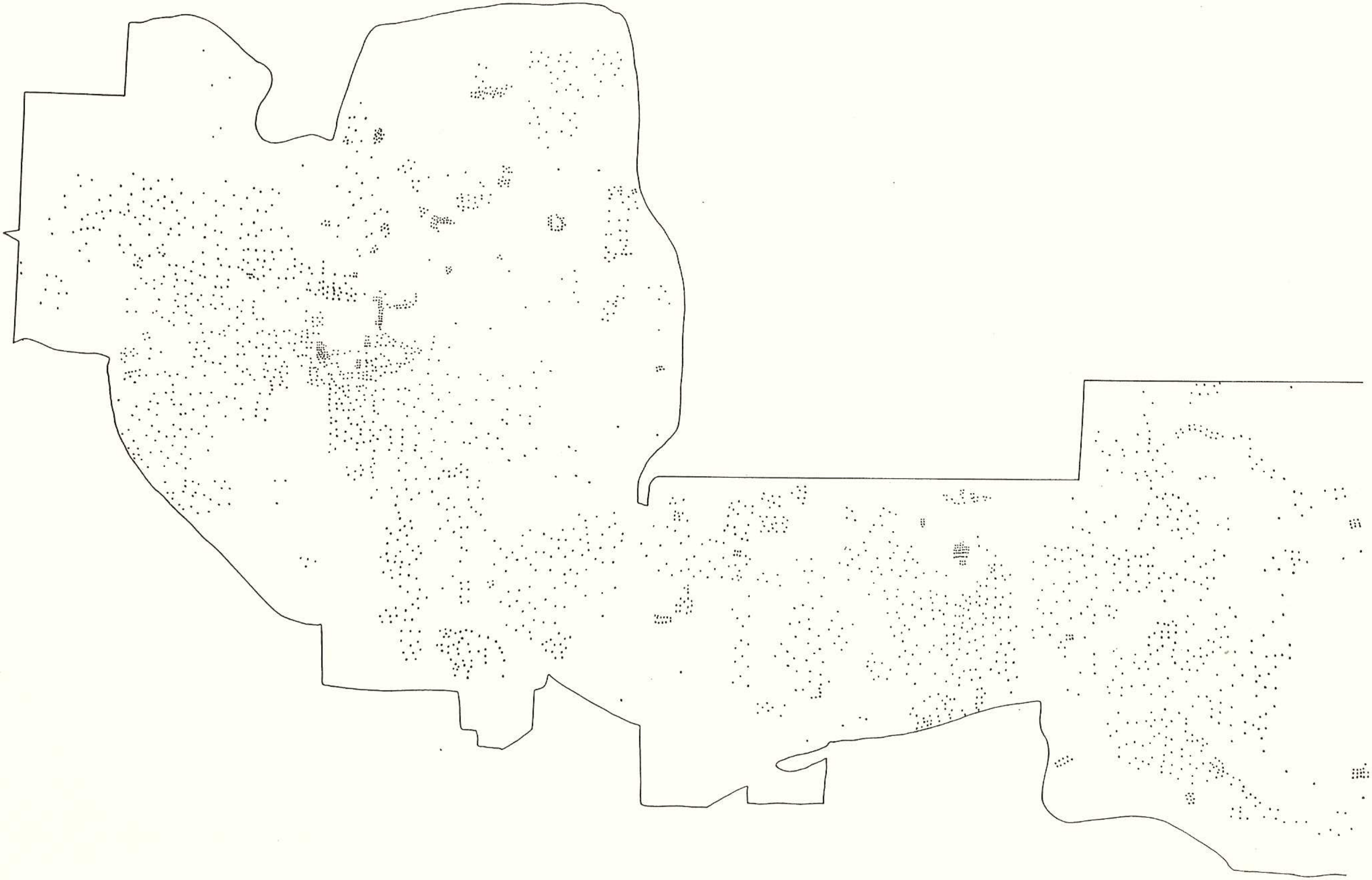


FIGURE 3.2.

ANN ARBOR–YPSILANTI: PERCENTAGE DOT MAP OF POPULATION.

One dot represents 132 individuals. Aggregation units from U. S. Census block data.



concentrated pockets of population, such as University of Michigan dormitories. This map may be used to generate quick estimates of the percentage of population contained within a subregion with an irregularly-shaped boundary and it may also be extended easily, without altering the basic map, to accommodate changes through time in the underlying population, simply by adding or deleting suitable dots.

Thus, when the population dot map (Figure 3.2) is used in conjunction with the bus-route envelope map (Figure 3.1), a quick estimate of the population within bus route envelopes, can be calculated. Of further interest is the number of individuals not served within the 1/4 mile bus-route envelopes. Table 3.5 shows the results of counting the dots (Figure 3.2) in the unserved islands of Figure 3.1.

A total of 67, 584 people, of the 131, 997 in the metropolitan area (smaller than the Section 15 transit UZA), are estimated by superimposition of the dot map (Figure 3.2) on the envelope map (Figure 3.1) to live outside bus route envelopes. By far the largest single grouping lives in #26, the portion of Ypsilanti not currently served by AATA. Discounting this, a total of 38, 016 individuals do not lie within the 1/4 mile bus route envelope. Further, islands that are located within The University of Michigan campus are serviced by U-M buses–island 9 in Figure 3.1 is such a location. Thus, another 792 not originally included in the 38, 016 have easy access to bus service, leaving 37, 224 as the remainder outside the 1/4 mile bus route envelope. When coupled with information concerning origin–destination patterns, auto ownership, relative auto/bus travel times, and the like, the added visual evidence of Figure 3.1 might suggest that substantial improvement in service could come from introducing an east–west bus route along a road bisecting islands 7, 13, 19, and 21 serving 9504 people previously outside the 1/4 mile envelope. Apparently much of the population has easy access to the bus network.

Local Congestion Based on Bus–Stop Spacing

Table 3.*B* shows that Ann Arbor has a value of 7.64 on the bus–load index for the entire Ann Arbor transit–UZA. This places the entire transit authority into the "sparse" peer–group according to the breakpoint of 8.24, separating the sparse from the intermediate peer–groups, as listed in Table 3.2. Thus, we look to Section 15 measures of the boarding, deboarding population, and to inferred measures of transferring population, to provide more refined local insight into the nature of the "bus–load" along segments of individual bus routes. Data concerning the boarding and deboarding populations describe actual bus–load at selected sampling points along each route, and the measures assigning extra weight to transfer points between bus routes distinguish the locations with the potential for an unusually heavy boarding and deboarding population. To use these measures to find seg-

TABLE 3.5. POPULATION NOT WITHIN 1/4 MILE OF A BUS ROUTE (by island number in Figure 3.1).

Island Number	Population not within 1/4 mile of a bus route.
1	1980
2	396
3	1584
4	2112
5	0
6	1848
7	1980
8	7128
9	792
10	660
11	132
12	1320
13	1188
14	0
15	264
16	1584
17	132
18	528
19	660
20	1716
21	5676
22	660
23	3168
24	1584
25	924
26	29,568

ments where congestion due to "bus–load" is densest, we use the following visual strategy to pinpoint locations of concentrated pockets of population along bus–routes.

When key points, designated as timepoints on Section 15 forms for the AATA service areas, are used as centers of circles of radius one–quarter mile, a pattern of tightly clustered circles appears in the CBD and disperses with distance from the CBD. Specifically, in Figures 3.3, 3.4, 3.5, and 3.6, circles of radius 1/4 mile are centered on "timepoints," chosen by AATA as significant stops along each of the 18 bus routes, located in their correct positions. To consider the extent of local congestion along each route, or the potential for such congestion, we might have superimposed the dot map (Figure 3.2) on the maps of timepoint circles; because, however, there is necessarily error in the placement of the dots representing population and because a circle centered on a timepoint covers only an area of at most 0.2 miles we thought it more prudent to use only actual AATA data based on headcounts of numbers of passengers boarding and deboarding (leaving) buses to evaluate "bus–load".

The average populations boarding and deboarding at each timepoint are characterized as a percentage of the systemwide boarding and deboarding population. When the transit–UZA value of 7.64 (from Table 3.B) is superimposed on these rank–ordered percentages as the scale transformation, it falls close to the median (8), of the actual distribution, as calculated below. The top quarter of the data set contains entries of greater than or equal to 1.7% of boarders (deboarders) systemwide; the next quarter, those greater than or equal to 0.6% and less than 1.7%; the third quarter, those entries greater than or equal to 0.2% and less than 0.6%; and the bottom quarter, those less than 0.2%. (The distribution of values is badly skewed to the left so that median and quartile are better measures of central tendency than are mean and standard deviation.) A median weekday total passenger load is 13, 747, all of whom board and deboard once. Thus, applying the quartiles to this figure puts timepoints with more than 23 individuals waiting at them into the top quarter; those with more than 8 but fewer than 23 into the second highest quarter; those with more than 3 but fewer than 8 into the third quarter; and those with 0, 1, or 2 individuals as the least crowded timepoints. The closeness of the abstractly–determined value of 7.64 from the scale transformation to the actual median value of 8 is therefore highly encouraging in viewing the abstract notion of bus–load as one that, in some sense, is invariant under the transformation of scale change of transit region.

When the circles centered on the timepoints are shaded to correspond with the data given by quartile, Figures 3.3, 3.4, 3.5, and 3.6, exhibit a four-tiered pattern suggesting a range of values for boarding and deboarding values, inbound and outbound, from high to low. ("Inbound" and "outbound" always are in reference to the Ann Arbor CBD; thus, a bus approaching the Ypsilanti CBD is an "outbound" bus, moving away from the Ann Arbor

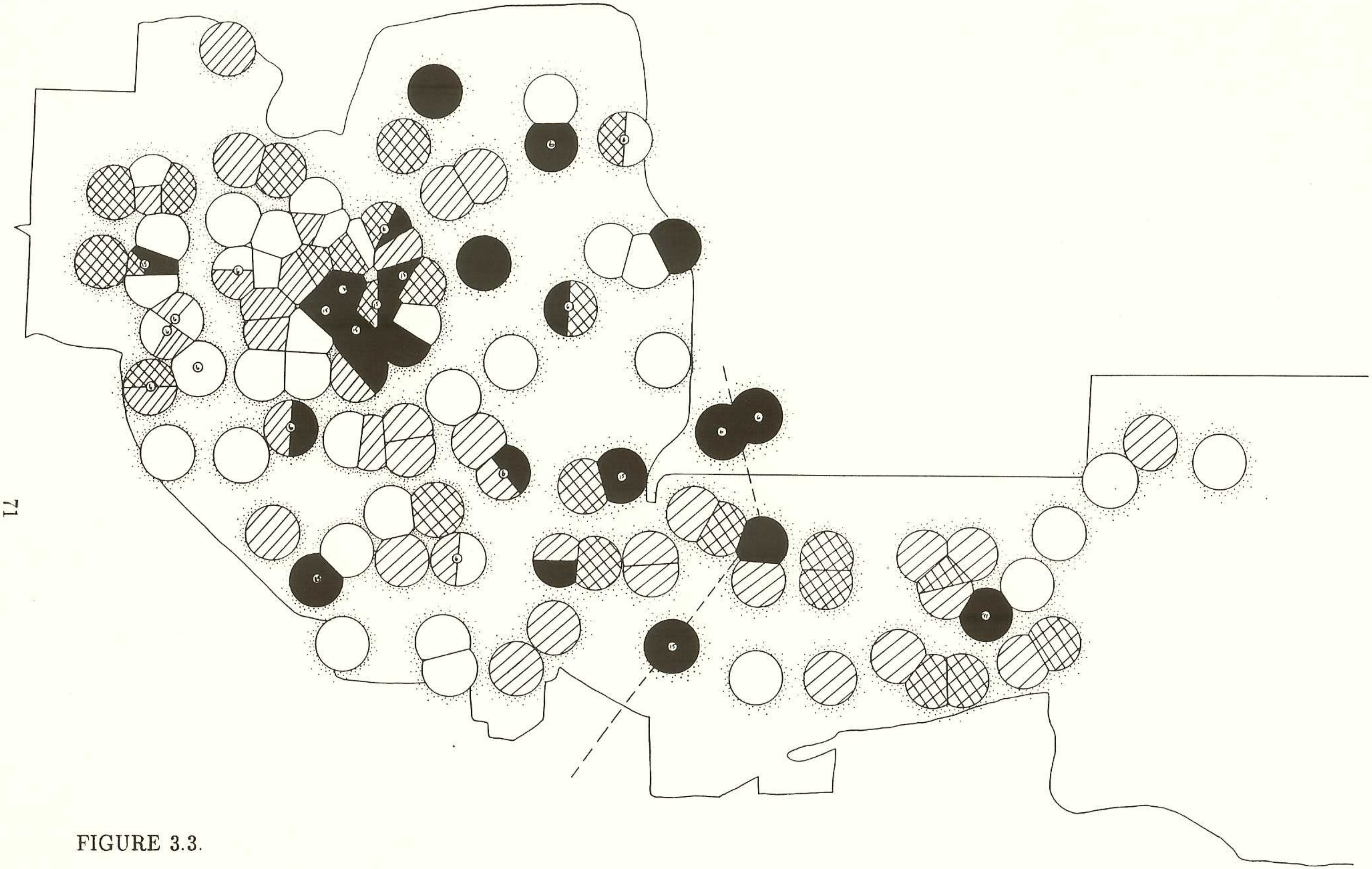


FIGURE 3.3.

POPULATION BOARDING BUSES OUTBOUND FROM ANN ARBOR CBD AT AATA-SELECTED TIMEPOINTS.

Timepoint circles shaded black represent an average of 23 or more boarding; those shaded with a criss-cross pattern, 8–22; those shaded with a striped pattern, 3–7; and, those left blank, 0, 1, or 2. Numbers interior to circles represent non-trivial transfer weights.

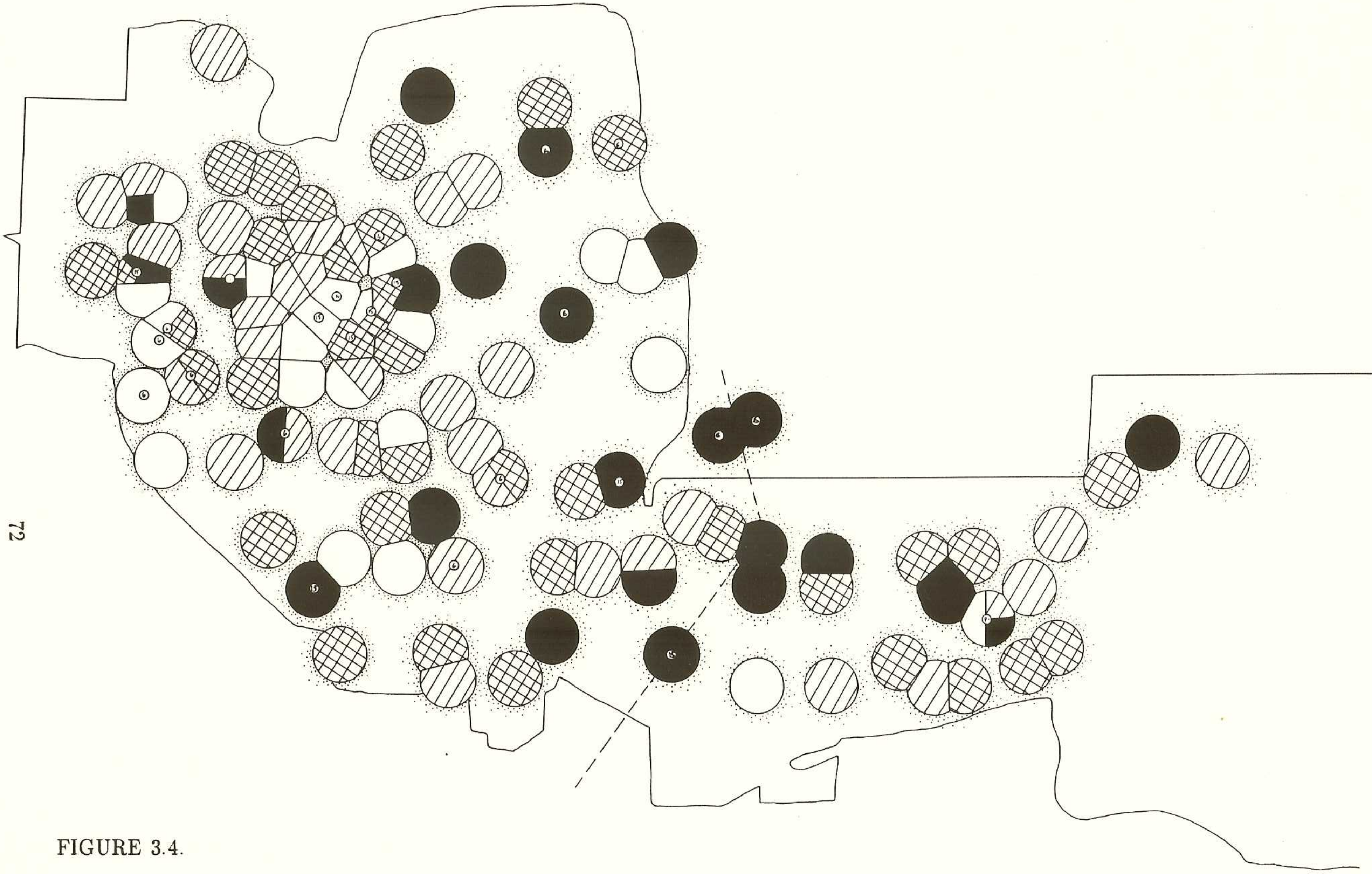


FIGURE 3.4.

POPULATION DEBOARDING BUSES OUTBOUND FROM ANN ARBOR CBD AT AATA-SELECTED TIMEPOINTS.

Timepoint circles shaded black represent an average of 23 or more deboarding; those shaded with a criss-cross pattern, 8–22; those shaded with a striped pattern, 3–7; and, those left blank, 0, 1, or 2. Numbers interior to circles represent non-trivial transfer weights.

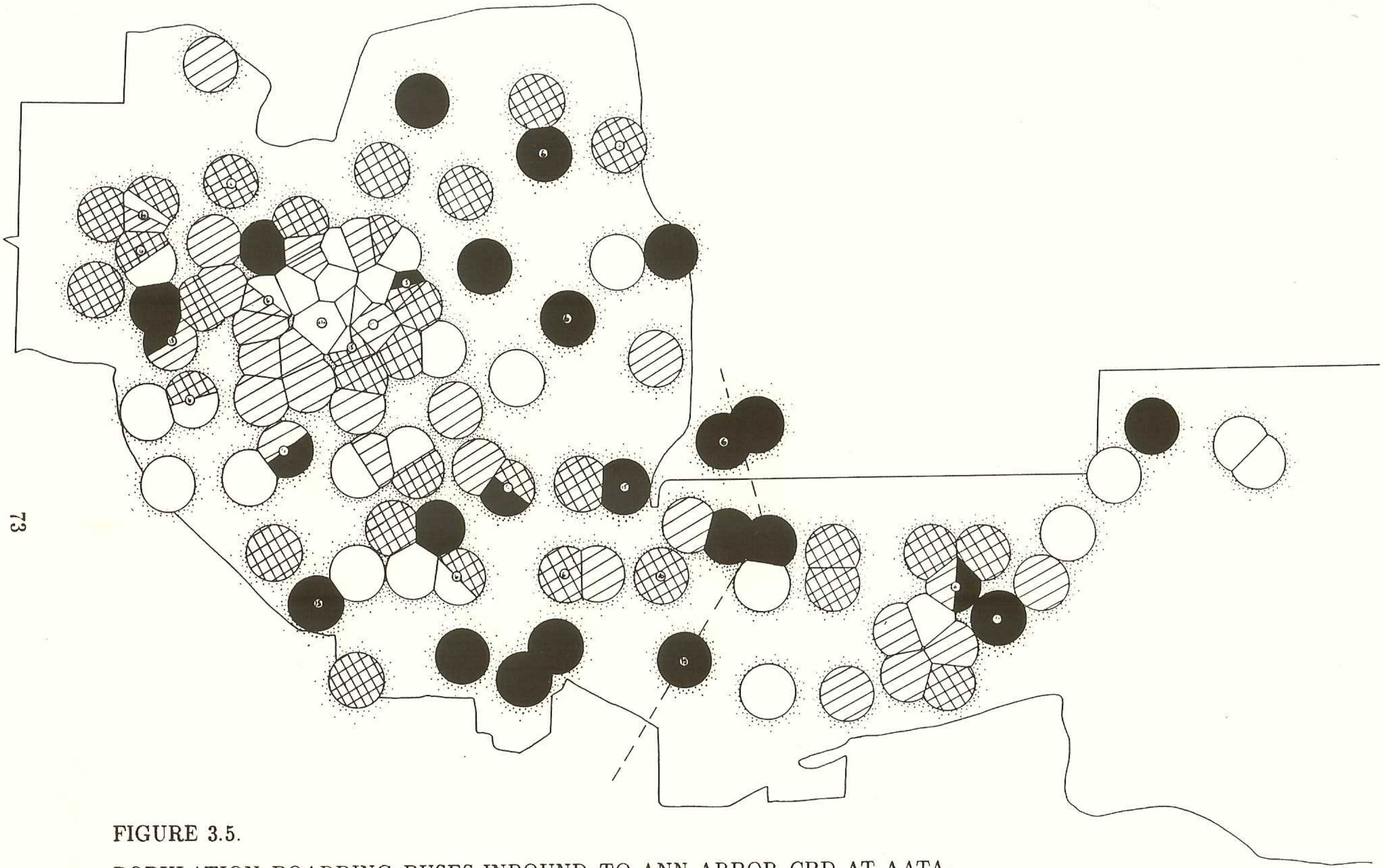


FIGURE 3.5.

POPULATION BOARDING BUSES INBOUND TO ANN ARBOR CBD AT AATA-SELECTED TIMEPOINTS.

Timepoint circles shaded black represent an average of 23 or more boarding; those shaded with a criss-cross pattern, 8–22; those shaded with a striped pattern, 3–7; and, those left blank, 0, 1, or 2. Numbers interior to circles represent non-trivial transfer weights.

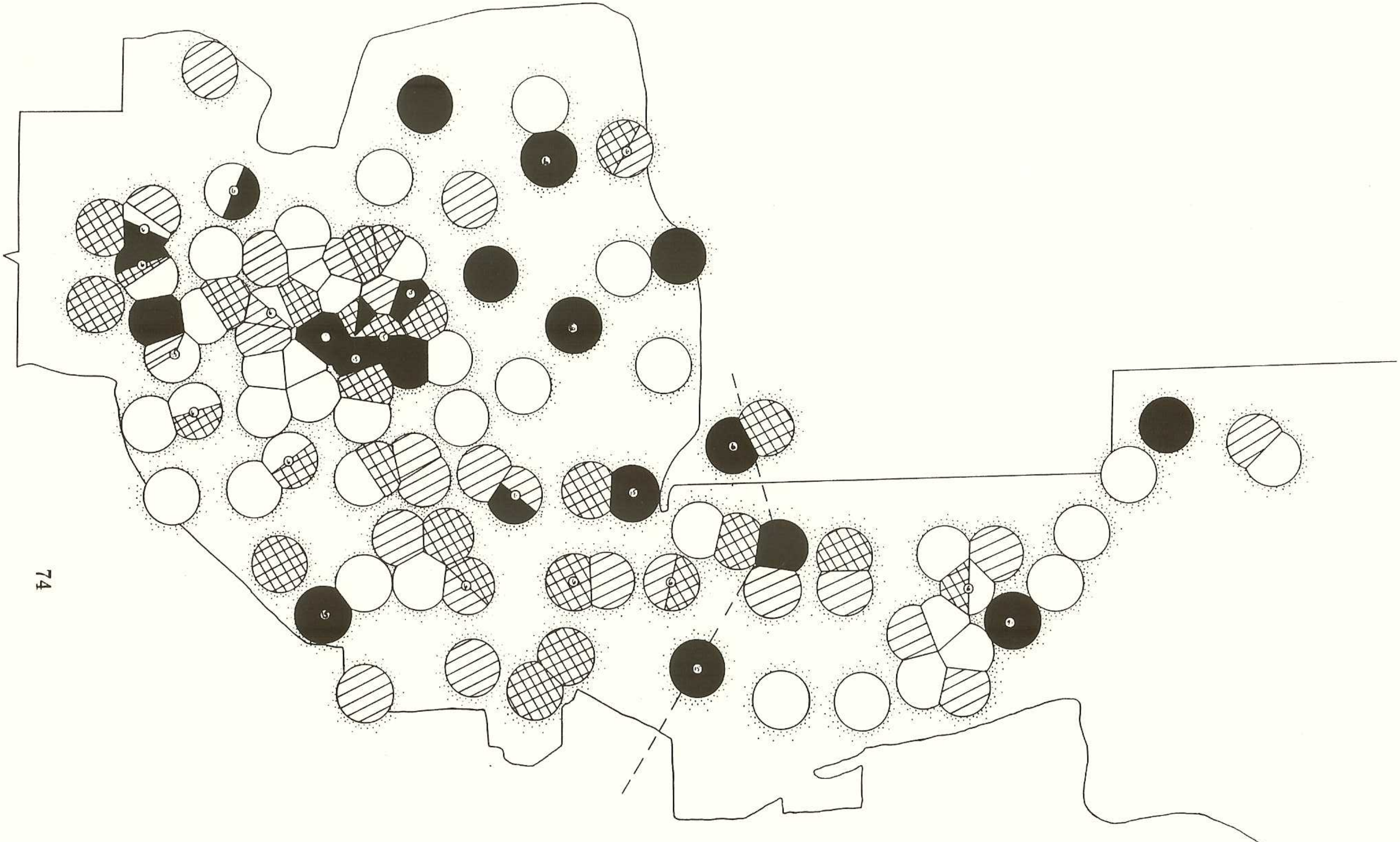


FIGURE 3.6.

POPULATION DEBOARDING BUSES INBOUND TO ANN ARBOR CBD AT AATA-SELECTED TIMEPOINTS.

Timepoint circles shaded black represent an average of 23 or more deboarding; those shaded with a criss-cross pattern, 8–22; those shaded with a striped pattern, 3–7; and, those left blank, 0, 1, or 2. Numbers interior to circles represent non-trivial transfer weights.

CBD.) Figures 3.3 and 3.4 are based on data for outbound buses; they show by quartile the percentage of individuals, systemwide, boarding (deboarding) buses from each timepoint. Figure 3.4 shows by quartile the percentage of individuals, systemwide, deboarding buses from each timepoint. Figures 3.5 and 3.6 are based on data for inbound buses, and show by quartile the percentage of individuals, systemwide, boarding (deboarding) buses from each timepoint. In all cases the data reflect total daily boarding (deboarding).

The underlying pattern of circles, which is identical in the two outbound maps (although the pattern of shading is not) clearly differs from the pattern of circles underlying both inbound maps. The inbound set differs from the outbound set because, in some cases, the bus makes a circuit near its terminus, while in others the difference occurs because AATA has simply designated different timepoints as checks on the progress of inbound and outbound buses. Timepoints inbound and outbound may produce different partitioning of the circles–both in terms of which circles are partitioned and into how many sectors a given circle is cut.

When viewed generally, all four maps conjure up a variety of images: from soap bubbles crushed together at Steiner points to fill CBD space with smaller bubble clusters at the edge of the UZA boundary, to embryonic cellular growth. These Figures suggest a number of more detailed insights about local congestion along bus routes which might best be observed within the following conceptual context.

First, deboarding should add more to congestion outside the bus than does boarding: both processes represent many-to-one relationships. Many people come to wait at a bus-stop to board a single bus; they arrive at different times and gather as an orderly mass directly next to where the bus will stop to pick them up. On the other hand, when the bus stops, many people deboard the bus and scatter simultaneously, causing a brief, potential source of local congestion.

Second, an additional source of local congestion arises from the variation in function of stops. Some stops present the opportunity for transferring from one route to others, while many other stops serve only a single route. Transfer points, in addition to obvious Central Business District stops, are locations with potential for high levels of passenger loading.

To regularize the data by accounting for the transfer possibility, we assign values to transfer stops, as "transfer weights," based on the potential for interaction between bus routes. The transfer weight is calculated as the combination of twice the number of routes at the stop taken two at a time. The rationale for this is that the passenger can choose from among all the routes, but at that particular stop at that particular time, can transfer only from one bus route (either inbound or outbound, but not both) to exactly one other bus route (either inbound or outbound, but not both). The distinction between inbound and outbound accounts for the doubling of the number of routes in the calculation of the transfer weight.

When these weights were calculated for each of the set of timepoints displayed in Figures 3.3 to 3.6, values ranged from a high of 630 to a low of 6 (Table 3.6); any stop which does not permit route transfers is assigned a value of 2 (from the combination of two routes (one inbound and one outbound) taken one at a time). The highest value occurs at the central terminus in downtown Ann Arbor; the next highest occurs at the central terminus in downtown Ypsilanti. Other values greater than 2, but substantially less than the two CBD values, occur typically at area shopping malls near the urban fringe, at high schools, and at hospitals. Of particular note is the northeasterly axis of values of 15 leading away from the Ann Arbor CBD toward the Central Campus of The University of Michigan and the higher transfer weights just northwest of the Ypsilanti CBD representing the campus of Eastern Michigan University (direct transfer is available on inbound buses only, on account of one way street patterns) (Figures 3.3–3.6).

At the Eastern Michigan University stop, outbound deboarding (from buses from central Ann Arbor) is heavy; outbound boarding is not as heavy; and, inbound deboarding is not as heavy as inbound boarding. Taken all together, we might infer that commuting students find rides away from the University once they get there using public transportion. Further, we used the timepoints between Ann Arbor and Ypsilanti to try to determine where a "bus–use" boundary might separate these two cities. Because passengers might go either toward the Ann Arbor CBD or the Ypsilanti CBD from timepoints near such a boundary, we looked for those timepoints between the CBD which had heavy boarding and deboarding on inbound and on outbound routes and which also were surrounded by timepoints experiencing lighter congestion. We linked these, using a dashed line in Figures 3.3 to 3.6, to suggest a bus use boundary.

A Geography of City Congestion Based on Bus Routes

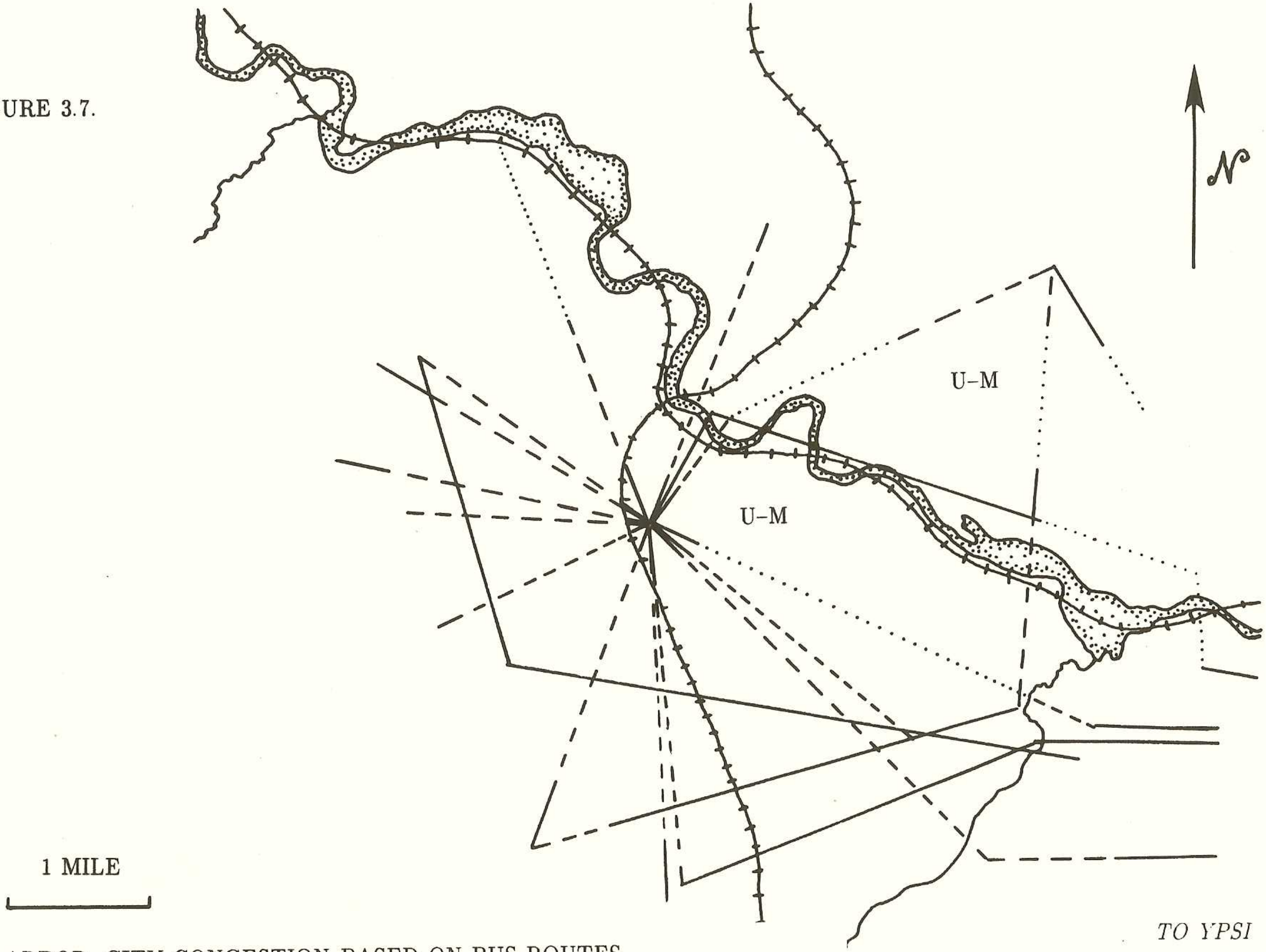
Congestion occurs along bus routes; however, bus routes also cause congestion. Reversing the customary vantage point often produces extra information; in the previous section congestion at bus route timepoints suggested position for a bus–use travel boundary. Taking this notion further, congestion at bus route timepoints might be used to suggest the underlying pattern of city congestion much as we used bus routes to characterize city terrain. Thus, we used the generalized bus route structure underlying Figure 2.9 and superimposed (by eyeballing) the general congestion trends involving boarding, deboarding, and transferring populations (represented in Figures 3.3 to 3.6), to come to an impressionistic view of Ann Arbor congestion based on bus routes (Figure 3.7). Route segments of "dense" congestion

TABLE 3.6. AATA TIMEPOINTS FROM FIGURES 3.3 TO 3.6 BY TRANSFER WEIGHT.

Transfer weight	Number of timepoints with the given transfer weight	
	Outbound	Inbound
C(4,2) = 6	14	15
C(6,2) = 15	8	7
C(14,2) = 91	1	1
C(36,2) = 630	1	1

A typical stop with no potential for transfer has weight of "2." There are different transfer time points inbound and outbound because of routing differences.

FIGURE 3.7.



ANN ARBOR: CITY CONGESTION BASED ON BUS ROUTES.

Four–layered, impressionistic, overlay of Figures 3.3–3.6. Solid lines represent densest bus route congestion, dashed lines next densest, dotted lines sparsest.

are those along which circles centered on timepoints on inbound or outbound routes display relatively high bus–load values (with the category of "dense" bridging the first–quartile boundary). In a similar manner, the class of route segments experiencing "intermediate" congestion bridges the median (second–quartile) of the rank–ordered list of bus–load data, and the class of route segments designated as those of "sparse" congestion bridges the third quartile of this bus–load data set. On this basis, congestion is characterized as dense in the CBD area, and higher in "cross–town" portions rather than in the radial bus routes draining the CBD. Congestion is sparse in the wealthiest areas of town and on those parts of The University of Michigan campus largely devoted to dormitories. Cross–hauling appears, from this evidence, to contribute significantly to congestion in Ann Arbor. All of which appears "sensible" on the basis of years of experience within and around Ann Arbor and the Ann Arbor Transportation Authority.

With the promise of a 1990 U. S. Census based on files stressing connectivity patterns characterized in an electronic environment using concepts from combinatorial topology to capture a previously unavailable range of data, it should be possible to incorporate (relatively easily) traditional transit planning tools such as origin–destination studies, on–site studies, or correlation analyses of various Section 15 indicators with non–traditional ones, such as those based on the percentage dot maps shown here. When local geographic and demographic data is loaded into electronic programs that have the capability to interact directly with census data, and to draw accurate maps on the basis of that interaction, tasks involving a rapidly fluctuating database that were previously laborious will become easy, freeing the mind to contemplate numerous other non–traditional, imaginative ideas for exploiting the power of the new technology.

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APPENDIX 3.*A*

TABLE 3.A. URBANIZED AREAS RANK ORDERED BY POPULATION DENSITY.

UZA #	UZA STATE & CITY NAME (# of transit authorities shown in parentheses.)	POPULATION DENSITY (1980 pop. per sq. mi.)
1	NY NEW YORK (22)	5552
2	CA LOS ANGELES (11)	5189
18	FL MIAMI (1)	4730
26	LA NEW ORLEANS (4)	4688
3	IL CHICAGO (15)	4526
4	PA PHILADELPHIA (3)	4052
6	CA SAN FRANCISCO (6)	4008
22	CA SAN JOSE (1)	3816
29	NY BUFFALO (1)	3768
5	MI DETROIT (1)	3649
28	FL FT. LAUDERDALE (2)	3490
7	DC WASHINGTON (2)	3424
14	MD BALTIMORE (2)	3357
94	CA BAKERSFIELD (1)	3268
72	CA FRESNO (1)	3251
99	MI ANN ARBOR (1)	3163
8	MA BOSTON (5)	3126
11	MO ST. LOUIS (1)	3096
21	CO DENVER (1)	3080
43	NY ROCHESTER (1)	3015
65	PA ALLENTOWN (1)	3006
67	NY SYRACUSE (3)	2963
27	OR PORTLAND (1)	2940
38	KY LOUISVILLE (1)	2916
20	WA SEATTLE (3)	2869
34	CA SACRAMENTO (2)	2864
35	RI PROVIDENCE (2)	2824
33	FL ST. PETERSBURG (2)	2815
16	CA SAN DIEGO (3)	2789
15	OH CLEVELAND (1)	2786
49	NB OMAHA (1)	2785
98	WI MADISON (1)	2775
55	OH TOLEDO (1)	2758
32	OH COLUMBUS (1)	2733
92	IN FORT WAYNE (1)	2718
56	TX EL PASO (1)	2703
66	TX AUSTIN (1)	2692
24	OH CINCINNATI (2)	2675
30	TX SAN ANTONIO (1)	2669
101	IL ROCKFORD (2)	2653
91	OH CANTON (1)	2633
36	TN MEMPHIS (1)	2617
54	FL W. PALM BEACH (1)	2605
57	AZ TUCSON (1)	2601
64	OH YOUNGSTOWN (1)	2573
12	PA PITTSBURGH (5)	2539
85	WA SPOKANE (1)	2493
60	CT BRIDGEPORT (2)	2491
53	NY ALBANY (1)	2475
50	CT HARTFORD (2)	2452
74	KS WICHITA (1)	2446
59	NM ALBUQUERQUE (1)	2446
23	WI MILWAUKEE (3)	2433
93	IN SOUTH BEND (1)	2408
45	OH DAYTON (2)	2399
48	OH AKRON (2)	2388
68	CT NEW HAVEN (2)	2375
62	DE WILMINGTON (3)	2375
83	MA WORCESTER (1)	2339
10	TX HOUSTON (2)	2300
71	MI FLINT (1)	2274
41	UT SALT LAKE CITY (1)	2225
19	AZ PHOENIX (1)	2199
87	LA SHREVEPORT (1)	2199
84	IA DES MOINES (1)	2190
63	WA TACOMA (1)	2150
88	IL PEORIA (1)	2125
70	LA BATON ROUGE (1)	2100
100	NC RALEIGH (1)	2087
61	PA SCRANTON (4)	2064
75	FL BRADENTON (2)	2036
81	PA HARRISBURG (1)	2031
79	IL ROCK ISLAND (3)	2007
39	CA SAN BERNARDINO (2)	1964
52	VA RICHMOND (1)	1959
82	CO COL. SPRINGS (1)	1950
31	IN INDIANAPOLIS (1)	1932
9	TX DALLAS (3)	1915
25	KS KANSAS CITY (1)	1864
46	FL ORLANDO (1)	1850
69	NC CHARLOTTE (1)	1846
37	VA NORFOLK (1)	1844
13	MN MINN.-ST.PAUL (1)	1824
78	AK LITTLE ROCK (1)	1800
51	MA SPRINGFIELD (1)	1787
17	GA ATLANTA (1)	1783
42	AL BIRMINGHAM (1)	1777
97	GA COLUMBUS (1)	1759
90	TX CORPUS CHRISTI (1)	1756
96	NC FAYETTEVILLE (1)	1741
73	VA HAMPTON (1)	1676
58	OK TULSA (1)	1648
89	GA AUGUSTA (1)	1611
95	FL PENSACOLA (1)	1577
86	MS JACKSON (1)	1541
40	OK OKLAHOMA CITY (1)	1502
77	AL MOBILE (1)	1500
80	TN KNOXVILLE (1)	1445
44	FL JACKSONVILLE (1)	1388
47	TN NASHVILLE (1)	1255
76	TN CHATTANOOGA (1)	1216

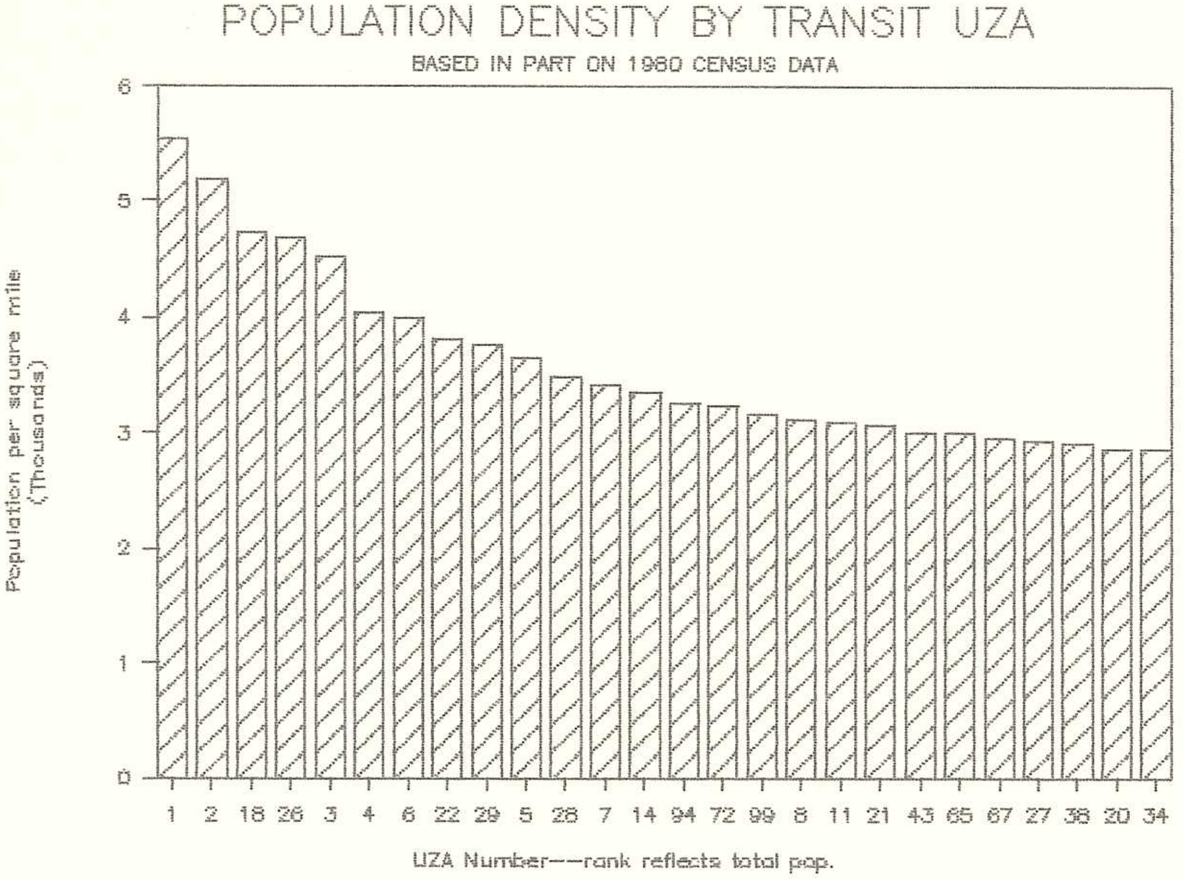
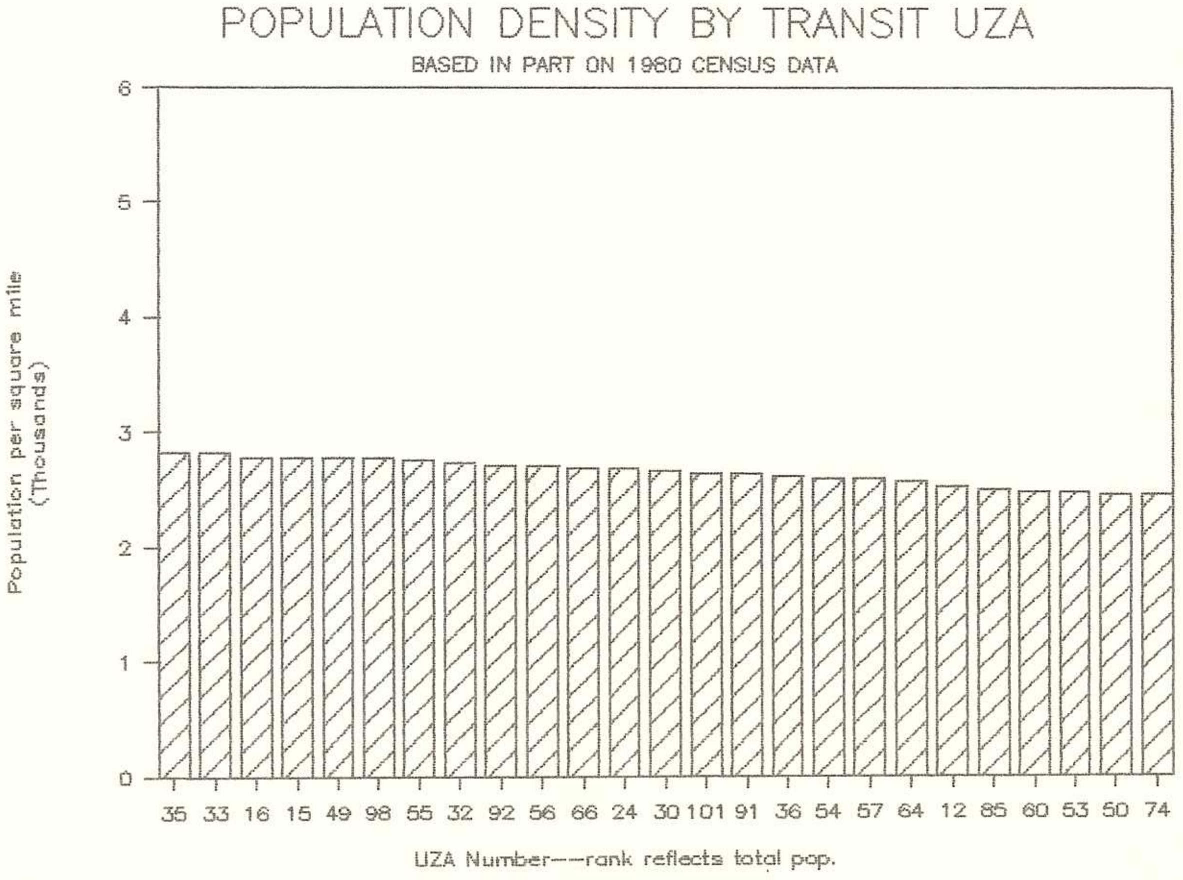
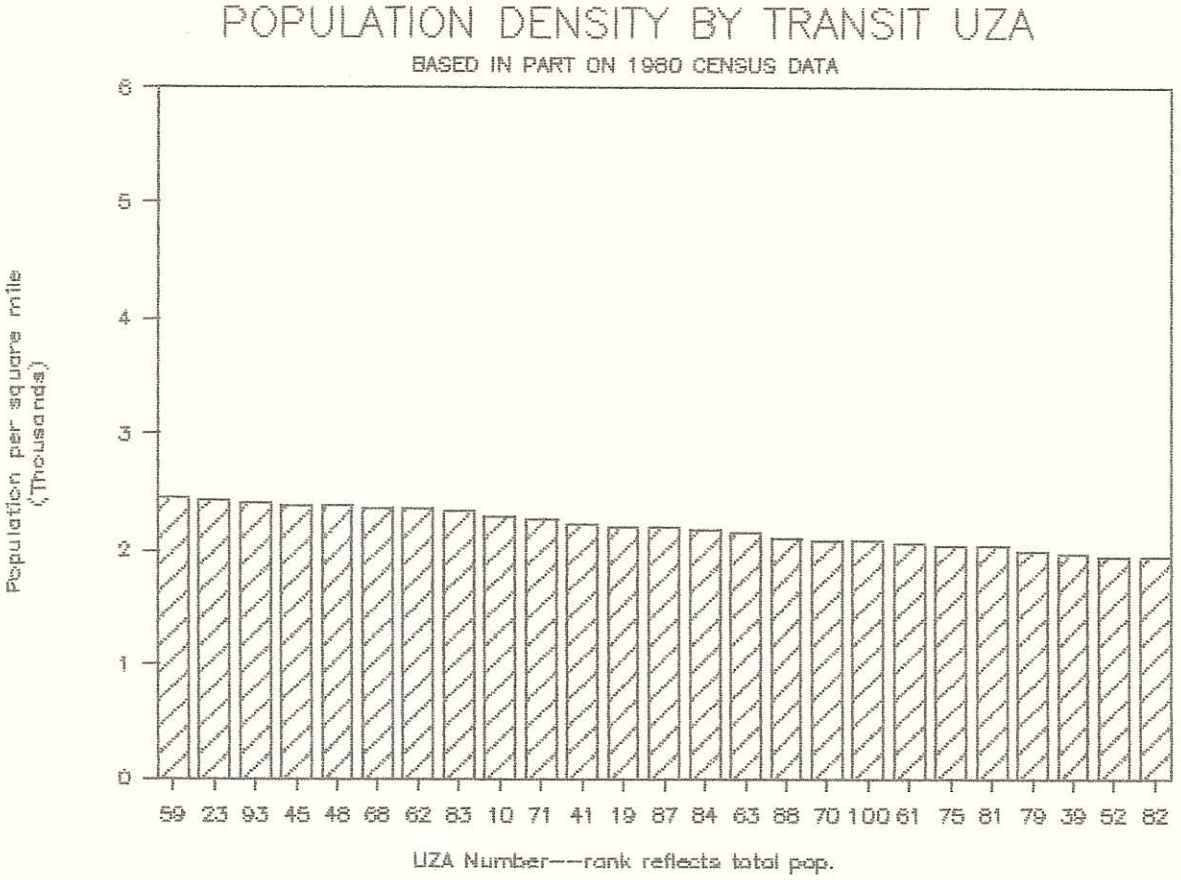

POPULATION DENSITY BY TRANSIT UZA
BASED IN PART ON 1980 CENSUS DATA
Population per square mile
(Thousands)
0
1
2
3
4
5
6
1 2 18 26 3 4 6 22 29 5 28 7 14 94 72 99 8 11 21 43 65 67 27 38 20 34
UZA Number--rank reflects total pop.

CHART 3.A.


POPULATION DENSITY BY TRANSIT UZA
BASED IN PART ON 1980 CENSUS DATA
Population per square mile
(Thousands)
0
1
2
3
4
5
6
35 33 16 15 49 98 55 32 92 56 66 24 30 101 91 36 54 57 64 12 85 60 53 50 74
UZA Number--rank reflects total pop.


POPULATION DENSITY BY TRANSIT UZA
BASED IN PART ON 1980 CENSUS DATA
Population per square mile
(Thousands)
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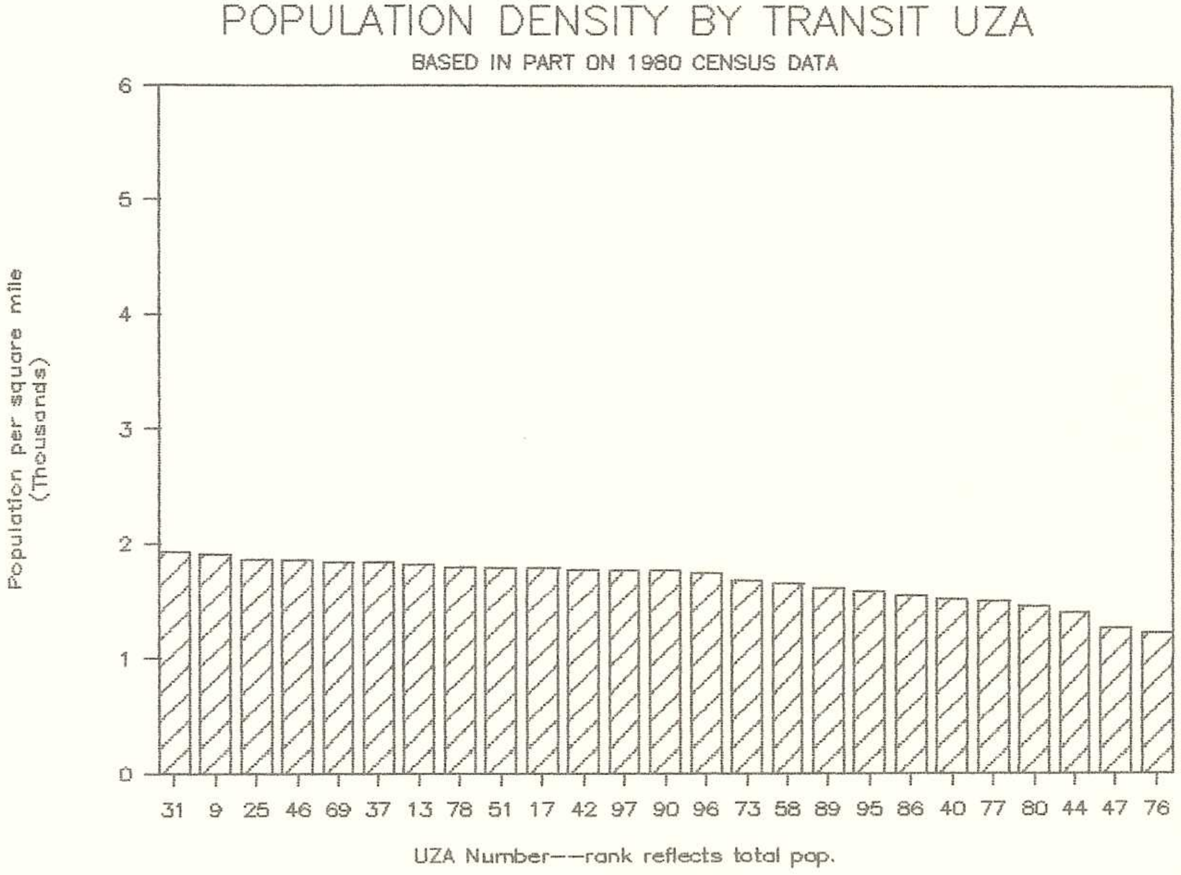
6
59
23
93
45
48
68
62
83
10
71
41
19
87
84
63
88
70
100
61
75
81
79
39
52
82
UZA Number--rank reflects total pop.

CHART 3.4.


POPULATION DENSITY BY TRANSIT UZA
BASED IN PART ON 1980 CENSUS DATA
Population per square mile
(Thousands)
0
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2
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4
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6
31
9
25
46
69
37
13
78
51
17
42
97
90
96
73
58
89
95
86
40
77
80
44
47
76
UZA Number--rank reflects total pop.

APPENDIX 3.B

TABLE 3.B. URBANIZED AREAS RANK ORDERED BY BUS LOAD.

UZA #	UZA STATE & CITY NAME (# of transit authorities shown in parentheses.)	BUS LOAD (Annual passenger miles per bus mile)
35	RI PROVIDENCE (2)	21.15
81	PA HARRISBURG (1)	20.42
80	TN KNOXVILLE (1)	19.96
37	VA NORFOLK (1)	19.16
15	OH CLEVELAND (1)	18.72
6	CA SAN FRANCISCO (6)	17.51
14	MD BALTIMORE (2)	17.17
2	CA LOS ANGELES (11)	17.04
56	TX EL PASO (1)	16.18
20	WA SEATTLE (3)	15.89
10	TX HOUSTON (2)	15.42
7	DC WASHINGTON (2)	15.10
42	AL BIRMINGHAM (1)	14.94
1	NY NEW YORK (22)	14.73
26	LA NEW ORLEANS (4)	14.62
3	IL CHICAGO (15)	14.13
12	PA PITTSBURGH (5)	13.91
45	OH DAYTON (2)	13.90
18	FL MIAMI (1)	13.88
34	CA SACRAMENTO (2)	13.78
17	GA ATLANTA (1)	13.76
4	PA PHILADELPHIA (3)	13.10
19	AZ PHOENIX (1)	13.03
5	MI DETROIT (1)	13.02
52	VA RICHMOND (1)	12.94
21	CO DENVER (1)	12.90
24	OH CINCINNATI (2)	12.72
50	CT HARTFORD (2)	12.60
32	OH COLUMBUS (1)	12.44
28	FL FT. LAUDERDALE (2)	12.00
29	NY BUFFALO (1)	11.86
9	TX DALLAS (3)	11.84
30	TX SAN ANTONIO (1)	11.82
13	MN MINN.-ST.PAUL (1)	11.72
68	CT NEW HAVEN (2)	11.65
38	KY LOUISVILLE (1)	11.39
31	IN INDIANAPOLIS (1)	11.32
25	KS KANSAS CITY (1)	11.19
43	NY ROCHESTER (1)	10.83
23	WI MILWAUKEE (3)	10.48
8	MA BOSTON (5)	10.33
11	MO ST. LOUIS (1)	10.24
16	CA SAN DIEGO (3)	10.18
44	FL JACKSONVILLE (1)	10.11
69	NC CHARLOTTE (1)	9.97
27	OR PORTLAND (1)	9.94
63	WA TACOMA (1)	9.56
70	LA BATON ROUGE (1)	9.53
53	NY ALBANY (1)	9.45
33	FL ST. PETERSBURG (2)	9.42
61	PA SCRANTON (4)	9.37
62	DE WILMINGTON (3)	9.18
73	VA HAMPTON (1)	9.18
86	MS JACKSON (1)	9.16
98	WI MADISON (1)	9.02
75	FL BRADENTON (2)	8.96
67	NY SYRACUSE (3)	8.90
100	NC RALEIGH (1)	8.86
55	OH TOLEDO (1)	8.71
87	LA SHREVEPORT (1)	8.68
47	TN NASHVILLE (1)	8.53
77	AL MOBILE (1)	8.52
76	TN CHATTANOOGA (1)	8.51
51	MA SPRINGFIELD (1)	8.46
22	CA SAN JOSE (1)	8.45
101	IL ROCKFORD (2)	8.29
59	NM ALBUQUERQUE (1)	8.25
85	WA SPOKANE (1)	8.24
58	OK TULSA (1)	8.12
39	CA SAN BERNARDINO (2)	8.10
60	CT BRIDGEPORT (2)	8.04
57	AZ TUCSON (1)	7.90
46	FL ORLANDO (1)	7.86
71	MI FLINT (1)	7.84
82	CO COL. SPRINGS (1)	7.73
99	MI ANN ARBOR (1)	7.64
41	UT SALT LAKE CITY (1)	7.53
65	PA ALLENTOWN (1)	7.44
72	CA FRESNO (1)	7.44
93	IN SOUTH BEND (1)	7.36
78	AK LITTLE ROCK (1)	7.26
96	NC FAYETTEVILLE (1)	6.89
36	TN MEMPHIS (1)	6.88
89	GA AUGUSTA (1)	6.81
66	TX AUSTIN (1)	6.76
88	IL PEORIA (1)	6.51
83	MA WORCESTER (1)	6.40
94	CA BAKERSFIELD (1)	6.07
84	IA DES MOINES (1)	6.02
95	FL PENSACOLA (1)	6.00
49	NB OMAHA (1)	5.82
48	OH AKRON (2)	5.54
97	GA COLUMBUS (1)	5.24
91	OH CANTON (1)	5.00
79	IL ROCK ISLAND (3)	4.85
40	OK OKLAHOMA CITY (1)	4.60
54	FL W. PALM BEACH (1)	4.38
92	IN FORT WAYNE (1)	4.30
64	OH YOUNGSTOWN (1)	4.07
74	KS WICHITA (1)	4.04
90	TX CORPUS CHRISTI (1)	3.94

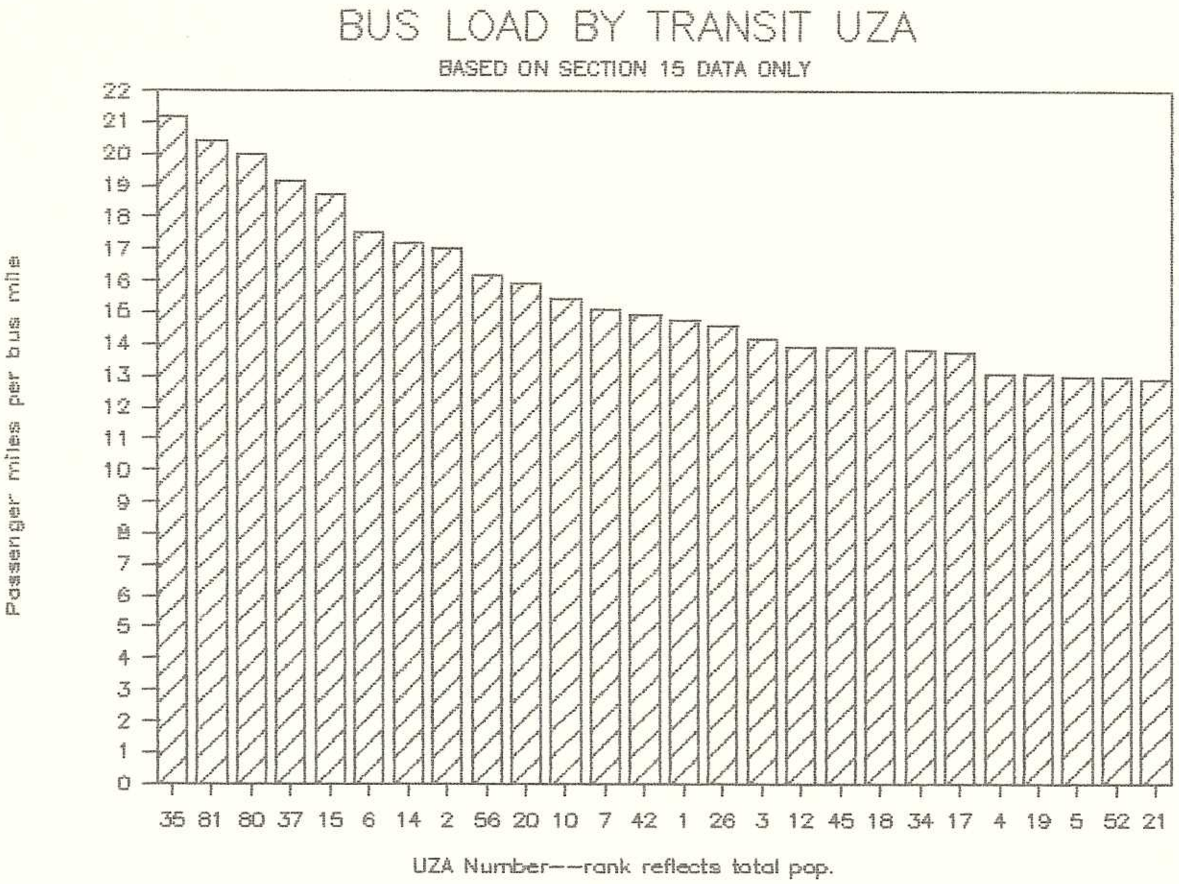
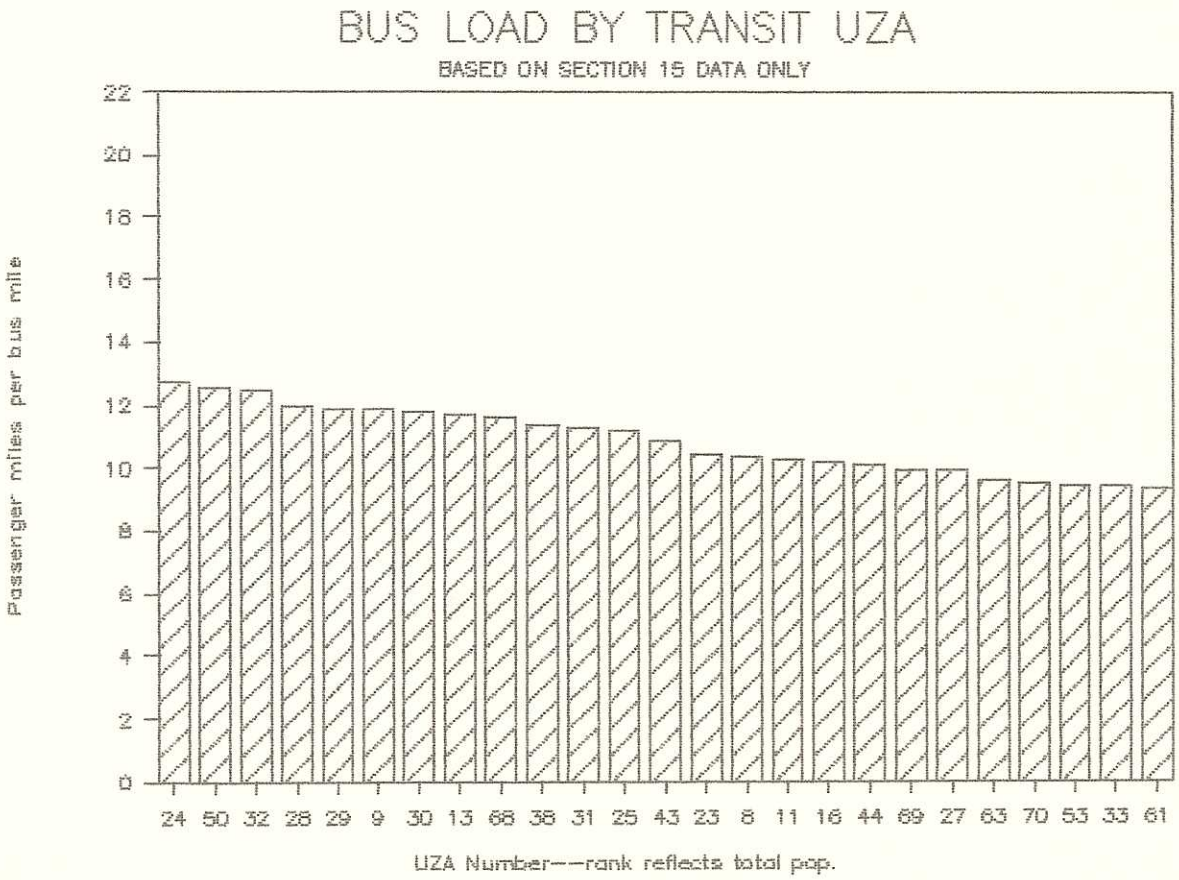

BUS LOAD BY TRANSIT UZA
BASED ON SECTION 15 DATA ONLY
Passenger miles per bus mile
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
35 81 80 37 15 6 14 2 56 20 10 7 42 1 26 3 12 45 18 34 17 4 19 5 52 21
UZA Number--rank reflects total pop.

CHART 3.*B*.


BUS LOAD BY TRANSIT UZA
BASED ON SECTION 15 DATA ONLY
Passenger miles per bus mile
0
2
4
6
8
10
12
14
16
18
20
22
24 50 32 28 29 9 30 13 68 38 31 25 43 23 8 11 16 44 69 27 63 70 53 33 61
UZA Number--rank reflects total pop.

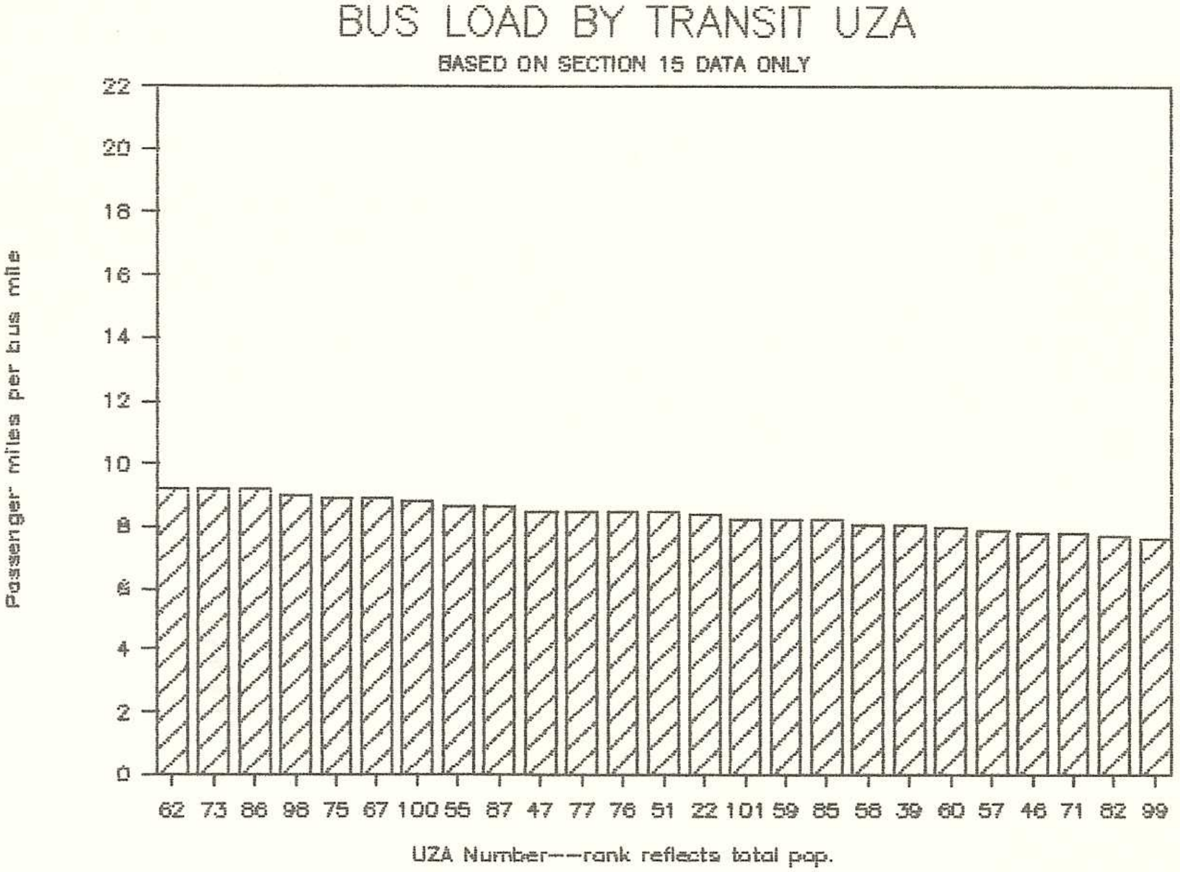
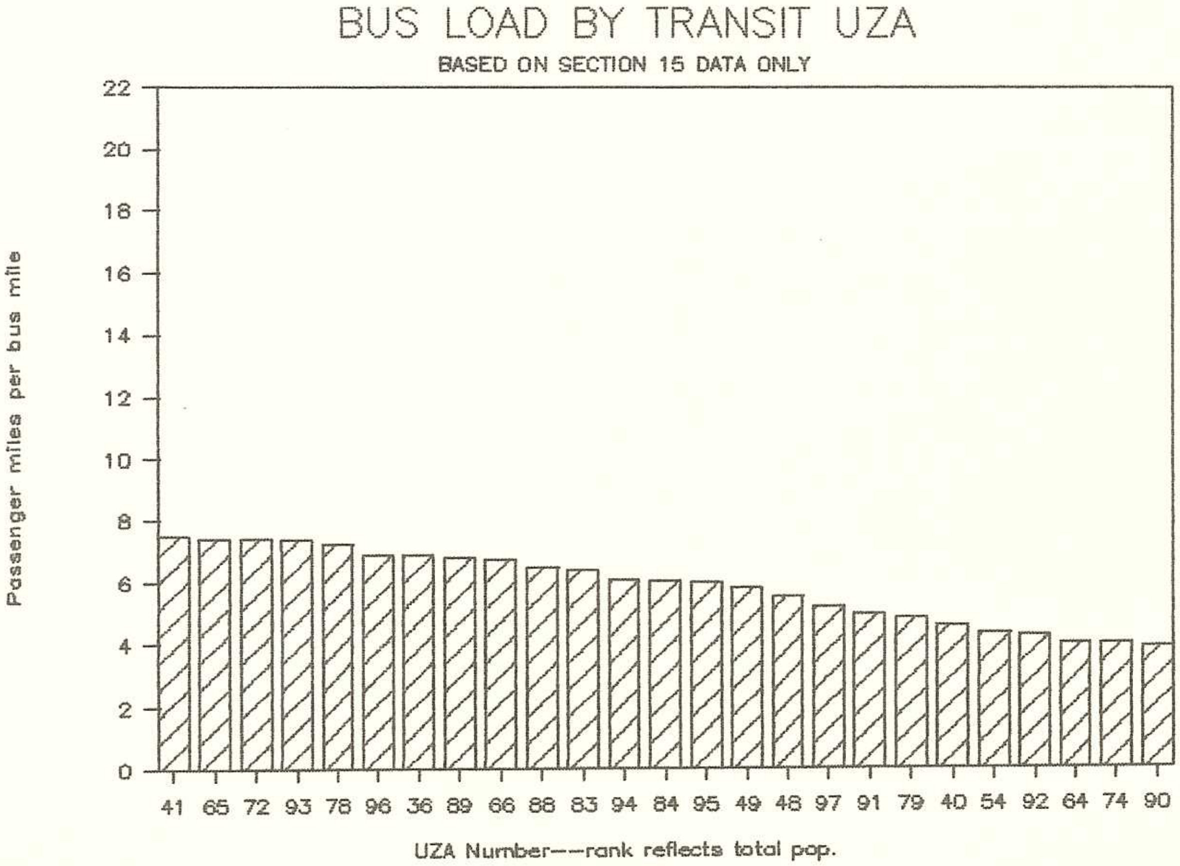

BUS LOAD BY TRANSIT UZA
BASED ON SECTION 15 DATA ONLY
Passenger miles per bus mile
22
20
18
16
14
12
10
8
6
4
2
0
62 73 86 98 75 67 100 55 87 47 77 76 51 22 101 59 85 58 39 60 57 46 71 82 99
UZA Number——rank reflects total pop.

CHART 3.B.


BUS LOAD BY TRANSIT UZA
BASED ON SECTION 15 DATA ONLY
Passenger miles per bus mile
22
20
18
16
14
12
10
8
6
4
2
0
41 65 72 93 78 96 36 89 66 88 83 94 84 95 49 48 97 91 79 40 54 92 64 74 90
UZA Number——rank reflects total pop.

APPENDIX 3.C

TABLE 3.C. URBANIZED AREAS RANK ORDERED BY BUS USE

UZA #	UZA STATE & CITY NAME (# of transit authorities shown in parentheses.)	BUS USE (Bus passenger miles per UZA resident.)
6	CA SAN FRANCISCO (6)	343.81
20	WA SEATTLE (3)	306.61
1	NY NEW YORK (22)	261.02
12	PA PITTSBURGH (5)	244.43
7	DC WASHINGTON (2)	238.53
2	CA LOS ANGELES (11)	217.79
17	GA ATLANTA (1)	215.85
15	OH CLEVELAND (1)	210.20
27	OR PORTLAND (1)	207.02
14	MD BALTIMORE (2)	206.48
98	WI MADISON (1)	193.01
3	IL CHICAGO (15)	189.49
18	FL MIAMI (1)	180.24
23	WI MILWAUKEE (3)	178.31
26	LA NEW ORLEANS (4)	175.03
21	CO DENVER (1)	174.96
50	CT HARTFORD (2)	162.07
30	TX SAN ANTONIO (1)	156.89
4	PA PHILADELPHIA (3)	151.21
24	OH CINCINNATI (2)	144.77
10	TX HOUSTON (2)	141.81
35	RI PROVIDENCE (2)	139.35
56	TX EL PASO (1)	137.84
85	WA SPOKANE (1)	136.02
32	OH COLUMBUS (1)	132.46
13	MN MINN.-ST.PAUL (1)	131.75
80	TN KNOXVILLE (1)	131.02
63	WA TACOMA (1)	125.43
81	PA HARRISBURG (1)	124.57
68	CT NEW HAVEN (2)	123.62
34	CA SACRAMENTO (2)	121.12
22	CA SAN JOSE (1)	119.99
37	VA NORFOLK (1)	119.86
52	VA RICHMOND (1)	117.78
38	KY LOUISVILLE (1)	116.92
5	MI DETROIT (1)	114.30
45	OH DAYTON (2)	113.07
29	NY BUFFALO (1)	113.00
16	CA SAN DIEGO (3)	112.29
53	NY ALBANY (1)	110.54
55	OH TOLEDO (1)	109.63
67	NY SYRACUSE (3)	109.19
11	MO ST. LOUIS (1)	107.33
43	NY ROCHESTER (1)	100.85
41	UT SALT LAKE CITY (1)	96.79
44	FL JACKSONVILLE (1)	93.89
9	TX DALLAS (3)	86.84
69	NC CHARLOTTE (1)	83.95
31	IN INDIANAPOLIS (1)	83.61
57	AZ TUCSON (1)	81.65
8	MA BOSTON (5)	81.19
28	FL FT. LAUDERDALE (2)	77.13
60	CT BRIDGEPORT (2)	74.91
25	KS KANSAS CITY (1)	73.28
51	MA SPRINGFIELD (1)	70.32
19	AZ PHOENIX (1)	68.05
47	TN NASHVILLE (1)	66.76
87	LA SHREVEPORT (1)	66.26
72	CA FRESNO (1)	65.35
61	PA SCRANTON (4)	65.27
73	VA HAMPTON (1)	64.73
59	NM ALBUQUERQUE (1)	63.84
49	NB OMAHA (1)	63.42
42	AL BIRMINGHAM (1)	62.82
100	NC RALEIGH (1)	61.38
39	CA SAN BERNARDINO (2)	58.93
82	CO COL. SPRINGS (1)	56.06

UZA #	UZA STATE & CITY NAME (# of transit authorities shown in parentheses.)	BUS USE (Bus passenger miles per UZA resident.)
93	IN SOUTH BEND (1)	55.35
62	DE WILMINGTON (3)	55.07
101	IL ROCKFORD (2)	53.11
36	TN MEMPHIS (1)	53.09
58	OK TULSA (1)	51.80
99	MI ANN ARBOR (1)	51.68
33	FL ST. PETERSBURG (2)	49.41
70	LA BATON ROUGE (1)	47.28
83	MA WORCESTER (1)	45.74
84	IA DES MOINES (1)	44.85
78	AK LITTLE ROCK (1)	44.79
76	TN CHATTANOOGA (1)	44.35
66	TX AUSTIN (1)	42.57
71	MI FLINT (1)	42.22
88	IL PEORIA (1)	39.32
94	CA BAKERSFIELD (1)	38.60
75	FL BRADENTON (2)	38.48
97	GA COLUMBUS (1)	37.41
46	FL ORLANDO (1)	36.86
48	OH AKRON (2)	34.85
65	PA ALLENTOWN (1)	33.95
92	IN FORT WAYNE (1)	33.60
86	MS JACKSON (1)	33.22
77	AL MOBILE (1)	33.16
74	KS WICHITA (1)	25.36
89	GA AUGUSTA (1)	25.03
95	FL PENSACOLA (1)	23.30
79	IL ROCK ISLAND (3)	22.82
91	OH CANTON (1)	22.37
54	FL W. PALM BEACH (1)	19.91
90	TX CORPUS CHRISTI (1)	18.75
96	NC FAYETTEVILLE (1)	17.59
40	OK OKLAHOMA CITY (1)	16.58
64	OH YOUNGSTOWN (1)	10.23

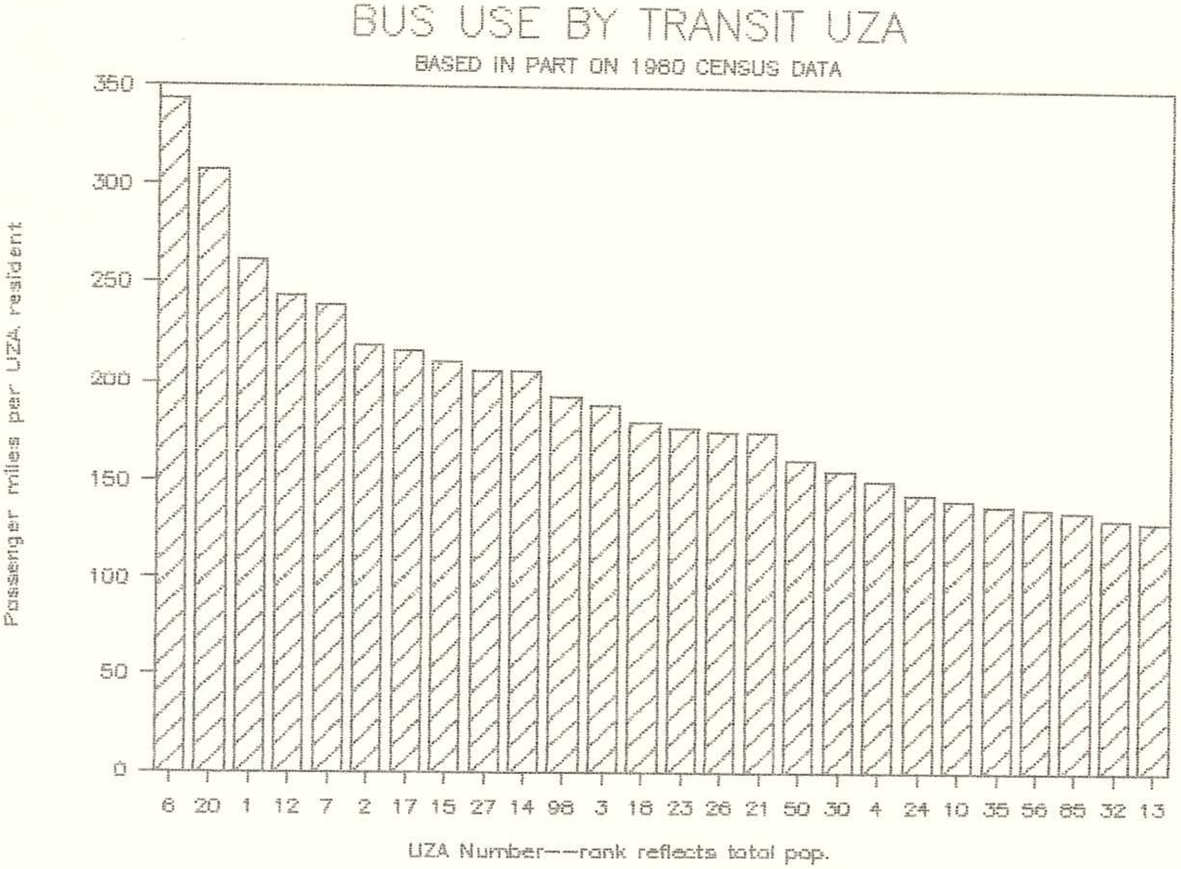
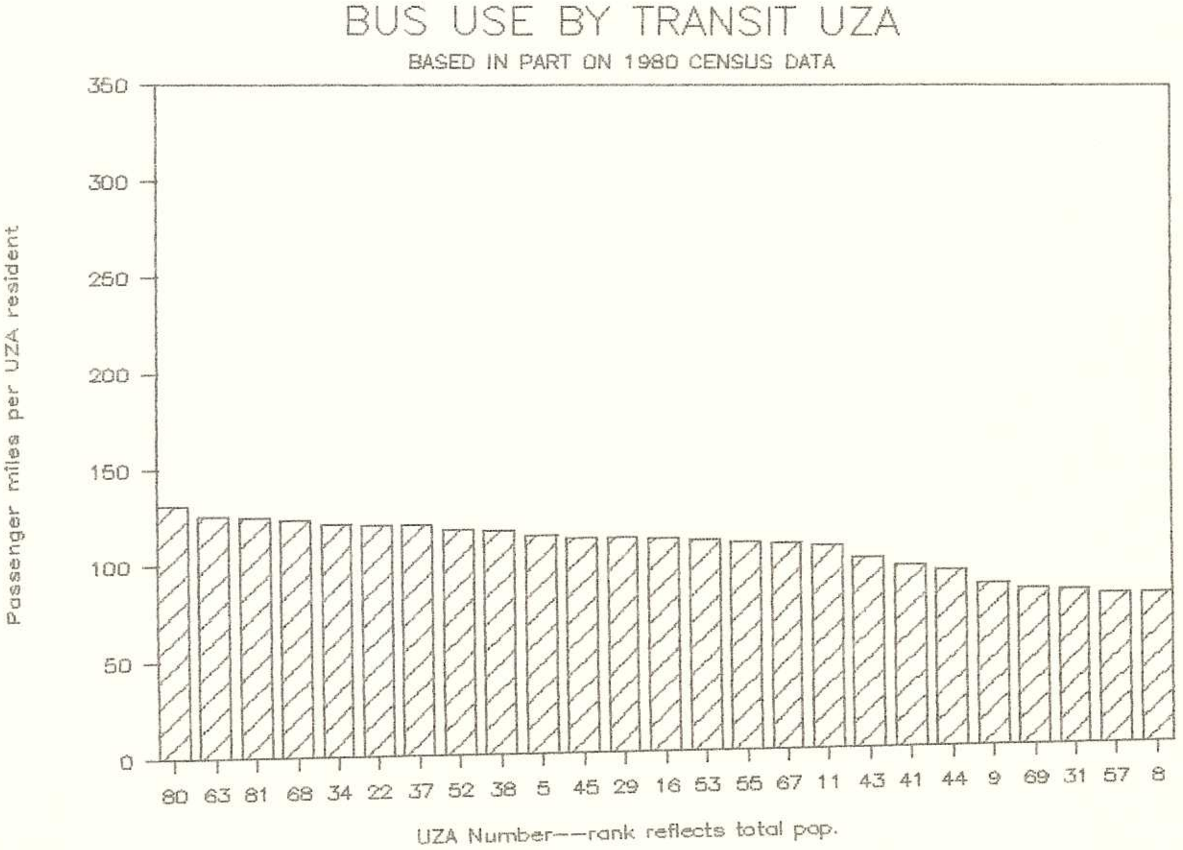

BUS USE BY TRANSIT UZA
BASED IN PART ON 1980 CENSUS DATA
Passenger miles per UZA resident
350
300
250
200
150
100
50
0
6
20
1
12
7
2
17
15
27
14
98
3
18
23
26
21
50
30
4
24
10
35
56
85
32
13
UZA Number——rank reflects total pop.

CHART 3.C.


BUS USE BY TRANSIT UZA
BASED IN PART ON 1980 CENSUS DATA
Passenger miles per UZA resident
350
300
250
200
150
100
50
0
80
63
81
68
34
22
37
52
38
5
45
29
16
53
55
67
11
43
41
44
9
69
31
57
8
UZA Number——rank reflects total pop.

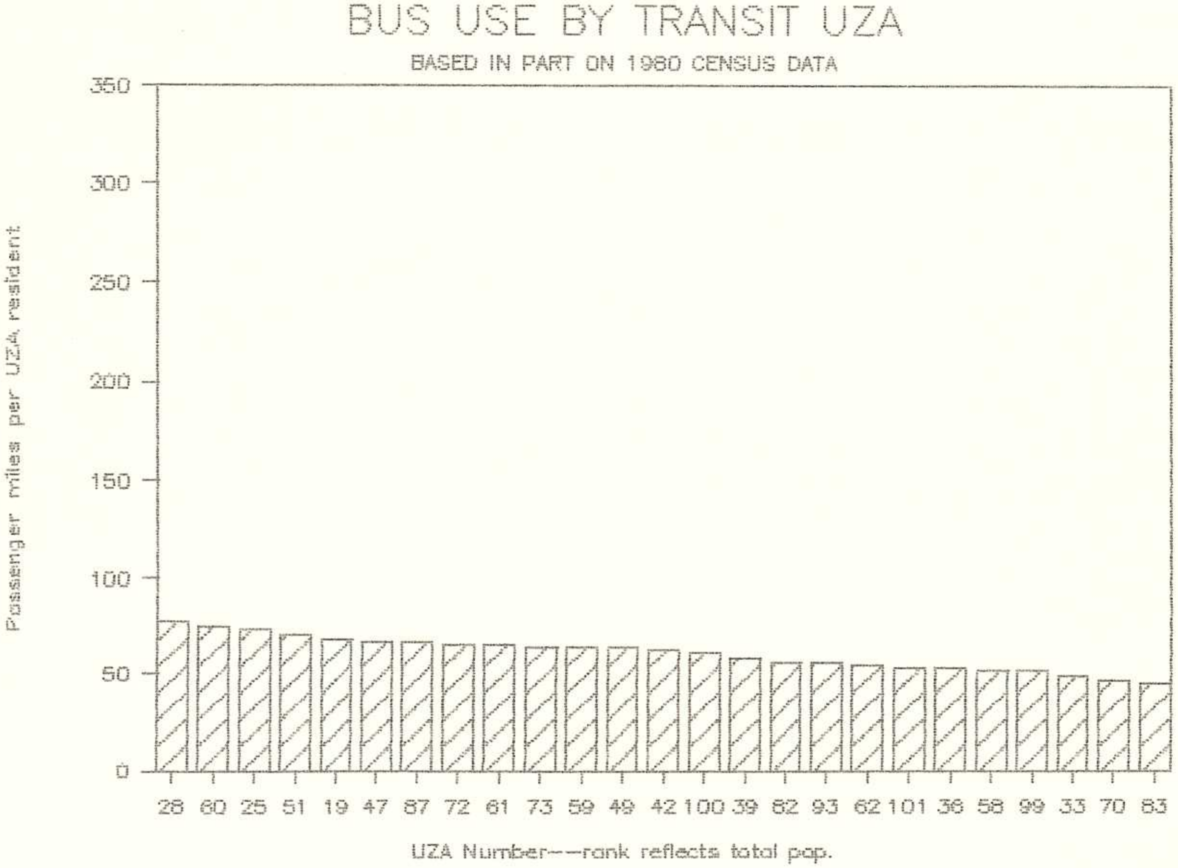
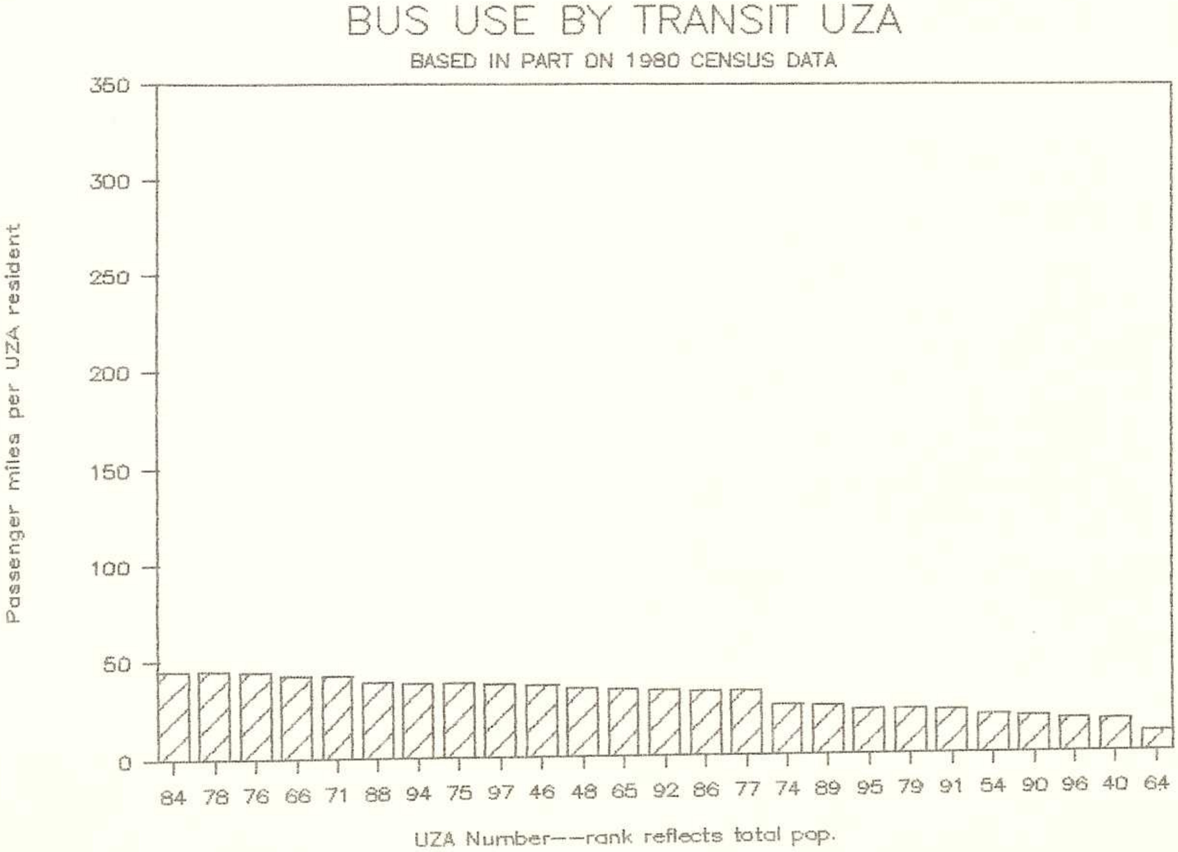

BUS USE BY TRANSIT UZA
BASED IN PART ON 1980 CENSUS DATA
Passenger miles per UZA resident
350
300
250
200
150
100
50
0
28 60 25 51 19 47 87 72 61 73 59 49 42 100 39 82 93 62 101 36 58 99 33 70 83
UZA Number——rank reflects total pop.

CHART 3.C.


BUS USE BY TRANSIT UZA
BASED IN PART ON 1980 CENSUS DATA
Passenger miles per UZA resident
350
300
250
200
150
100
50
0
84 78 76 66 71 88 94 75 97 46 48 65 92 86 77 74 89 95 79 91 54 90 96 40 64
UZA Number——rank reflects total pop.

APPENDIX 3.*D*

TABLE 3.D. BUS LOAD BY TRANSIT AUTHORITY FOR ALL 101 UZAs.
(A double asterisk marks each transit authority that has the
** same bus load value as its UZA. A single asterisk marks
* suspect data.)

UZA NUMBER	TRANSIT AUTHORITY BY STATE, SECTION 15 NUMBER, AND NAME.	BUS LOAD BY TRANSIT AUTHORITY
10 *	TX 6043 Houston-Kerrville	117.49
1	NY 2096 Putnam Area Rapid Transit	41.88
1	NY 2079 Yonkers-Liberty Lines	28.96
1	NY 2044 Yonkers-Riverdale	28.39
3	IL 5082 Harvey-South Suburban Safeway	27.46
1	NY 2007 East Meadow MSBA	25.56
1	NY 2041 Yonkers-Pelham Parkway	24.39
1	NY 2073 Brooklyn-Command	23.24
6	CA 9016 San Francisco-MUNI	23.17
35	RI 1001 Providence-Rhode Island PTA	22.52
1	NY 2043 Queens Transit Corporation	22.11
6	CA 9016 San Francisco-Golden Gate TD	21.60
1	NY 2008 New York CTA	21.09
81 **	PA 3014 Harrisburg-CAT	20.42
80 **	TN 4002 Knoxville TA	19.96
37 **	VA 3005 Norfolk-Tidewater TDC	19.16
2	CA 9021 Los Angeles SCRTD	18.85
15 **	OH 5015 Cleveland RTA	18.72
1	NY 2045 Steinway Transit	18.55
14	MD 3043 Columbia TS	17.68
2	CA 9008 Santa Monica Muni Bus	17.50
6	CA 9009 San Mateo County District	17.38
1	NJ 2092 Bergenfield-Rockland TC	17.30
14	MD 3034 Baltimore MTA	17.16
20	WA 0001 Seattle Metro	16.83
3	IL 5086 Transit Management of West Towns	16.77
60	CT 1050 Greater Bridgeport TD	16.67
3	IL 5042 East Chicago Bus TS	16.58
56 **	TX 6006 El Paso PTA	16.18
1	NY 2038 Jamaica-Green Bus Lines	16.14
7	DC 3030 Washington, D.C.-WMATA	15.62
4	PA 3019 Philadelphia SEPTA	15.42
42 **	AL 4042 Birmingham-Jefferson County TA	14.94
26	LA 6032 New Orleans Public Service	14.87
1	NY 2039 New York-Jamaica Bus	14.63
3	IL 5066 Chicago CTA	14.59
6	CA 9014 Alameda Contra Costa TD	14.55
45	OH 5017 Dayton Miami Valley RTA	14.36
16	CA 9026 San Diego TS	14.25
12	PA 3022 Pittsburgh-PAT	14.08
10	TX 6008 Houston-MTA	14.06
1	NY 2006 Long Beach TA	13.89
18 **	FL 4034 Miami-Dade County TA	13.88
34	CA 9019 Sacramento RTD	13.86
24	OH 5012 Cincinnati SORTA	13.77
17 **	GA 4022 Atlanta MARTA	13.76
26	LA 6029 Gretna-Westside Transit	13.75
26	LA 6021 Harahan-La. Tran. Co.	13.50
9	TX 6004 Dallas TS	13.33
12	PA 3023 Beaver BCTA	13.05
19 **	AZ 9032 City of Phoenix TS	13.03
5 **	MI 5031 Detroit-SEMTA	13.02
50	CT 1048 Hartford-Connecticut Transit	12.95
52 **	VA 3006 Greater Richmond Transit	12.94
21 **	CO 8006 Denver RTA	12.90
34	CA 9090 Woodland-Yolobus	12.70
3	IL 5080 Des Plaines-North Suburban TD	12.56
32 **	OH 5016 Columbus-COTA	12.44
28	FL 4059 Metro Dade-Broward County	12.21
2	CA 9036 Orange County	12.13
1	NY 2076 Westchester County	12.09
28	FL 4029 Fort Lauderdale-Broward County	12.00
29 **	NY 2004 Buffalo-Niagara Frontier	11.86
30 **	TX 6011 San Antonio-VIA Metro Tr.	11.82
68	CT 1055 New Haven-Connecticut Transit	11.80
13 **	MN 5027 Minneapolis MTC	11.72
20	WA 0005 City of Everett	11.65

38	**	KY	4018	Louisville-TA of River City	11.39
31	**	IN	5050	Indianapolis PTC	11.32
25	**	KS	7005	Kansas City Area TA	11.19
2		CA	9010	City of Torrance	11.11
2		CA	9023	Long Beach PTC	11.08
8		MA	1004	Brockton Area TA	10.99
12		PA	3044	Westmoreland County TA	10.87
43	**	NY	2113	Rochester-RTS	10.83
23		WI	5094	Waukesha County Highway	10.80
2		CA	9039	Culver City	10.72
23		WI	5008	Milwaukee County TS	10.65
61		PA	3015	Kingston-Luzerne County TA	10.45
67		NY	2016	Auburn-Onondaga	10.42
8		MA	1003	Boston-MBTA	10.40
11	**	MO	7006	St. Louis Bi-State	10.24
44	**	FL	4040	Jacksonville TA	10.11
20		WA	0029	Lynnwood-Comm. Transit	10.08
1		NY	2046	Jackson Heights-Triboro Coach	10.03
33		FL	4039	St. Petersburg MTS	9.99
69	**	NC	4008	Charlotte TS	9.97
27	**	OR	0008	Portland Tri-County MTD	9.94
3		IL	5084	Trnasit Management of Waukegan	9.79
1		NJ	2981	Newark-NJT	9.58
63	**	WA	0003	Tacoma-Pierce County Trans.	9.56
70	**	LA	6022	Baton Rouge-Capital Transp.	9.53
62		DE	3031	Wilmington-DART	9.52
67		NY	2018	Syracuse-CNY Centro	9.51
75		FL	4026	Bradenton-Manatee County Tr.	9.46
53	**	NY	2002	Albany-Capital District TA	9.45
73	**	VA	3004	Hampton-Pentran	9.18
61		PA	3017	Nanticoke Public Service	9.17
86	**	MS	4015	Jackson-JATRAN	9.16
3		IL	5087	Wilmette Muni	9.14
2		CA	9041	Montebello Muni	9.04
98	**	WI	5005	Madison Metro	9.02
100	**	NC	4007	Raleigh-NC Transit Div	8.86
1		NY	2084	Pomona Transportation of Rockland	8.73
55	**	OH	5022	Toledo RTA	8.71
87	**	LA	6024	Shreveport Area TS	8.68
33		FL	4027	Pinellas Suncoast TA	8.68
39		CA	9029	San Bernardino-Omnitrans	8.67
47	**	TN	4004	Nashville-MTA	8.53
77	**	AL	4043	Mobile	8.52
76	**	TN	4001	Chattanooga Area RTA	8.51
75		FL	4046	Sarasota County Area Trans.	8.50
51	**	MA	1008	Pioneer Valley TA	8.46
22	**	CA	9013	Santa Clara County	8.45
101		IL	5058	Rockford MTS	8.42
1		NY	2071	Huntington Area Rapid	8.27
59	**	NM	6019	Albuquerque-Sun-Tran	8.25

85	**	WA	0002	Spokane Transit Authority	8.24
58	**	OK	6018	Metropolitan Tulsa TA	8.12
57	**	AZ	9033	City of Tucson MTS	7.90
46	**	FL	4035	Orlando TCT	7.86
71	**	MI	5032	Flint-MTA	7.84
61		PA	3025	Scranton-Lackawanna TA	7.84
9		TX	6007	Fort Worth CITRAN	7.82
82	**	CO	8005	Colorado Springs Transit	7.73
48		OH	5097	Kent-Campus Bus Service	7.65
99	**	MI	5040	Ypsilanti-Ann Arbor TA	7.64
12		PA	3028	Greater Alliquippa TA	7.62
24		KY	4019	Ft. Wright TA of No. Ky	7.60
4		NJ	2982	Newark NJT/Philadelphia	7.57
41	**	UT	8001	Salt Lake City-Utah TA	7.53
7		DC	3051	Rockville Ride On	7.51
62		DE	3047	Dover-Delaware TA	7.48
65	**	PA	3010	Allentown-LANTA	7.44
72	**	CA	9027	Fresno TS	7.44
93	**	IN	5052	South Bend PTC	7.36
2		CA	9043	City of Commerce	7.31
78	**	AK	6033	Little Rock Metroplan	7.26
45		OH	5019	Middletown TS	7.25
101		IL	5055	Loves Park TS	7.22
39		CA	9031	Riverside Transit Agency	7.14
9		TX	6005	Dallas Surtran	6.97
96	**	NC	4009	Fayetteville Area Transit	6.89
36	**	TN	4003	Memphis Area TA	6.88
3		IL	5068	Elgin-DOT	6.87
8		MA	1061	Fitchburg, Montachusett RTA	6.84
89	**	GA	4023	Augusta TD	6.81

66	**	TX	6002	Austin TS	6.76
88	**	IL	5056	Greater Peoria Mass TD	6.56
83	**	MA	1014	Worcester RTA	6.40
26		LA	6028	Chalmette-St. Bernard Bus	6.22
3		IL	5073	Glen Ellyn Transit	6.13
2		CA	9042	Gardena	6.09
16		CA	9095	San Diego Reg. Trans. Serv.	6.07
94	**	CA	9004	Bakersfield-Golden Empire TD	6.07
3		IL	5077	Naperville-GNATS	6.07
50		CT	1063	Middletown TD	6.05
84	**	IA	7010	Des Moines MTA	6.02
6		CA	9078	Central Contra Costa TS	6.01
95	**	FL	4038	Pensacola-Escambia	6.00
16		CA	9030	N. San Diego Transit Dev.	5.92
49	**	NB	7002	TA of Omaha	5.82
79		IL	5057	Rock Island County MTS	5.76
88	**	IL	5065	Pekin Municipal Bus Service	5.67
2		CA	9022	Norwalk	5.51
62		DE	2985	Newark-NJY.T/Wilmington	5.37
4		PA	3020	Pottstown Urban Transit	5.28
97	**	GA	4024	Columbus-METRA	5.24
3		IN	5045	Gary PTC	5.06
91	**	OH	5011	Canton RTA	5.00
48		OH	5010	Akron-Metro RTA	4.94
40	**	OK	6017	Central Oklahoma PTA	4.60
1		NY	2085	Nanuet, Clarkstown Mini TR	4.47
79		IA	7009	Davenport Public Transit	4.40
6		CA	9028	Vallejo Transit	4.39
54	**	FL	4037	W. Palm Beach-Florida Transit	4.38
92	**	IN	5044	Fort Wayne PTC	4.30
68		CT	1070	Wallingford-NE Trans	4.13
1		NY	2072	Hauppage-Suffolk Transit	4.08
64	**	OH	5024	Youngstown-Western Reserve	4.07
74	**	KS	7015	Wichita MTA	4.04
90	**	TX	6003	Corpus Christi TS	3.94
35		MA	1064	Greater Attleboro-Taunton RBA	3.85
8		MA	1005	Lowell RTA	3.84
1		NY	2089	Village of Spring Valley	3.67
2		CA	9060	Hermosa Beach Free Bus	3.54
3		IL	5074	Highland Park Transit	3.38
12		PA	3050	Washington-Cannonsburgh-GG&C Bus	3.21
3		IL	5100	Chicago RTA	3.09
23		WI	5096	Waukesha Metro Transit	3.02
67		NY	2017	Syracuse & Oswego ML	2.82
61		PA	3016	Wilkes Barre-Williams Bus	2.74
3		IL	5077	Village of Niles	2.64
1		NY	2109	Yonkers Airport Transportation	2.63
3		IN	5102	Hammond Intercity System	2.39
60		CT	1060	Milford TD	2.23
79		IA	7007	Bettendorf TS	2.11
8		MA	1053	Gloucester-Cape Ann TA	1.76

CHAPTER 4: COMBINED EFFECTS

NATIONWIDE

With peer groups in-hand that indicate those transit authorities with the harshest climate, those with the steepest terrain, and those with the densest congestion, it seems natural to ask which transit authority has the worst combination of this set of environmental effects. The answer, however, is neither well-defined nor unique. Table 4.1 lists transit authorities according to the "worst" portion of these three variables; only transit authorities in Pittsburgh and in Yonkers appear on all three "worst" lists. In some respects, therefore, these two cities might be considered to have transit authorities that suffer the worst combined effects of the environmental variables of climate, terrain, and congestion (although nowhere near the worst individual effects–witness Syracuse with a climate norm of 149.9).

In the case of Yonkers, what is particularly severe is the congestion; climate is harsh, but just barely. This leads us to note that population patterns, unlike those of topography or climate, are highly changeable over short periods of time: people do move and do polarize as groups whereas terrain and climate cannot. Thus, there are other transit authorities, from the standpoint of climate and terrain, that would suffer much more heavily from the combined environmental effects if they experienced the congestion of Yonkers. These are enumerated in Table 4.2 as transit authorities with potential to become severely affected by this combination of environmental effects. Further, if yet other environmental factors, such as problems associated with salt spray, smog, and heavy use of air conditioning, are considered, transit authorities in cities such as Los Angeles or San Diego might then be included in the "worst" set.

Observations based on comparing these lists, and on looking at the potential for an urban area to have severe problems with a substantial increase in congestion, might be of use to transportation planners and to municipal authorities, especially when coupled with a study of how the "worst" cities handle these difficulties. Pittsburgh, for example, has roads dedicated to express buses built in old railroad beds. This relieves some congestion, and perhaps more important, because the old railroad tracks generally followed river valleys in steep terrain, the bus routes following the path of these tracks are situated along a route of low grade. Pittsburgh is perhaps in a situation where any improvement is significant, unlike cities such as Chicago whose flatness is a mass-transit luxury.

TABLE 4.1. COMBINED EFFECTS: CLIMATE, TERRAIN, AND CONGESTION.
Transit authorities rank-ordered by climate norm, terrain allometric radius, and bus-load.

HARSHEST CLIMATES	NORM	STEEPEST TERRAIN	ALLOMETRIC RADIUS	DENSEST CONGESTION (based on bus load, only)	BUS LOAD
Syracuse	149.9	Los Angeles	3.80	Putnam Area Rapid Transit	41.88
Buffalo	116.5	San Diego	2.28	Yonkers-Liberty Lines	28.96
Rochester	114.1	San Francisco	2.03	Yonkers-Riverdale	28.39
Binghamton	113.8	Washington DC	2.03	Harvey-South Suburban Safeway	27.46
Erie	111.9	Boston	1.77	East Meadow MSBA	25.56
Denver	97.4	Seattle	1.77	Yonkers-Pelham Parkway	24.39
Salt Lake City	96.2	Kansas City	1.77	Brooklyn-Command	23.24
Spokane	95.0	Pittsburgh	1.52	San Francisco-MUNI	23.17
Springfield MA	91.9	Cincinnati	1.52	Providence-Rhode Island PTA	22.52
Duluth	91.7	Newport	1.52	Queens Transit Corporation	22.11
Manchester	85.3	Oakland	1.52	San Francisco-Golden Gate TD	21.60
Worcester	85.1	Omaha	1.52	New York CTA	21.09
Portland	82.4	Yonkers	1.27	Harrisburg-CAT	20.42
Colorado Sprngs	83.6	Worcester	1.01	Knoxville TA	19.96
Cleveland	75.3	Duluth	0.76	Norfolk-Tidewater TDC	19.16
Utica	74.7	San Mateo	0.76	Los Angeles SCRTD	18.85
Albany	74.6	Ventura	0.76	Cleveland RTA	18.72
Youngstown	64.3	Charleston	0.76	Steinway Transit	18.55
Scranton	60.0	Dubuque	0.76	Columbia TS	17.68
Jackson MI	55.6	Johnstown	0.51	Santa Monica Muni Bus	17.50
Lincoln	54.2			San Mateo County District	17.38
Dubuque	54.1			Bergenfield-Rockland TC	17.30
Cedar Rapids	54.1			Baltimore MTA	17.16
Sioux City	53.7			Seattle Metro	16.83
South Bend	53.4			Transit Management of West Towns	16.77
Omaha	52.3			Greater Bridgeport TD	16.67
Flint	51.6			East Chicago Bus TS	16.58
Detroit	49.6			El Paso PTA	16.18
Ann Arbor	49.6			Jamaica-Green Bus Lines	16.14
Racine	48.8			Washington, D.C.-WMATA	15.62
Kenosha	48.8			Philadelphia SEPTA	15.42
Milwaukee	48.8			Birmingham-Jefferson County TA	14.94
Madison	48.3			New Orleans Public Service	14.87
Harrisburg	45.0			New York-Jamaica Bus	14.63
Altoona	45.0			Chicago CTA	14.59
Des Moines	44.8			Alameda Contra Costa TD	14.55
Kalamazoo	43.5			Dayton Miami Valley RTA	14.36
St. Paul	43.5			San Diego TS	14.25
St. Cloud	43.5			Pittsburgh-PAT	14.08
Allentown	42.9			Houston-MTA	14.06
Kingston	42.9			Long Beach TA	13.89
Johnstown	42.0			Miami-Dade County TA	13.88
Pittsburgh	41.9			Sacramento RTD	13.86
Waterloo	41.9			Cincinnati SORTA	13.77
Saginaw	38.2			Atlanta MARTA	13.76
Bay City	38.2			Gretna-Westside Transit	13.75
Gary	33.7			Harahan-La. Tran. Co.	13.50
Chicago	33.7			Dallas TS	13.33

Waukegan	33.7
Des Plaines	33.7
Joliet	33.7
Haverhill	33.6
Boston	33.6
Lowell	33.6
La Crosse	33.6
Appleton	32.0
Oshkosh	32.0
Fargo	31.9
Hartford	31.0
New Haven	31.0
Toledo	31.0
Elgin	28.4
Aurora	28.4
Rockford	28.4
Kent	28.1
Canton	28.1
Akron	28.1
Rock Island	28.0
Davenport	28.0
Fort Wayne	22.7
White Plains	22.0
Yonkers	22.0
Newark	22.0

Beaver BCTA	13.05
City of Phoenix TS	13.03
Detroit-SEMTA	13.02
Hartford-Connecticut Transit	12.95
Greater Richmond Transit	12.94
Denver RTA	12.90
Woodland-Yolobus	12.70
Des Plaines-North Suburban TD	12.56
Columbus-COTA	12.44
Metro Dade-Broward County	12.21
Orange County	12.13
Westchester County	12.09
Fort Lauderdale-Broward County	12.00
Buffalo-Niagara Frontier	11.86
San Antonio-VIA Metro Tr.	11.82
New Haven-Connecticut Transit	11.80

TABLE 4.2. TRANSIT AUTHORITIES SUBJECTED TO THE HARSHEST ENVIRONMENTAL EFFECTS.

Transit authorities that are members of all three harshest classes of climate, terrain, and congestion.

- Pittsburgh-PAT
- Beaver-BCTA (Pittsburgh UZA)
- Yonkers-Liberty Lines
- Yonkers-Riverdale
- Yonkers-Pelham Parkway

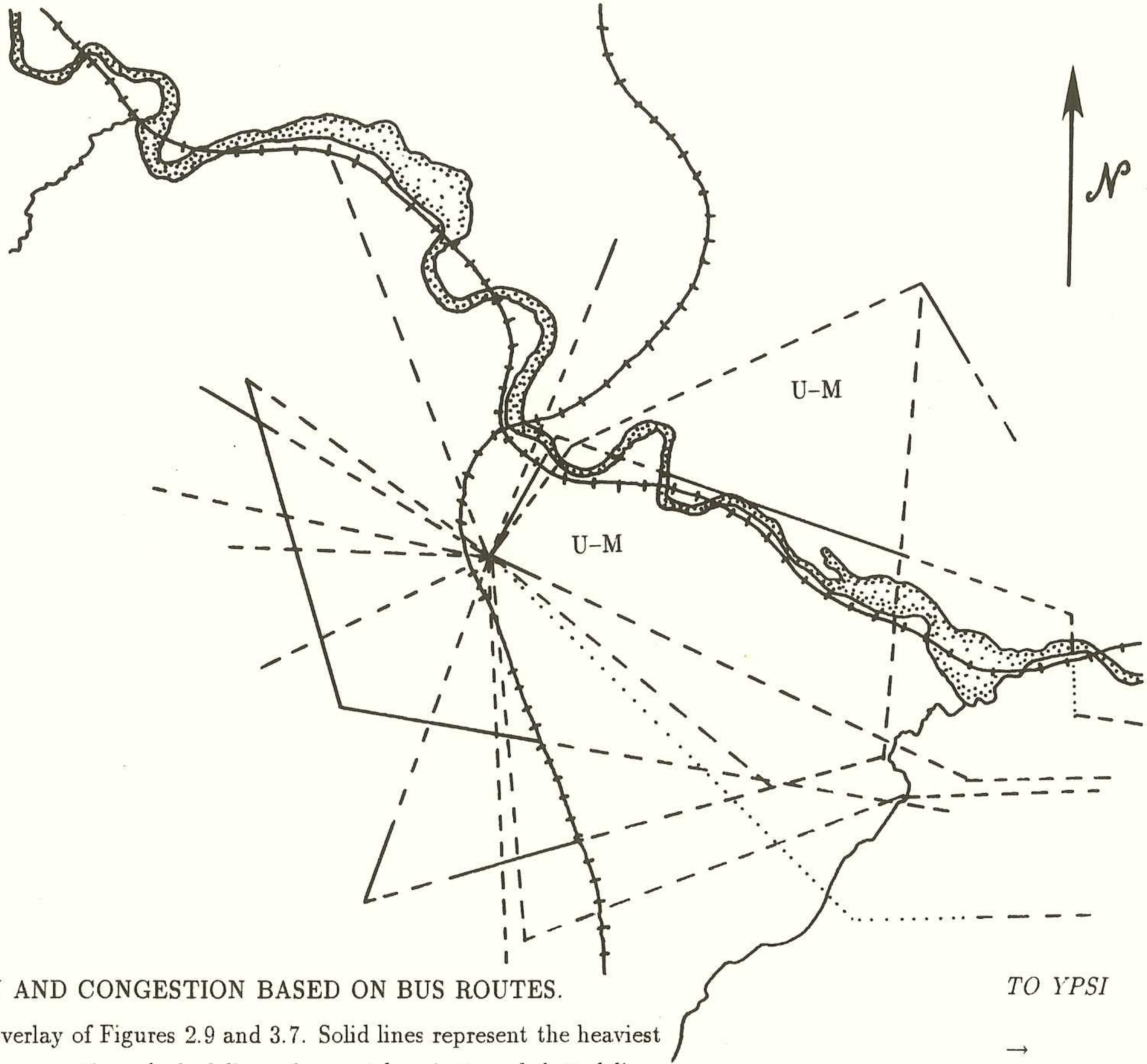
Transit authorities that have the potential, with increased congestion, to become members of the above set; rank-ordered from most to least severe effects, given equal congestion for all.

- Duluth
- Worcester
- Dubuque
- Omaha/Council Bluffs
- Johnstown
- Pittsburgh transit authorities from above and added transit authorities of Westmoreland County and Greater Aliquippa.
- Boston UZA: Boston MBTA; Lowell; Gloucester-Cape Ann.
- Yonkers transit authorities from above.

ANN ARBOR

Similar observations might be made at the local, Ann Arbor, scale in an effort to understand which routes, and which portions of routes, are likely to have the severest environmental effect on the buses of the AATA. In a local study, climate is not a factor by which one can distinguish one route from another; Ann Arbor has a relatively harsh climate that does not vary from bus route to bus route. In contrast to climate, both congestion and terrain vary from bus route to bus route. Overall, however, congestion and terrain have the fundamental difference that management decisions can alter general congestion patterns but not general topographic patterns: the "social" situation is more easily altered than is the "natural" situation. Thus, to determine "worst" intervals along bus routes, it is sufficient, ignoring climate, to superimpose the terrain and the congestion maps (Figures 2.9 and 3.7) to produce a single map (Figure 4.1) in which the solid lines represent segments of bus routes with the heaviest combined effects of terrain and congestion, the dashed lines the next heaviest, and the dotted lines the lightest. The longest stretch of "worst" route is one linking a set of radial routes on the west and south west sides of town; as in the nationwide case, other presently less–congested regions also have significant potential to become "worst." In particular, a glance at Figure 3.7 shows that routes to the north east and to the north west of town are in the steep set, but have segments of light congestion. Were traffic patterns to change substantially as a result, perhaps, of concentrated urban development, these routes in particular would offer the strongest environmental challenge to the buses of the AATA.

FIGURE 4.1



ANN ARBOR: TERRAIN AND CONGESTION BASED ON BUS ROUTES.

Two–way impressionistic overlay of Figures 2.9 and 3.7. Solid lines represent the heaviest combined effect of terrain and congestion, dashed lines the next heaviest, and dotted lines the lightest.

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"Imagination is more important than knowledge"
Albert Einstein

IMaGe MONOGRAPH SERIES–1988 PRICE LIST

Exclusive of shipping; prices listed and payable in U.S. funds.

1. *Mathematical Geography and Global Art: the Mathematics of David Barr's "Four Corners Project,"* Sandra L. Arlinghaus, Director of IMaGe, and John D. Nystuen, Professor of Geography and Urban Planning, College of Architecture and Urban Planning, The University of Michigan, Ann Arbor, MI 48109. IMaGe@umichum; Nystuen@umichum. 1986. $9.95.

This monograph contains Nystuen's calculations, actually used by sculptor David Barr to position his abstract tetrahedral sculpture within the earth, as well as a Preface by Barr. Placement of the sculpture vertices in Easter Island, South Africa, Greenland, and Indonesia was chronicled in film by The Archives of American Art for The Smithsonian Institution. In addition to the archival material, this monograph also contains Arlinghaus's solutions to broader theoretical questions–was Barr's choice of a tetrahedron unique within his initial geographic constraints, and, within the set of Platonic solids?

2. *Down the Mail Tubes: the Pressured Postal Era, 1853-1984*, Sandra L. Arlinghaus, Director of IMaGe. IMaGe@umichum. 1986. $9.95.

The history of the pneumatic post, in Europe and in the United States, is examined for the lessons it might offer to the technological scenes of the late twentieth century. As Sylvia L. Thrupp, Alice Freeman Palmer Professor Emeritus of History, The University of Michigan, commented in her review of this work "Such brief comment does far less than justice to the intelligence and the stimulating quality of the author's writing, or to the breadth of her reading. The detail of her accounts of the interest of American private enterprise, in New York and other large cities on this continent, in pushing for construction of large tubes in systems to be leased to the government, brings out contrast between American and European views of how the new technology should be managed. This and many other sections of the monograph will set readers on new tracks of thought."

3. *Essays on Mathematical Geography*, Sandra L. Arlinghaus, Director of IMaGe. 1986. $15.95.

A collection of essays intended to show the range of power in applying pure mathematics to human systems. There are two types of essay: those which employ traditional mathematical proof, and those which do not. As mathematical proof may itself be regarded as art, the former style of essay might represent "traditional" art, and the latter, "surrealist" art. Essay titles are: "The well-tempered map projection," "Antipodal graphs," "Analogue clocks," "Steiner transformations," "Concavity and urban settlement patterns," "Measuring the vertical city," "Fad and permanence in human systems," "Topological exploration in geography," "A space for thought," and "Chaos in human systems–the Heine-Borel Theorem."

4. *A Historical Gazetteer of Southeast Asia*, Robert F. Austin, Director of Automated Mapping and Facility Management Systems, Baystar Service Corporation, 311 Park Place Blvd. Suite 650, Clearwater, FL 34619. 1986. $12.95.

Dr. Austin's Gazetteer draws geographic coordinates of Southeast Asian place-names together with references to these place-names as they have appeared in historical and literary documents. This book is of obvious use to historians and to historical geographers specializing in Southeast Asia. At a deeper level, it might serve as a valuable source in establishing place-name linkages which have remained previously unnoticed, in documents describing trade or other communications connections, because of variation in place-name nomenclature.

5. *Essays on Mathematical Geography–II*, Sandra L. Arlinghaus, Director of IMaGe. IMaGe@umichum. 1987. $12.95.

Written in the same format as IMaGe Monograph #3, that seeks to use "pure" mathematics in real-world settings, this volume contains the following material: "Frontispiece–the Atlantic Drainage Tree," "Getting a Handel on Water-Graphs," "Terror in Transit: A Graph Theoretic Approach to the Passive Defense of Urban Networks," "Terrae Antipodum," "Urban Inversion," "Fractals: Constructions, Speculations, and Concepts," "Solar Woks," "A Pneumatic Postal Plan: The Chambered Interchange and ZIPPR Code," "Endpiece."

6. *Theoretical Market Areas Under Euclidean Distance*, Pierre Hanjoul, Hubert Beguin, and Jean-Claude Thill: respectively, Electrical Engineer and Ph.D. candidate in Sciences, University of Louvain-la-Neuve; Professor of Economic and Quantitative Geography, University of Louvain-la-Neuve; National Fund for Scientific Research (Belgium). Address: Université Catholique de Louvain, Batîment Mercator, Place Pasteur 3, B-1348, Louvain-la-Neuve, Belgium. Beguin@buclln11. 1988. (English language text; abstracts written in French and in English.) $15.95.

Though already initiated by Rau in 1841, the economic theory of the shape of two-dimensional market areas has long remained concerned with a representation of transportation costs as linear in distance. In the general gravity model, to which the theory also applies, this corresponds to a decreasing exponential function of distance deterrence. Other transportation cost and distance deterrence functions also appear in the literature, however. They have not always been considered from the viewpoint of the shape of the market areas they generate, and their disparity asks the question whether other types of functions would not be worth being investigated. There is thus a need for a general theory of market areas: the present work aims at filling this gap, in the case of a duopoly competing inside the Euclidean plane endowed with Euclidean distance.

(Bien qu'ébauchée par Rau dès 1841, la théorie économique de la forme des aires de marché planaires s'est longtemps contentée de l'hypothèse de coûts de transport proportionnels à la distance. Dans le modèle gravitaire généralisé, auquel on peut étendre cette théorie, ceci correspond au choix d'une exponentielle décroissante comme fonction de dissuasion de la distance. D'autres fonctions de coût de transport ou de dissuasion de la distance apparaissent cependant dans la littérature. La forme des aires de marché qu'elles engendrent n'a pas toujours été étudiée ; par ailleurs, leur variété amène à se demander si d'autres fonctions encore ne mériteraient pas d'être examinées. Il paraît donc utile de disposer d'une théorie générale des aires de marché : ce à quoi s'attache ce travail en cas de duopole, dans le cadre du plan euclidien muni d'une distance euclidienne.)

7. *Nystuen—Dacey Nodal Analysis*, Keith J. Tinkler Editor, Professor, Department of Geography, Brock University, St. Catharine's, Ontario, Canada L2S 3A1. 1988. $15.95.

Professor Tinkler's volume displays the use of this graph theoretical tool in geography, from the original Nystuen—Dacey article, to a bibliography of uses, to original uses by Tinkler. Some reprinted material is included, but by far the larger part is of previously unpublished material. (Unless otherwise noted, all items listed below are previously unpublished.) Contents: " 'Foreward' " by Nystuen, 1988; "Preface" by Tinkler, 1988; "Statistics for Nystuen—Dacey Nodal Analysis," by Tinkler, 1979; Review of Nodal Analysis literature by Tinkler (pre–1979, reprinted with permission; post—1979, new as of 1988); FORTRAN program listing for Nodal Analysis by Tinkler; "A graph theory interpretation of nodal regions" by John D. Nystuen and Michael F. Dacey, reprinted with permission, 1961; Nystuen—Dacey data concerning telephone flows in Washington and Missouri, 1958, 1959 with comment by Nystuen, 1988; "The expected distribution of nodality in random (p, q) graphs and multigraphs," by Tinkler, 1976.

8. *The Urban Rank-size Hierarchy: A Mathematical Interpretation* by James W. Fonseca, Associate Professor of Geography and Acting Dean of the Graduate School, George Mason University, Fairfax, Virginia 22030. Jfonseca@gmuvax.bitnet. 1989. $15.95.

The urban rank-size hierarchy can be characterized as an equiangular spiral of the form $r = ae^{\theta cot\alpha}$. An equiangular spiral can also be constructed from a Fibonacci sequence. The urban rank-size hierarchy is thus shown to mirror the properties derived from Fibonacci characteristics such as rank-additive properties. A new method of structuring the urban rank-size hierarchy is explored which essentially parallels that of the traditional rank-size hierarchy below rank 11. Above rank 11 this method may help explain the frequently noted concavity of the rank-size distribution at the upper levels. The research suggests that the simple rank-size rule with the exponent equal to 1 is not merely a special case, but rather a theoretically justified norm against which deviant cases may be measured. The spiral distribution model allows conceptualization of a new view of the urban rank-size hierarchy in which the three largest cities share functions in a Fibonacci hierarchy.

9. *An Atlas of Steiner Networks*, Sandra L. Arlinghaus, Director of IMaGe. IMaGe@umichum. 1989. $15.95.

A Steiner network is a tree of minimum total length joining a prescribed, finite, number of locations; often new locations are introduced into the prescribed set to determine the minimum tree. This Atlas explains the mathematical detail behind the Steiner construction for prescribed sets of n locations and displays the steps, visually, in a series of Figures. The proof of the Steiner construction is by mathematical induction, and enough steps in the early part of the induction are displayed completely that the reader who is well-trained in Euclidean geometry, and familiar with the concepts of graph theory and elementary number theory, should be able to replicate the constructions for full as well as for degenerate Steiner trees.

10. *Simulating $K = 3$ Christaller Central Place Structures: An Algorithm Using A Constant Elasticity of Substitution Consumption Function*, Daniel A. Griffith, Professor of Geography, Syracuse University, 343 H.B. Crouse Hall, Syracuse, NY 13244-1160. Griffith@sunrise. 1989. $15.95.

An algorithm is presented that uses BASICA or GWBASIC on IBM compatible machines. This algorithm simulates Christaller $K = 3$ central place structures, for a four–level hierarchy. It is based upon earlier published work by the author. A description of the spatial theory, mathematics, and sample output runs appears in the monograph. A digital version is available from the author, free of charge, upon request; this request must be accompanied by a 5.5–inch formatted diskette. This algorithm has been developed for use in Social Science classroom laboratory situations, and is designed to (a) cultivate a deeper understanding of central place theory, (b) allow parameters of a central place system to be altered and then graphic and tabular results attributable to these changes viewed, without experiencing the tedium of massive calculations, and (c) help promote a better comprehension of the complex role distance plays in the space–economy. The algorithm also should facilitate intensive numerical research on central place structures; it is expected that even the sample simulation results will reveal interesting insights into abstract central place theory.

The background spatial theory concerns demand and competition in the space–economy; both linear and non–linear spatial demand functions are discussed. The mathematics is concerned with (a) integration of non–linear spatial demand cones on a continuous demand surface, using a constant elasticity of substitution consumption function, (b) solving for roots of polynomials, (c) numerical approximations to integration and root extraction, and (d) multinomial discriminant function classification of commodities into central place hierarchy levels. Sample output is presented for contrived data sets, constructed from artificial and empirical information, with the wide range of all possible central place structures being generated. These examples should facilitate implementation testing. Students are able to vary single or multiple parameters of the problem, permitting a study of how certain changes manifest themselves within the context of a theoretical central place structure. Hierarchical classification criteria may be changed, demand elasticities may or may not vary and can take on a wide range of non–negative values, the uniform transport cost may be set at any positive level, assorted fixed costs and variable costs may be introduced, again within a rich range of non–negative possibilities, and the number of commodities can be altered. Directions for algorithm execution are summarized. An ASCII version of the algorithm, written directly from GWBASIC, is included in an appendix; hence, it is free of typing errors.

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REVIEWS OF IMaGe MONOGRAPHS

Monograph #2: Down the Mail Tubes: the Pneumatic Postal Era, 1853-1984. by Sandra Lach Arlinghaus. *Review by* **Sylvia Thrupp**, *Alice Freeman Palmer Professor Emeritus of History, University of Michigan.*

This lively and lucid account of experimentation with underground mailing systems in large cities should appeal to the growing number of readers who nowadays enjoy puzzling over the life histories of new forms of technology. Writing on these, at least in the English language, has tended to concentrate heavily on shifts in the sources of energy and their influence on industry and on long-distance transport and communication. Books and articles on the history and sociology of modern urbanism abound, but seldom touch on the theme treated in the Arlinghaus monograph.

The treatment is distinctive in five ways. 1) It is based throughout on information available in official reports involving postal authorities and brightened, not by journalistic simplification but pictorially, by maps showing the shape and extent of the tubal networks developed in the main cities discussed. 2) The discussion throughout is comparative, showing how far London, Paris, Berlin and New York dealt by similar or diverse means with the congestion of postal services that became common to all of them. 3) The financial problem of constructing underground networks and maintaining the efficiency of the air pressure systems adopted are adequately described. 4) The reasons for the return to surface distribution of mail, and the timing, in different countries, of the abandonment of the more rapid tubal transmission, are compared. 5) The most original part of the whole discussion, modestly relegated to an appendix, is the use made of all the historical evidence deployed in showing the limits of variance in the spatial design of the tubal networks. History is thus linked to geographical theory and both, to urban ecology.

Such brief comment does far less than justice to the intelligence and the stimulating quality of the author's writing, or to the breadth of her reading. The detail of her accounts of the interest of American private enterprise, in New York and other large cities on this continent, in pushing for construction or large tubes in systems to be leased to the government, brings out contrast between American and European views of how the new technology should be managed. This and many other sections of the monograph will set readers on new tracks of thought.

Monographs #3 and #5. Essays on Mathematical Geography, I and II, by Sandra Lach Arlinghaus. *Reviewed by* **Lynn Arthur Steen** *in The American Mathematical Monthly, "Telegraphic Reviews," June-July, 1989.*

Two parts of a series of typescript publications from "IMaGe," the Institute of Mathematical Geography. These volumes contain a diverse series of papers and reports ranging from the practical (graph theory applied to urban networks; geometry of shadows and solar energy) to the speculative (applying the Heine-Borel Theorem to Middle Eastern politics). Innovative, imaginative, and *very* unconventional.

Monograph #8. Urban Rank-size Hierarchy: A Mathematical Interpretation, by James W. Fonseca. *Reviewed by* **Martin Cadwallader**, *in the Newsletter of the Urban Geography Specialty Group of the Association of American Geographers.*

For many years now urban geographers have been fascinated by the nature of city size distributions. Indeed, the plotting of such distributions has been seen as a necessary preliminary to the detailed description of urban systems. More often than not, however, this kind of research has degenerated into a rather sterile empirical exercise, involving goodness-of-fit tests and estimating the exponent in the ubiquitous rank-size distribution.

Within this context, Fonseca's monograph is a pleasant surprise, as it outlines a novel approach to the characterization of city size distributions. In particular, the author contends that data which approximate a rank-size distribution can also be described by the curve of an equiangular spiral. This contention is first demonstrated empirically, using urbanized area data for the United States, and then some of the mathematical implications are explored. The notion of Fibonacci numbers is central to the argument, as an equiangular spiral represents the mathematical plot of a particular Fibonacci sequence. In addition, the author offers the physical analogy of a conical shell to suggest how a continuous distribution, such as that exhibited by a rank-size relationship, can simultaneously be considered a hierarchical distribution, as generated by settlements in a central place system. Throughout the discussion individual ideas are subjected to rigorous empirical analysis, and the author concludes by suggesting a number of directions for future research.

In sum, this monograph provides a thorough overview of our current knowledge concerning city size distributions, and presents an alternative mathematical interpretation of those distributions. My major reservation with respect to this genre of research is that the mathematical and statistical exploration of city size distributions appears to have contributed remarkably little to our understanding of the underlying processes responsible for urban growth, decline, and overall system evolution.