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# Climatic Effects on Bus Durability

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FINAL REPORT

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16. Abstract  A study was conducted to establish climatic peer groups that may be used, in combination with any set of Section 15 indicators, as a guide to understanding how climate affects participating transit authorities. Three climatic indicators were used to partition 203 transit authorities into "harsh," "intermediate," and "benign" climatic peer groups. The results are mapped and also displayed in tabular form. The hypothesis that bus durability is adversely affected in harsh climates was tested, using data from Section 15 indicators, to illustrate the method of employing these climatic peer groups. Section 15 indicators on "age distribution," "distance between roadcalls," and "vehicle miles per maintenance dollar," partitioned by climate class, provide support for this hypothesis. Implications resulting from the testing of this hypothesis suggest which climatic peer groups might benefit from additional evaluation of their maintenance strategy and which climatic peer groups might serve as maintenance models for others.			
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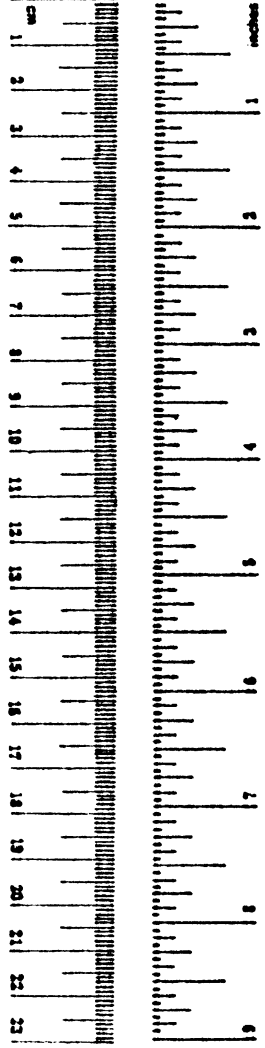
We wish to acknowledge support from an UMTA grant awarded to the University of Michigan Transportation Research Institute. In addition we thank Gordon J. Fielding of the Institute of Transportation Studies and School of Social Sciences of the University of California, Irvine, for supplying us with materials about his research. The maps in Figure 1 are reprinted from Climatic Atlas of the United States by Stephen Sargent Visher by permission of Harvard University Press. Year of first publication was 1954. Errors in fact or interpretation that remain are, of course, ours alone.

### METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

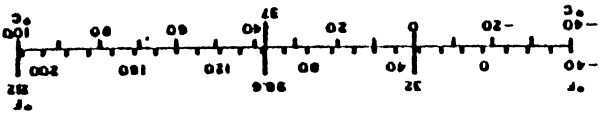
Symbol	When You Know	Multiply by	To Find	Symbol
m	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
<b>AREA</b>				
sq in	square inches	6.5	square centimeters	cm <sup>2</sup>
sq ft	square feet	0.09	square meters	m <sup>2</sup>
sq yd	square yards	0.8	square meters	m <sup>2</sup>
sq mi	square miles	2.6	square kilometers	km <sup>2</sup>
acres	acres	0.4	hectares	ha
<b>MASS (weight)</b>				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
short tons	short tons	0.9	tonnes	t
<b>VOLUME</b>				
teaspoon	teaspoons	5	milliliters	ml
Tablespoon	tablespoons	15	milliliters	ml
fluid ounce	fluid ounces	30	milliliters	ml
cup	cups	0.24	liters	l
pint	pints	0.47	liters	l
quart	quarts	0.95	liters	l
gallon	gallons	3.8	liters	l
cu ft	cubic feet	0.03	cubic meters	m <sup>3</sup>
cu yd	cubic yards	0.76	cubic meters	m <sup>3</sup>
<b>TEMPERATURE (exact)</b>				
°F	Fahrenheit temperature	5/9 factor subtracting 32)	Celsius temperature	°C

\* 1 m = 2.54 exactly. For other exact conversions and more detailed tables, see NBS Spec. Publ. 200, Units of Weights and Measures, Price \$2.25, SD Catalog No. C13.10.206.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
km	kilometers	1.1	yards	yd
mi	miles	0.6	miles	mi
<b>LENGTH</b>				
sq mm	square millimeters	0.16	square inches	in <sup>2</sup>
sq cm	square centimeters	1.2	square inches	in <sup>2</sup>
sq m	square meters	0.9	square yards	yd <sup>2</sup>
sq km	square kilometers	0.4	square miles	mi <sup>2</sup>
ha	hectares (10,000 m <sup>2</sup> )	2.5	acres	acres
<b>MASS (weight)</b>				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	short tons
<b>VOLUME</b>				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m <sup>3</sup>	cubic meters	35	cubic feet	cu ft
m <sup>3</sup>	cubic meters	1.3	cubic yards	cu yd
<b>TEMPERATURE (exact)</b>				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F





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## INTRODUCTION

Cars and buses heavily scarred by rust are a familiar sight to residents of the Great Lakes Basin and other regions that experience heavy concentrations of snow and road salt, or heat and airborne salt. Other environmental stresses that contribute to the aging of a bus fleet involve the steepness of the terrain and the density of traffic congestion; steep grades produce extra strain on the motor and powertrain, and frequent stopping and starting wears the brakes, the engine, and the drive train. These components are often repaired or replaced, but disintegration of the sheet metal 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 affected regions with an opportunity to build healthier, more efficient bus fleets.

The study discussed here derived measures of climatic conditions that can be used in analysis of several factors related to vehicle performance. It exploited 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."<sup>(1)</sup> These climatic 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.

## CLIMATIC PEER GROUPS

The mechanics of constructing climatic peer groups involves 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 climatic peer group. It does so using the lengths of climate vectors (vector norms) measured in a coordinate system with national average as the origin.

### Peer Groups Formed by a Simple Numerical Procedure

We assume that when road salt is used as an aid in snow removal, it speeds bus-body corrosion; we do not assume that all corrosion is caused by road salt, nor do we assume that all communities employ road salt in snow removal. Thus the measures that appear below 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. While these are issues which could be superimposed on the

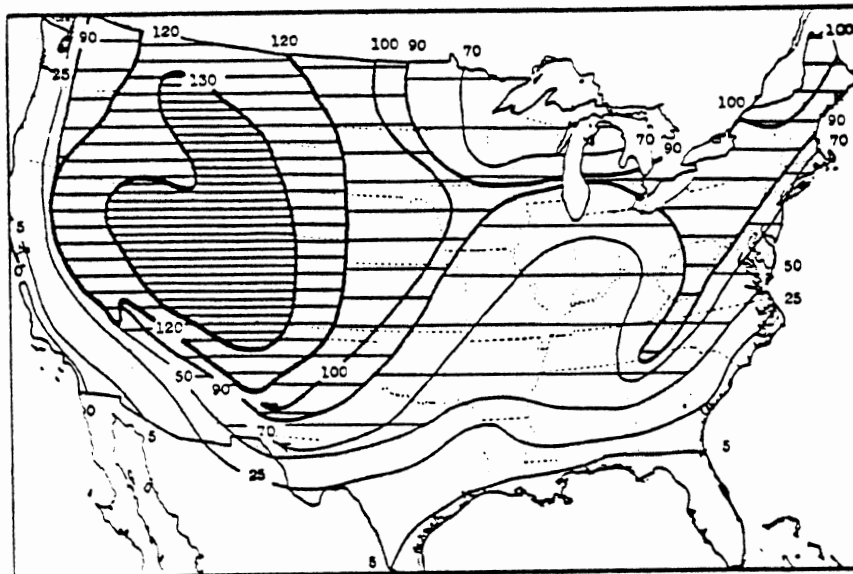
results of this study, they are beyond its scope as they do not contribute, at the fundamental level, to sorting transit authorities by climatic type; it is the typology that is dominant here.

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 are available on a city by city basis in the tables of "Normals, Means, and Extremes," in Climates of the States.<sup>(2)</sup> These tables report data only from locations with complete weather stations. Only data from those weather stations

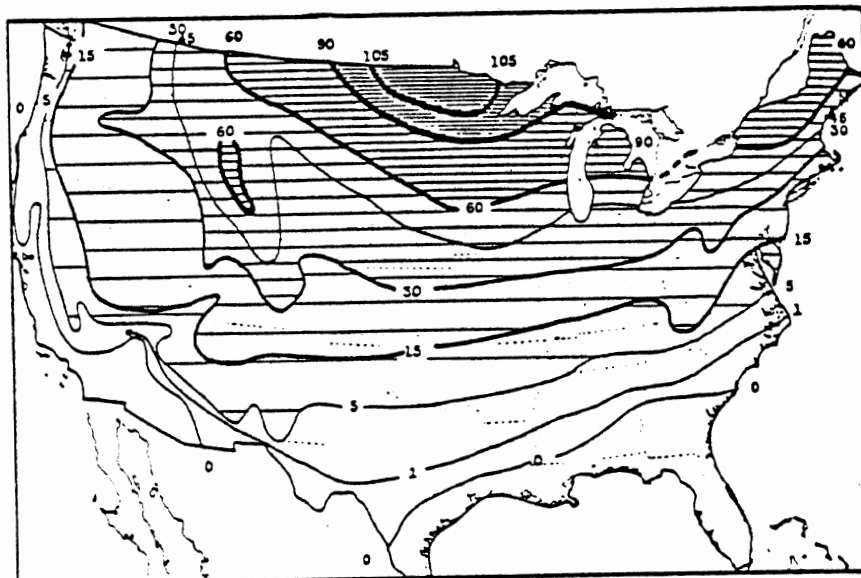
in cities with bus systems were included. Cities with bus systems, but not with reporting weather stations, were grouped with the weather station in their climatic zone, as shown in maps of "Climatic Zones" in Climates of the States. Data for the third variable come from the maps in Figures 1A, B, and C, which appeared originally in Stephen Visher's Climatic Atlas of the United States.<sup>(3)</sup> To form the isolines in this map, Figure 1A, Visher used the differences found by subtracting "Normal annual number of days with temperature continuously below freezing" (Figure 1B) from "Normal annual number of nights with frost (minimum of 32° or lower)" (Figure 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, since these climatic values generally do not vary linearly between isolines. Numerical values for this climatic indicator range from 0 days to 130 days. High values of this "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, since 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



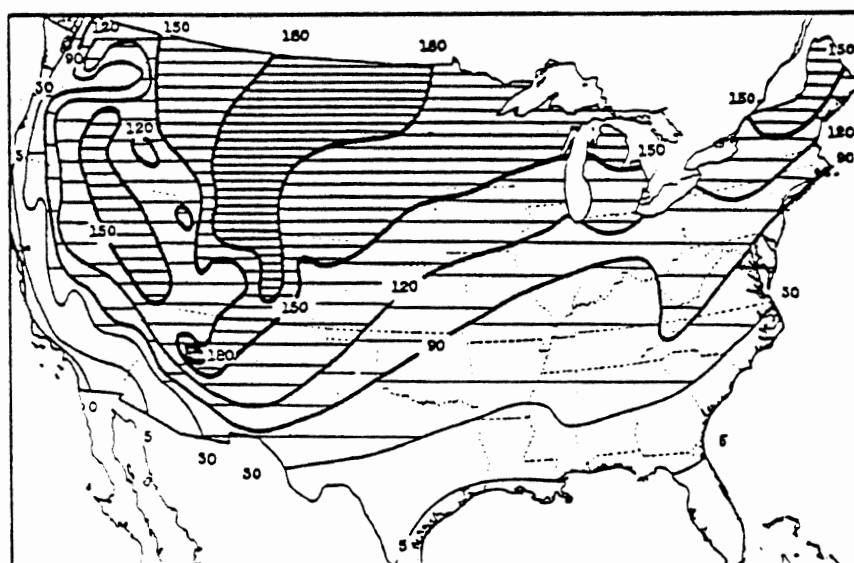
(A)

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. VISHER MAPS

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, 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. Table 1 classifies the 193 cities according to the sign of their ordered triples. 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 Table 1. 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 Table 1. The cities associated with the remaining sign possibilities are grouped in the "intermediate" climate class of Table 1.

Figure 1 partitions the continental United States into "harsh," "benign," and "intermediate" climatic peer groups of transit authorities. Peer group boundaries were drawn to separate transit authorities in, or near, cities of harsh climate (Table 1) from transit authorities in, or near, cities of intermediate climate (Table 1). The latter were separated, in turn, from transit authorities in, or near, cities of benign climate (Table 1). As is evident from the underlying scatter of dots in Figure 2, the accuracy with which these climatic peer group boundaries were placed is greater in the east than in the west.



TABLE 1: CITIES BY CLIMATE CLASS--ORDERED FROM EAST TO WEST BY LONGITUDE<sup>a</sup>

HARSH	BENIGN	INTERMEDIATE	HARSH	BENIGN	INTERMEDIATE
Portland ME	Norfolk VA	<u>Class (-,-,+)</u>	Jackson MI	Phoenix AZ	Jackson Hts. NY
Haverhill MA	Hampton VA	Phila. PA	Fort Wayne IN	San Diego CA	New York NY
Boston MA	Raleigh NC	Wilmington DE	Kalamazoo MI	San Bern. CA	E. Meadow NY
Lowell MA	Fayetteville NC	Lancaster PA	South Bend IN	Riverside CA	Brooklyn NY
Manchester NH	W. Palm Beach FL	Washington DC	Gary IN	Oceanside CA	W. Cox'ie NY
Worcester MA	Ft. Laud'dale FL	Lynchburg VA	Chicago IL	Garden Grove CA	Louisville KY
Springfield MA	Miami FL	Columbus OH	Racine WI	Norwalk CA	<u>Class (-,0,0)</u>
Hartford CT	S. Daytona FL	Knoxville TN	Kenosha WI	Montebello CA	Indianapolis IN
New Haven CT	Savannah GA	Chattanooga TN	Waukegan IL	Long Beach CA	Urbana IL
White Plains NY	Orlando FL	Kansas City MO	Des Plaines IL	Los Angeles CA	Decatur IL
Albany NY	Jacksonville FL	Topeka KA	Milwaukee WI	Santa Monica CA	Peoria IL
Yonkers NY	Augusta GA	Tulsa OK	Joliet IL	Gardena CA	Springfield IL
Newark NJ	Gainesville FL	Wichita KA	Elgin IL	Torrance CA	<u>Class (+,-,+)</u>
Utica NY	Tampa FL	Okla. City OK	Aurora IL	Bakersfield CA	Bridgeport CT
Allentown PA	St. Pete. FL	Amarillo TX	Appleton WI	Ventura CA	Stamford CT
Scranton PA	Bradenton FL	Lubbock TX	Oshkosh WI	Santa Barbara CA	Asheville NC
Kingston PA	Clearwater FL	Albuquerque NM	Rockford IL	Fresno CA	<u>Class (-,0,+)</u>
Binghamton NY	Tallahassee FL	<u>Class (-,-,0)</u>	Madison WI	Stockton CA	Huntington WV
Syracuse NY	Columbus GA	Richmond VA	Rock Island IL	Sacramento CA	Charleston WV

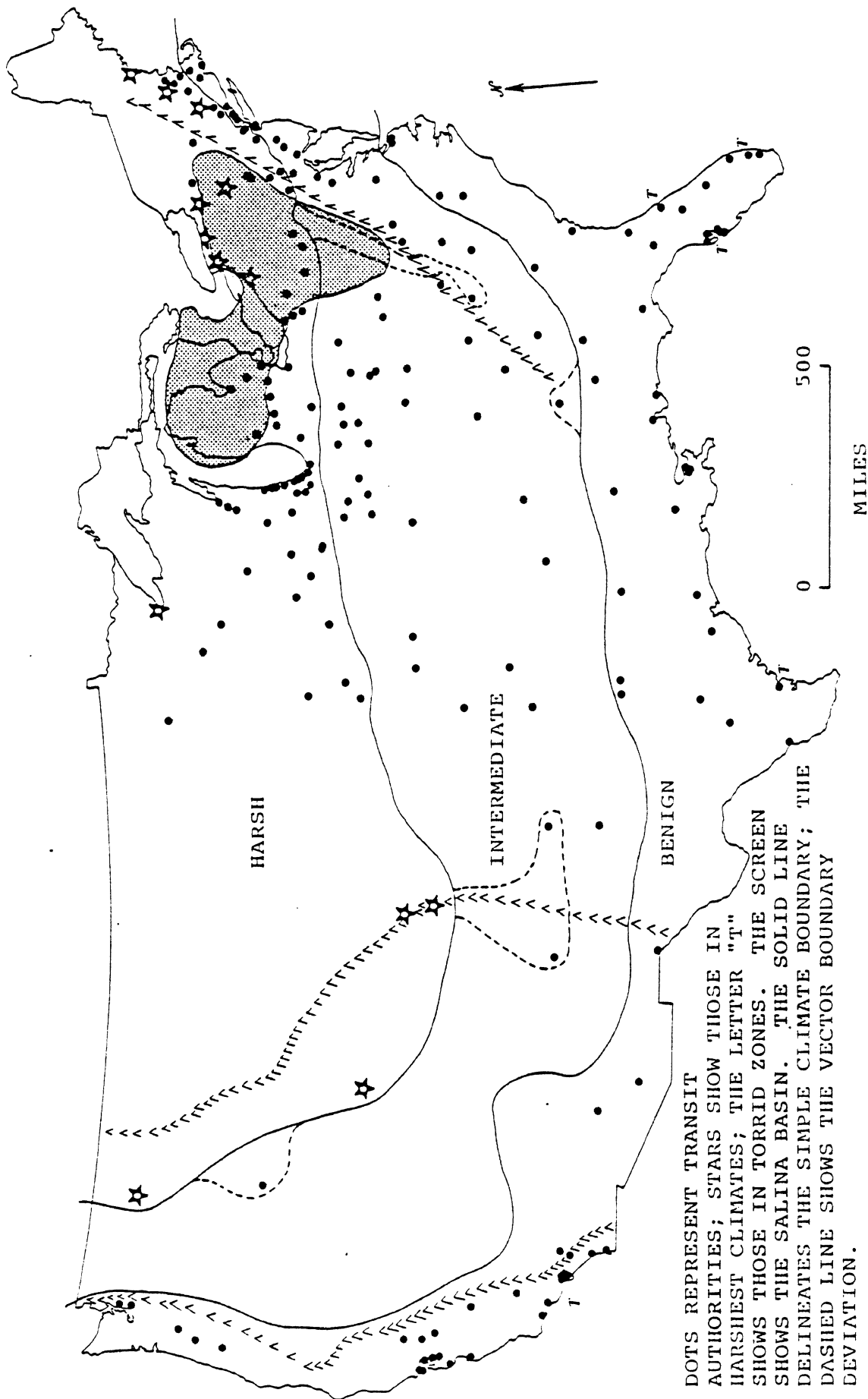
Harrisburg PA	Montgomery AL	Winston-Salem NC	Davenport IA	Monterey CA	<u>Class (0,-,+)</u>
Rochester NY	Pensacola FL	Charlotte NC	Dubuque IA	San Jose CA	Baltimore MD
Altoona PA	Mobile AL	Dayton OH	La Crosse WI	Santa Cruz CA	<u>Class (+,0,+)</u>
Johnstown PA	Harahan LA	Atlanta GA	Cedar Rapids IA	Oakland CA	Roanoke VA
Buffalo NY	Gretna LA	Cincinnati OH	Duluth MN	Seattle WA	<u>Class (-,+,+)</u>
Pittsburgh PA	New Orleans LA	Newport KY	Waterloo IA	San Mateo CA	Boise ID
Erie PA	Jackson MS	Lexington KY	St. Paul MN	San Francisco CA	<u>HARSHEST PLACES:</u>
Youngstown OH	Baton Rouge LA	Nashville TN	Des Moines IA	Tacoma WA	Portland ME, Man-
Kent OH	Shreveport LA	Birmingham AL	St. Cloud MN	Salem OR	chester NH,
Canton OH	Houston TX	Memphis TN	Sioux City IA	Eugene OR	Springfield MA,
Akron OH	Dallas TX	St. Louis MO	Lincoln NB	Portland OR	Albany, Utica,
Cleveland OH	San Antonio TX	Little Rock AR	Fargo ND	Binghamton, Syracuse, Rochester,	
Detroit MI	Fort Worth TX	<u>Class (+,+,0)</u>	Omaha NB	Buffalo, Erie, Duluth, Col. Spgs.,	
Toledo OH	Corpus Christi TX	New Bedford MA	Col. Spgs. CO	Denver, Salt Lake City, Spokane.	
Saginaw MI	Austin TX	Brockton MA	Denver CO	<u>CITIES CLOSEST TO AVERAGE:</u>	
Ann Arbor MI	Laredo TX	Providence RI	Salt Lake C. UT	Indianapolis, Urbana, Peoria,	
Flint MI	El Paso TX	Flushing NY	Spokane WA	Springfield IL, Decatur, Baltimore,	
Bay City MI	Tucson AZ	Jamaica NY		Charleston WV, Huntington WV.	

<sup>a</sup>Some cities may have more than one transit authority associated with them.

In much of the western mountainous region the boundary follows topographic features such as mountain ranges and river basins. Since the climatic indicators that formed the basis for delineating climatic peer groups were chosen for their capability to link road salt to snow, Figure 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 climatic peer group.

#### The Distribution of Climate Vectors

The three climatic peer groups shown in Figure 2 exhibit a great deal of variation within each group; this section shows how to determine the peers most closely related, in both climate and geographic position, to an arbitrarily chosen transit authority. The map in Figure 3 displays the grid standardly 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, we substitute climate for latitude; the column "climate vector norms" in Table 2 shows single climate values, based on all three climatic indicators, used in place of latitude in the map of Figure 3. Then dots on that map that are close have both climate and longitude (geographic position) that are close. Hence the nearest neighbors, within a semi-circular band, of a given point are its geographically proximate climate-peers. Table 3 displays the names of each transit authority represented in Figure 2 and its nearest climate-peers. For example, there is no transit authority with winters as severe as those in Duluth, nearer than Springfield MA on the east, or than Denver on the west. Thus Springfield and Denver are Duluth's geographically nearest

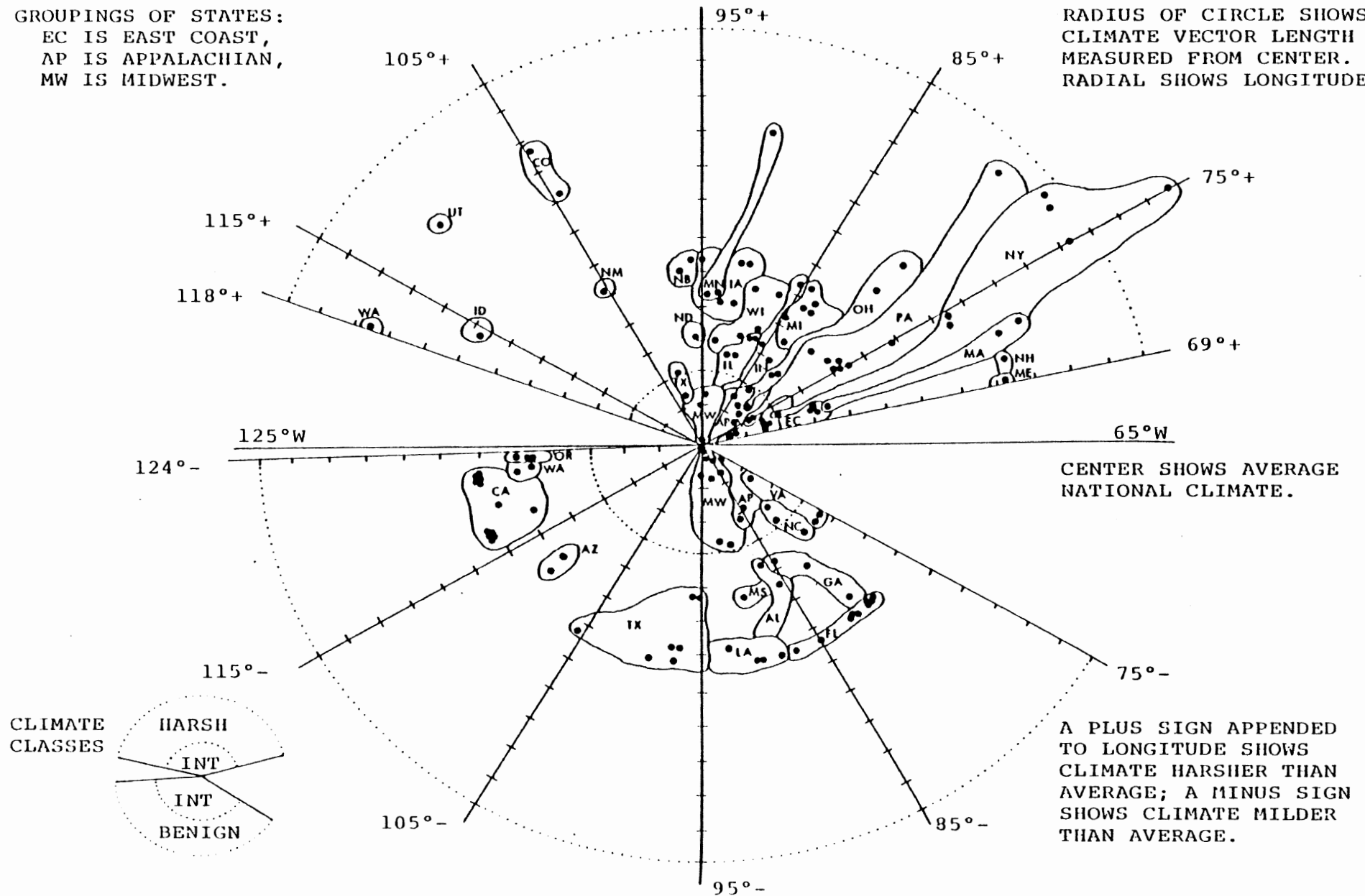


DOTS REPRESENT TRANSIT AUTHORITIES; STARS SHOW THOSE IN HARSH CLIMATES; THE LETTER "T" SHOWS THOSE IN TORRID ZONES. THE SCREEN SHOWS THE SALINA BASIN. THE SOLID LINE DELINEATES THE SIMPLE CLIMATE BOUNDARY; THE DASHED LINE SHOWS THE VECTOR BOUNDARY DEVIATION.

FIGURE 2. CLIMATIC REGIONS FOR BUSES

GROUPINGS OF STATES:  
 EC IS EAST COAST,  
 AP IS APPALACHIAN,  
 MW IS MIDWEST.

RADIUS OF CIRCLE SHOWS  
 CLIMATE VECTOR LENGTH  
 MEASURED FROM CENTER.  
 RADIAL SHOWS LONGITUDE.



CENTER SHOWS AVERAGE  
 NATIONAL CLIMATE.

A PLUS SIGN APPENDED  
 TO LONGITUDE SHOWS  
 CLIMATE HARSHER THAN  
 AVERAGE; A MINUS SIGN  
 SHOWS CLIMATE MILD  
 THAN AVERAGE.

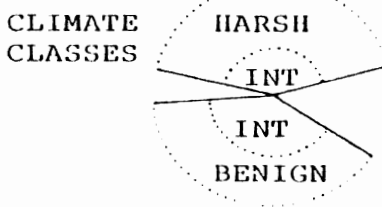


FIGURE 3. BUS CLIMATE VECTORS GROUPED BY STATE

TABLE 2: CLIMATE VECTOR NORMS OF CITIES ARRANGED BY CLIMATIC PEER GROUP<sup>b</sup>

HARSH	NORM	LONGITUDE ° ,	BENIGN	NORM	LONGITUDE ° ,	INTERMEDIATE	NORM	LONGITUDE ° ,
Portland	82.4	70 16	Norfolk	37.4	76 15	Philadelphia	15.7 †	75 13
Haverhill	33.6	71 05	Hampton	37.4	76 21	Wilmington	9.9 †	75 33
Boston	33.6	71 07	Raleigh	37.4	78 39	Lancaster	15.7 †	76 20
Lowell	33.6	71 18	Fayetteville	37.4	78 54	Washington DC	9.9 †	77 00
Manchester	85.3	71 30	M. Palm Beach	63.7	80 04	Lynchburg	13.7 †	79 08
Worcester	85.1	71 49	Ft. Laud'dale	63.7	80 09	Columbus	15.7 †	83 00
Springfield MA	91.9	72 35	Miami FL	63.7	80 11	Knoxville	3.3 †	83 55
Hartford	31.0	72 40	S. Daytona	63.7	81 02	Chattanooga	1.9 †	85 15
New Haven	31.0	72 55	Savannah	60.0	81 07	Kansas City	14.5 †	94 35
White Plains	22.0	73 47	Orlando	63.7	81 22	Topeka	12.7 †	95 41
Albany	74.6	73 50	Jacksonville	63.7	81 40	Tulsa	0.3 †	95 58
Yonkers	22.0	73 54	Augusta	46.0	82 00	Wichita	7.1 †	97 21
Newark	22.0	74 10	Gainesville	63.7	82 20	Okla. City	3.3 †	97 32
Utica	74.7	75 10	Tampa	63.7	82 25	Amarillo	23.0 †	101 49
Allentown	42.9	75 30	Bradenton	63.7	82 35	Lubbock	16.7 †	101 50
Scranton	60.0	75 45	St. Pete.	63.7	82 38	Albuquerque	50.3 †	106 40
Kingston	42.9	75 50	Clearwater	63.7	82 45	Richmond	15.5	77 30
Binghamton	113.8	75 55	Tallahassee	63.7	84 17	Winston-Salem	26.3	80 15
Syracuse	149.9	76 10	Columbus GA	39.5	84 56	Charlotte	29.6	80 50

Harrisburg	45.0	76 50	Montgomery	46.0	86 17	Dayton	4.8	84 15
Rochester	114.1	77 35	Pensacola	63.7	87 13	Atlanta	21.8	84 23
Altoona	45.0	78 25	Mobile	63.7	88 03	Cincinnati	8.3	84 30
Johnstown	42.0	78 50	Harahan	63.7	90 00	Newport	8.3	84 30
Buffalo	116.5	78 51	Gretna	63.7	90 00	Lexington	6.3	84 30
Pittsburgh	41.9	80 01	New Orleans	63.7	90 05	Nashville	24.2	86 48
Erie	111.9	80 05	Jackson MS	45.3	90 10	Birmingham	38.0	86 49
Youngstown	64.3	80 40	Baton Rouge	63.7	91 10	Memphis	29.6	90 03
Kent	28.1	81 20	Shreveport	60.0	93 46	St. Louis	8.3	90 15
Canton	28.1	81 25	Houston	63.7	95 21	Little Rock	28.7	92 16
Akron	28.1	81 30	Dallas	43.0	96 48	New Bedford	17.0	70 55
Cleveland	75.3	81 42	San Antonio	59.9	97 08	Brockton	17.0	71 01
Detroit	49.6	83 10	Fort Worth	42.3	97 20	Providence	17.0	71 23
Toledo	31.0	83 35	Corpus Christi	63.7	97 24	Flushing	8.3	73 50
Saginaw	38.2	83 40	Austin	59.3	97 42	Jamaica	8.3	73 50
Ann Arbor	49.6	83 45	Laredo	63.7	99 29	Jackson Hts	8.3	73 50
Flint	51.6	83 45	El Paso	63.7	106 27	New York	6.3	73 58
Bay City	38.2	83 55	Tucson	56.9	111 00	E. Meadow	6.3	73 58

Jackson MI	55.6	84 25	Phoenix	50.7	112 00	Brooklyn	6.3	73 58
Fort Wayne	22.7	85 10	San Diego	63.7	117 10	W. Cox'ie	6.3	73 58
Kalamazoo	43.5	85 40	San Bern.	63.7	117 19	Louisville	17.0	85 45
South Bend	53.4	86 20	Riverside	63.7	117 21	Indianapolis	6.0	86 08
Gary	33.7	87 21	Oceanside	63.7	117 22	Urbana	1.0	88 15
Chicago	33.7	87 37	Garden Grove	63.7	117 56	Decatur	2.0	88 59
Racine	48.8	87 49	Norwalk	63.7	118 05	Peoria	1.0	89 35
Kenosha	48.8	87 50	Montebello	63.7	118 06	Springfield IL	2.0	89 37
Waukegan	33.7	87 51	Long Beach	63.7	118 12	Bridgeport	16.5 †	73 12
Des Plaines	33.7	87 54	Los Angeles	63.7	118 15	Stamford	16.5 †	73 32
Milwaukee	48.8	87 55	Santa Monica	63.7	118 19	Asheville	15.9 †	82 35
Joliet	33.7	88 05	Gardena	63.7	118 19	Charleston	12.8 †	81 35
Elgin	28.4	88 16	Torrance	63.7	118 20	Huntington	12.8 †	82 25
Aurora	28.4	88 18	Bakersfield	59.9	119 00	Baltimore	15.9 †	76 38
Appleton	32.0	88 27	Ventura	63.7	119 18	Roanoke	20.3	79 55
Oshkosh	32.0	88 35	Santa Barbara	63.7	119 43	Boise	67.7 †	116 12
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			

<sup>b</sup>Arrows indicate "above" (†) or "below" (+) average norm.



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			
Col. Spgs.	83.6	104 48			
Denver	97.4	104 59			
Salt Lake C.	96.2	111 52			
Spokane	95.0	117 25			

TABLE 3: VECTOR RANK-ORDERING OF TRANSIT AUTHORITIES  
 WITHIN CLIMATIC PEER GROUPS<sup>C</sup>

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, Montgomery, Jackson MS, Dallas, Forth 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.

<sup>c</sup>Transit authorities listed by semi-circular bands from Figure 3 and ordered from east to west within a semi-circular band.

climatic 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 of equal weight in describing severity of winter (as explained above). Thus, to compare vectors, adjustment of the set of values over which individual components may range is required. A variety of strategies is available for this purpose, and each could lead to means for determining climatic 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 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 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 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. Since 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) [since  $x/130 = 1/109$ ]; the unit vector on the y-axis stretches to (0, 4.0625, 0) [since  $y/130 = 1/32$ ]; 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 2 shows 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 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 3, represents a meridian of 65°W Longitude to the right of the map center and a meridian of 125°W 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° in the above average zone, and at 75° and 124° 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 (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, 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, which might generally suggest latitude on a projection of this sort, represent instead length of climate vector; the interval measuring the spacing is ten 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, while 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  $||v|| = \sqrt{p^2+q^2+r^2}$ .(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  $||w|| = |\sqrt{s^2+t^2} - \sqrt{u^2}|$ ; 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 any of the other possibilities. The vector head of a mixed vector was placed in the above average zone of Figure 3 if the difference inside the absolute value sign were positive, and in the below average zone if that difference were negative. Entries in Table 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 3 shows the entries in Table 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°W in the below average zone, and mountain Washington, with a harsh climate, lying between 115+ and 125°W 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 labelled MW in Figure 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, South Pennsylvania cities near the coast (Philadelphia, Lancaster) have vector heads lying just above the map center while those in mountain 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, while an upstate section, containing a number of lake effect cities, exhibits climatic indices for buses that are in the harshest climates in the nation.

What this suggests, of 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 semi-

circular bands in the above and below average zones of Figure 3 suggest rank ordering for transit authorities within climatic peer groups (Table 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 2 and 3 are ordered by longitude.

Based on this more technically precise vector approach, Figure 3 and Tables 2 and 3 were used to generate "vector" boundaries separating harsh, intermediate, and benign climatic peer groups. To find these boundaries, note that in Figure 3 cities 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 semi-circle 20 units from the center. In the below average zone the semi-circle 30 units below the center appeared a natural choice. When these vector boundaries were superimposed on the map in Figure 2 they were coincident with the "simple" boundaries, determined in the first part of this report, in all but five locations.

In particular, Boise, Roanoke, Albuquerque, and Amarillo belonged in the "intermediate" climatic peer group according to the simple partition, but shifted to the "harsh" climatic peer group in the vector partition. At the other extreme, Birmingham AL was classed as "intermediate" initially but as "benign" in the vector approach (Figure 2). The content of the climate vectors suggests reasons for these transit authorities to be climatic "boundary dwellers."<sup>(5)</sup> In all cases the Visher index had by far the greatest numerical value, often due to



the presence of mountains, suggesting that in a rain or snow storm, the frequent freezing and thawing might cause difficulties for buses. Thus in mild winters these cities might be classed in the more benign of the two peer groups, since there would be little need for salt, while 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, while those linked to Boise exhibit it to have the greatest. Other than these boundary dwellers, the climatic peer groups of "harsh," "intermediate," and "benign" that were formed using the simple procedure correspond identically to those generated by the vector approach. Thus the vector approach serves not only to pin-point nearest climate-peers but also to verify the more broadly based scheme displayed in Figure 2, within which we next consider other factors such as age profiles and performance.

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

The application of these climatic 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 4 show the expected, versus the actual, annual and aggregate age stratification of the bus population by climatic peer group. For example, in 1978-79, 35.8% of all buses were in transit authorities in a "harsh" environment; thus one would expect that 35.8% of 0-5 year old buses, 35.8% of 6-10 year old buses, 35.8% of 11-15 year old buses, and so forth, would lie in the harsh class in 1978-79. The position of the

horizontal line in Figure 4A represents this "expected" value. In fact, however, this harsh class contained 38.7% of 0-5 year olds, 34.7% of 6-10 year olds, 36.8% of the 11-15 generation, 29.8% of the 16-20 year olds, 23.0% of the 21-25 generation, and 21.3% of the 25+ group (Figure 4A.i). The remaining frames in Figure 4 display similar breakdowns of data on bus-age across climatic peer groups; frames ii, iii, and iv, in Figure 4 show age stratification in the harsh class for the remaining three years while Figure 4A.v displays the aggregate of Figures 4A.i-4A.iv. Figure 4B shows five frames depicting, in chronological sequence, the annual and aggregate age stratification of the bus population in the "intermediate" climatic peer groups, while Figure 4C represents the same sequence for the "benign" climatic peer group.

Of particular note is the distribution of the oldest buses across these peer groups. The harsh group has 23.8% of the oldest buses, rather than the expected 34.8% (Figure 4A.v); the intermediate group has 12.4% rather than the expected 38.1% (Figure 4B.v); and, the benign group has 63.8% rather than the expected 28.9% (Figure 4C.v). The fact that the intermediate peer group has a smaller percentage of very old buses than does even the harsh peer-group might suggest (1) lack of expenditure in maintaining intermediate-climate buses, or (2) the 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 very old buses; we suspect that the graphic distinctions already evident in Figure 3 might become even more apparent if we were able to identify and eliminate buses subject to airborne salt in warm, humid climates. Figure 4C 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

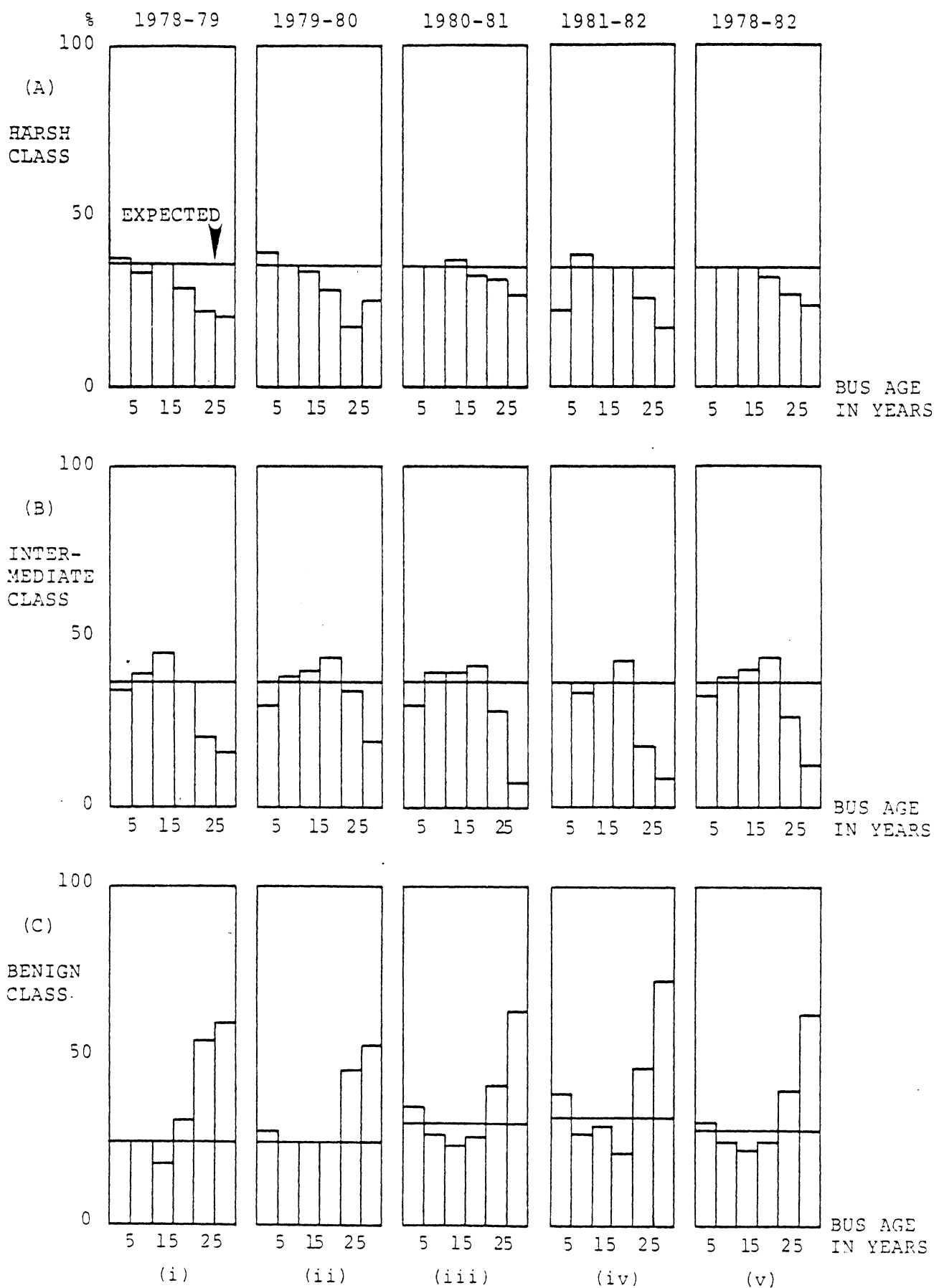


FIGURE 4. TIME-SERIES AND AGGREGATE STRATIFICATION CHARTS BY CLIMATE CLASS

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 CLIMATIC PEER GROUPS

Figure 4 serves to display differences in age profiles between climatic 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 climatic 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 climatic peer group. We looked at the maintenance indicators, "vehicle miles per roadcall" and "total vehicle miles per dollar spent on maintenance." The former indicator appeared less reliable than the latter, on an annual basis, since any single transit authority might have a cluster of roadcalls toward the end of one year followed by very few in the next year. Many entries were missing, especially in the first year, but were filled in, where possible, for "distance between roadcalls," using data from "total vehicle miles" divided by "total roadcalls," 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 4 shows distances between roadcalls over the entire four-year span for the national bus population and for the bus population in the three climate peer groups. The breakdown into size peer groups 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 5 shows miles per maintenance dollar on an annual basis for the bus population by size peer group within each climatic peer group. All three peer groups show declining mileage per maintenance dollar from 1978-79 to 1981-82, (Table 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 4 and 5 are available. This is a first effort to analyze the relation between maintenance and climate; thus, a significant function of these data is to suggest directions in which this climatic partition 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 suggest 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 5 shows an improvement in vehicle miles per maintenance

TABLE 4: DISTANCE BETWEEN ROADCALLS BY CLIMATE AND SIZE PEER GROUP

NO. OF BUSES/ TRANSIT AUTHORITY	YEAR OF SECTION 15 REPORT					NO. OF ENTRIES			
	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-size--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-size--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-size--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-size--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 5: VEHICLE MILES PER MAINTENANCE DOLLAR BY CLIMATE AND SIZE PEER GROUP <sup>d</sup>

NO. OF BUSES/ TRANSIT AUTHORITY	YEAR OF SECTION 15 REPORT					NO. OF ENTRIES			
	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-size--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-size--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-size--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-size--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

<sup>d</sup> Entries marked with an asterisk include data from New York City; without it, they become: 1.41, 1.65, 1.84, 2.21.

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 4 and 5 provide yet another means of identifying different subclasses within the Section 15 data.

#### CONCLUSION

The primary contribution of this study 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 nearest climatic peers of transit authorities within each of the broader categories.

In addition, an indication was given as to how these climatic 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 involving several factors related to vehicle performance, while the nearest neighbor map (Figure 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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