Terrain Effects on Bus Maintenance Performance

SANDRA L. ARLINGHAUS AND JOHN D. NYSTUEN

In this paper, a methodology to classify terrain is presented. The taxonomy is devised using a terrain template based on evidence from topographic maps, and the resulting classes are characterized as steep, intermediate, and flat terrain peer groups of transit authorities. A set of 181 transit authorities was classified according to terrain type; in borderline cases, graphic displays were used to supplement the tabular display format of the classification. The terrain template was derived from applying allometric growth and census data to topographic evidence. Sets of Section 15 bus maintenance performance indicators were examined within terrain peer groups as an example of the potential for the application of these procedures. When the indicators miles per gallon, employees per vehicle-mile, and cost per vehicle-mile were displayed by terrain peer groups, relationships were found between quality of maintenance and miles per gallon in steeper environments.

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 systems. Terrain peer groups for buses, formed from a set of transit authorities participating in the Section 15 reporting system, assist in understanding the impact terrain might have on bus maintenance performance. The application of a simple terrain template permits either transit managers or 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. When independent variables other than terrain such as climate or congestion were introduced into the analysis, a comprehensive view of bus maintenance performance as a function of environmental, as well as of routing and economic, considerations followed.

More specifically, when the methodology was applied, it suggested numerical maintenance subclasses within terrain peer groups, with which transit authorities might compare their miles-per-gallon figures. Because the application of method was to maintenance data, this study meshed with the authors' previous methodological study *Climatic Effects on Bus Durability (1)*, suggesting the potential for cross-class empirical comparisons of cross-sectional performance data.

The primary 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. The goal is to present ideas in their broadest form to suggest the range of uses for these procedures to a variety of researchers.

TERRAIN PEER GROUPS

The mechanics of developing terrain peer groups 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, which 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

---

S. L. Arlinghaus, Institute of Mathematical Geography, 2790 Briarcliff, Ann Arbor, Mich. 48105. J. D. Nystuen, Geography and Urban Planning, University of Michigan, Ann Arbor, Mich. 48109.

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 $A = 0.00151\ P^{0.8757}$, 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 $R = 0.0219237\ P^{0.43785}$ *(3)*. Calculations were then made to determine population sizes that corresponded to radii of 0.5, 1.0, 1.5, 2.0, 2.5, . . . , 23.0 mi. 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 1 presents these values of radii, which include all cities in the study. A set of circles of radii 0.25, 0.51, 0.76, 1.01, . . . , 5.58 in. 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 1, transit authorities were rank-ordered from the 1980 census within terrain classes by total city population *(5, 6)*. 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, and 3.55. Consequently, these values were not included in this table.

To analyze the terrain within a circle required sampling the spacing between the line pattern of contour lines. Hammond *(4)* commented that terrain steeper than about an 8 percent grade causes problems for virtually any sort of vehicle, while Ullman (unpublished data) 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, but using other percentages would not alter the general procedure.

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 was spaced to

TABLE 1 TERRAIN TYPE AND ALLOMETRIC RADII OF 181 TRANSIT AUTHORITIES

STEEP TERRAIN: 20 Transit Authorities[a]

5.58—No entries
3.80—Los Angeles, Calif.
3.30—No entries
3.04—No entries
2.79—No entries
2.53—No entries
2.28—San Diego, Calif.
2.03—San Francisco, Calif.; Washington, D.C.
1.77—Boston, Mass.; Seattle, Wash.; Kansas City, Mo.
1.52—Pittsburgh, Pa.; Cincinnati, Ohio/Newport, Ky.; Oakland, Calif.; Omaha, Neb.
1.27—Yonkers, N.Y.
1.01—Worcester, Mass.
0.76—Duluth, Minn.; San Mateo, Calif.; Ventura, Calif.; Charleston, W.Va.; Dubuque, Iowa
0.51—Johnstown, Pa.
0.25—No entries

INTERMEDIATE TERRAIN: 80 Transit Authorities[a]

5.58—No entries
3.80—No entries
3.30—No entries
3.04—Philadelphia, Pa.
2.79—No entries
2.53—No entries
2.28—Dallas, Tex.
2.03—Baltimore, Md.; San Antonio, Tex.; Memphis, Tenn.; Minneapolis/St. Paul, Minn.; Milwaukee, Wis.; San Jose, Calif.
1.77—Cleveland, Ohio; Denver, Colo.; Nashville, Tenn.; St. Louis, Mo.
1.52—El Paso, Tex.; Atlanta, Ga.; Fort Worth, Tex.; Portland, Oreg.; Austin, Tex.; Charlotte, N.C.
1.27—Birmingham, Ala.; Akron, Ohio; Colorado Springs, Colo.; Jackson, Miss.; Mobile, Ala.; Dayton, Ohio
1.01—Des Moines, Iowa; Montgomery, Ala.; Knoxville, Tenn.; Lincoln, Neb.; Madison, Wis.; Riverside, Calif.; Syracuse, N.Y.; Chattanooga, Tenn.; Columbus, Ga.; Salt Lake City, Utah; Flint, Mich.; Little Rock, Ark.; Springfield, Mass.; Raleigh, N.C.; Rockford, Ill.; Hartford, Conn.; Winston-Salem, N.C.; New Haven, Conn.; Peoria, Ill.; Erie, Pa.; Topeka, Kans.; Youngstown, Ohio; Cedar Rapids, Iowa; Ann Arbor, Mich.
0.76—Eugene, Oreg.; Davenport, Iowa; Stamford, Conn.; Boise, Idaho; Albany, N.Y.; Roanoke, Va.; Brockton, Mass.; Canton, Ohio; Lowell, Mass.; Laredo, Tex.; Manchester, N.H.; Salem, Mass.; Scranton, Pa.; Sioux City, Iowa; Tallahassee, Fla.; Kalamazoo, Mich.; Oceanside, Calif.; Waterloo, Iowa; Utica, N.Y.; Wilmington, Del.; Huntington, W.Va.; Appleton, Wis.; Lynchburg, Va.; Fayetteville, N.C.; Altoona, Pa.; Binghamton, N.Y.; Asheville, N.C.; Harrisburg, Pa.
0.51—Augusta, Ga.; Haverhill, Mass.; Jackson, Mich.; Kent, Ohio
0.25—No entries

FLAT TERRAIN: 81 Transit Authorities[a]

5.58—New York City, N.Y.
3.80—Chicago, Ill.
3.30—Brooklyn, N.Y.
3.04—No entries
2.79—Houston, Tex.
2.53—Detroit, Mich.
2.28—No entries
2.03—Phoenix, Ariz.; Indianapolis, Ind.
1.77—New Orleans, La.; Columbus, Ohio; Jacksonville, Fla.
1.52—Long Beach, Calif.; Buffalo, N.Y.; Toledo, Ohio; Miami, Fla.; Oklahoma City, Okla.; Tulsa, Okla.; Albuquerque, N. Mex.; Tucson, Ariz.
1.27—Louisville, Ky.; Wichita, Kans.; Sacramento, Calif.; Tampa, Fla.; Norfolk, Va.; Rochester, N.Y.; Corpus Christi, Tex.; St. Petersburg, Fla.; Baton Rouge, La.; Richmond, Va.; Fresno, Calif.; Shreveport, La.; Lexington, Ky.
1.01—Lubbock, Tex.; Fort Wayne, Ind.; Spokane, Wash.; Tacoma, Wash.; Providence, R.I.; Fort Lauderdale, Fla.; Gary, Ind.; Stockton, Calif.; Amarillo, Tex.; Bridgeport, Conn.; Savannah, Ga.; Torrance, Calif.; Orlando, Fla.; Garden Grove, Calif.; Hampton, Va.; San Bernardino, Calif.; South Bend, Ind.
0.76—Bakersfield, Calif.; Allentown, Pa.; Springfield, Ill.; New Bedford, Mass.; Urbana-Champaign, Ill.; Decatur, Ill.; Clearwater, Fla.; Norwalk, Calif.; Gainesville, Fla.; Kenosha, Wis.; Saginaw, Mich.; Waukegan, Ill.; West Palm Beach, Fla.; Portland, Maine; Pensacola, Fla.; Lancaster, Pa.; Daytona, Fla.; Des Plaines, Ill.; Montebello, Calif.
0.51—Oshkosh, Wis.; La Crosse, Wis.; Rock Island, Ill.; Gardena, Calif.; St. Cloud, Minn.; Bay City, Mich.; Santa Cruz, Calif.; Bradenton, Fla.; Gretna, La.; Kingston, Pa.
0.25—Harahan, La.

[a] Numbers are rank-ordered by allometric radius and are proportional to city size.

represent 2 and 8 percent grades on a 1:250,000 topographic map with a 50-ft contour interval to evaluate spacing between contours *(4)*. Adjustments may be made easily for 100- and 200-ft contour intervals. A 2 percent slope at a scale of 1:250,000 would be represented by a set of short, vertical parallel line segments spaced 0.12 in. apart; an 8 percent slope at 1:250,000 would be represented by a set of short vertical parallel line segments spaced 0.03 in. apart. When a horizontal line is drawn perpendicular to each set of vertical parallel line segments through the set of vertical parallel lines, a comb-like configuration appears, corresponding to each spacing pattern. Each contour comb is then transferred to a transparency. When either transparency is superimposed on both the allometric circle and the topographic map so that the horizontal line (comb handle) passes through the center of the circle, the horizontal line samples contour line spacing. Rotating this line 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 1 min each) determination of the general terrain of most cities as steep, intermediate, or flat. Table 1 presents the results of applying the template to a set of 181 transit authorities; in Table 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 1 includes maps of this sort for selected transit authorities that did not fall clearly into a particular terrain type. Figure 1 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. The content of Figure 1 is organized, generally, according to increasing steepness of terrain; 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 1. 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 1, Detroit, Indianapolis, Sacramento, 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-Saint 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 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 retaining of classificatory structure that parallels the form underlying the research in *Climatic Effects on Bus Durability*, thereby facilitating cross-class comparisons between corresponding climate and terrain peer

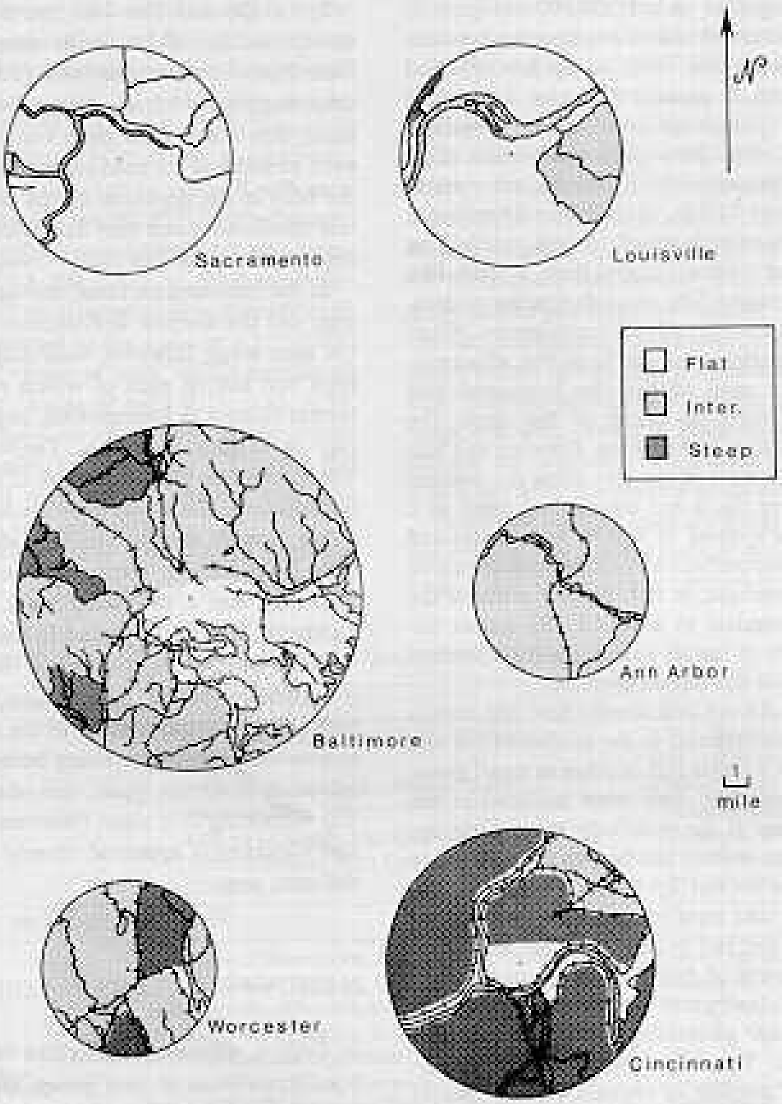

FIGURE 1 Terrain snapshots.

groups. Further, this research is an effort involving the development of methodology, as was the climate research. Therefore, it appears appropriate to keep underlying assumptions as uncluttered as possible to permit the widespread dissemination and use of these ideas by researchers from a variety of backgrounds.

The material that follows, which 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 (7)*; 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 hr/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 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 compresses four dimensions of data (maintenance value, maintenance efficiency, percentage per quarter of the miles-per-gallon indicator, and percentage of transit authorities per maintenance subclass) into two geometric dimensions. For example, the bar in the

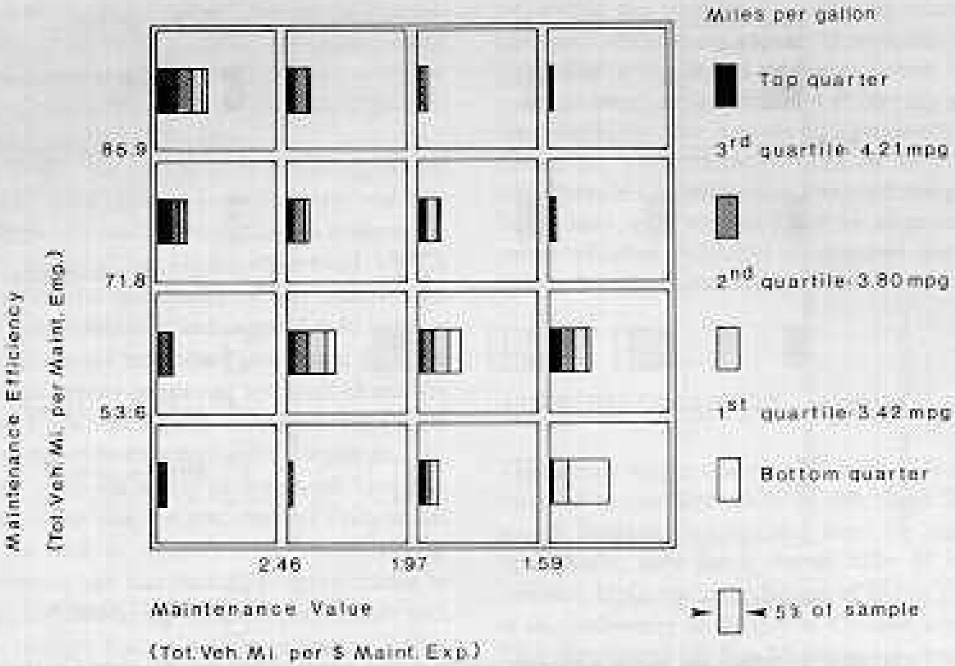

FIGURE 2 Miles-per-gallon indicator within maintenance subclasses (sample size: 181 transit authorities).

upper-left-hand corner of Figure 2 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. 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 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

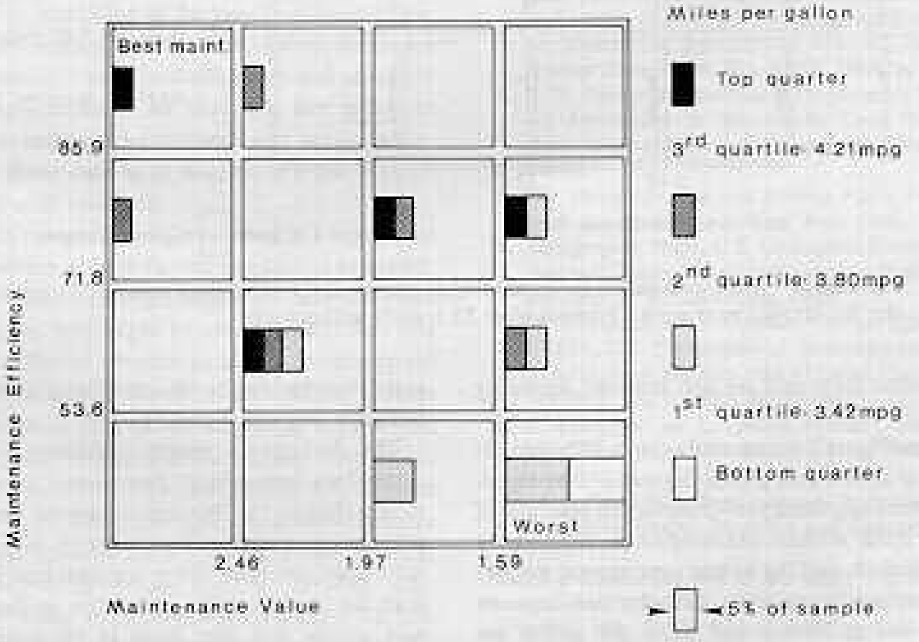

FIGURE 3 Miles-per-gallon indicator within maintenance subclasses measured across the steep-terrain peer group (sample size: 20 transit authorities).

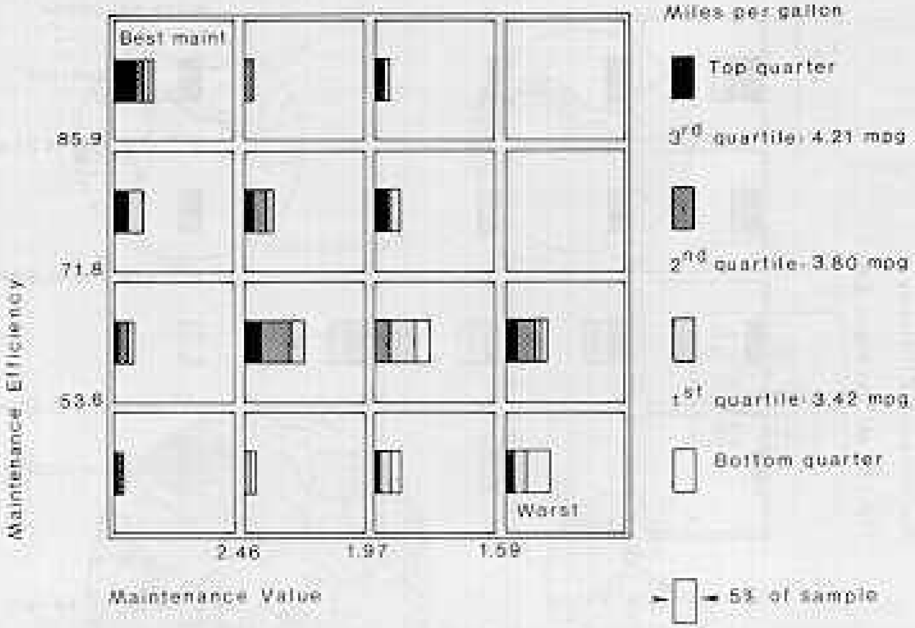

FIGURE 4 Miles-per-gallon indicator within maintenance subclasses measured across the intermediate-terrain peer group (sample size: 80 transit authorities).

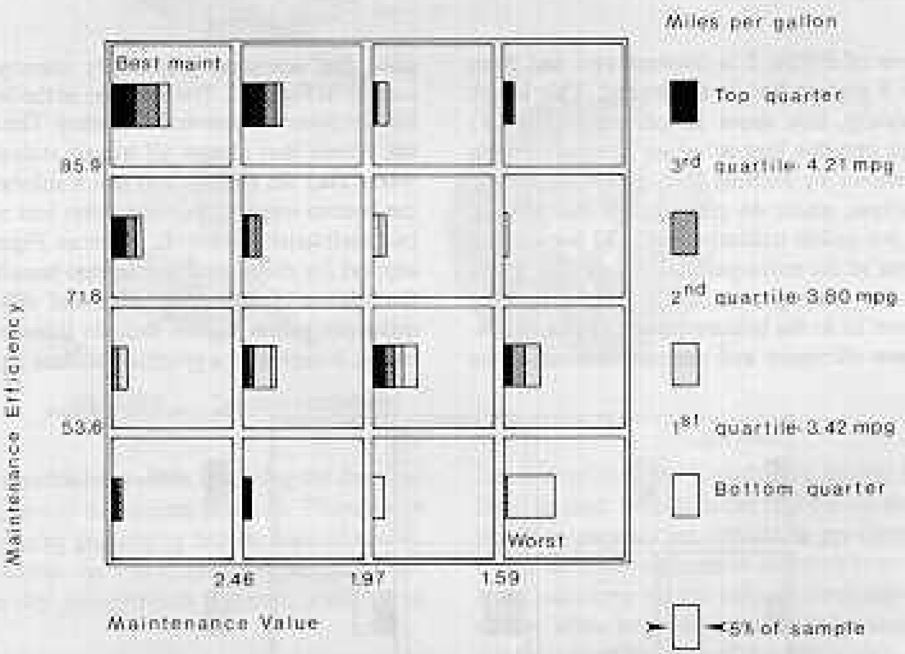

FIGURE 5 Miles-per-gallon indicator within maintenance subclasses measured across the flat-terrain peer group (sample size: 81 transit authorities).

same sort of chart when these data are also stratified according to terrain class.

When the data from Figure 2 were sorted using a fifth data dimension according to terrain peer group, Figures 3–5 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 3 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; in flatter surroundings other factors apparently overshadow the effects of terrain on the miles-per-gallon indicator (Figures 4 and 5).

The distinctions among maintenance subclasses within a figure fade increasingly from steep terrain (Figure 3) to flat terrain (Figure 5). 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 5 than there is in the corresponding position in Figure 4, suggesting better performance in flat terrain.

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 very from year to year.

At a deeper level, when the effect of terrain on fuel consumption is viewed as but one element derived from cross-sectional performance data, to measure some component of maintenance performance and bus durability, opportunities to use this methodology for classifying terrain in conjunction with other types of data emerge. Such a merger of methodologies permits a more comprehensive evaluation of the effects of this and other independent variables such as climate and congestion on bus maintenance and equipment life *(1)*.

CONCLUSION

The major contribution of this report 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 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. As this is a first effort in analyzing the relation between maintenance and terrain, a significant function of these data is to suggest a framework in which to test other transit concepts.

These broad terrain categories might be used in a regression analysis context 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 even out the numerical size of terrain peer groups would result in misclassification because there are fewer steep cities. At an integrative empirical level, this taxonomy might be used in conjunction with climate peer groups and congestion peer groups formed on the basis of route curviness, stop spacing, and population density to serve as one arm of a more comprehensive empirical study of *Environmental Effects on Bus Durability* (*1*; *8*; Arlinghaus and Nystuen, unpublished data). Another avenue for further research is suggested by the observation that this method of classifying terrain appears to lend itself to automated analysis using computer techniques. At the theoretical level, fractal geometry, which has been used to simulate terrain, might be used to identify self-similar terrain characteristics that prevail independently of the partition chosen for terrain classes *(9–13)*. At the pragmatic level, the usefulness of the peer groups produced using this methodology likely rests on their capability to augment the explanatory power of other indicators to improve our understanding of system level performance statistics.

ACKNOWLEDGMENTS

The authors wish to acknowledge support from an UMTA grant awarded to the University of Michigan Transportation Research Institute that enabled them to carry out this study. Specifically, they thank Aaron Adiv of UMTRI. James F. Foerster, Professor in the School of Urban Planning and Policy at the University of Illinois at Chicago and Chairman of the TRB Committee on Bus Maintenance, read several drafts of this report and commented on them constructively. The authors appreciate his specific comments on maintenance cost data and his suggestions for overcoming communications difficulties across interdisciplinary boundaries. Of course, errors in fact or interpretation that remain are the authors' alone.

REFERENCES

1. S. Arlinghaus and J. Nystuen. Climatic Effects on Bus Durability. In *Transportation Research Record 1066*. TRB, National Research Council, Washington, D.C., 1986, pp. 29–39.
2. S. Nordbeck. *The Law of Allometric Growth*. Discussion Paper 7. Michigan Inter-University Community of Mathematical Geographers (John D. Nystuen, ed.), Ann Arbor, Mich., 1965. (Reprinted by Institute of Mathematical Geography, 1986.)
3. W. Tobler. The Spectrum of U.S. 40, *Papers of the Regional Science Association*, Vol. XXIII, 1969, pp. 45–52.
4. E. H. Hammond. Analysis of Properties in Land Form Geography: An Application to Broad-Scale Land Form Mapping. *Annals, Association of American Geographers*, Vol. 54, No. 1, 1964, pp. 11–19.
5. *The World Almanac and Book of Facts, 1985*. Newspaper Enterprise Association, Inc., New York, 1985.
6. Topographic Maps. U.S. Geological Survey, 1:250,000.
7. *National Urban Mass Transportation Statistics*. UMTA, U.S. Department of Transportation, 1983.
8. S. Arlinghaus and J. Nystuen. *Terrain Effects on Bus Durability*. UMTA, U.S. Department of Transportation, 1987.
9. S. Arlinghaus. Fractals Take a Central Place. *Geografiska Annaler*, Vol. 67B, No. 2, 1985, pp. 83–88.
10. S. Arlinghaus and J. Nystuen. Fractal Constructions. Poster. Association of American Geographers, National Meetings, Minneapolis, May 1986.
11. M. F. Goodchild. The Fractional Brownian Process as a Terrain Simulation Model. *Modeling and Simulation*, Vol. 13, 1982, pp. 1133–1137.
12. M. F. Goodchild and D. M. Mark. The Fractal Nature of Geographic Phenomena. *Annals, Association of American Geographers*, Vol. 77, No. 2, June 1987, pp. 265–278.
13. H.-O. Peitgen and P. H. Richter. *The Beauty of Fractals*. Springer-Verlag, Berlin, 1985.