THE MODIFIABLE AREAL UNIT PROBLEM (MAUP)

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Even though Gehlke and Biehl (1934) discovered certain aspects of the modifiable areal unit problem (MAUP), the term MAUP was not coined formally until Openshaw and Taylor (1979) evaluated systematically the variability of correlation values when different boundaries systems were used in the analysis. The problem is called "the modifiable areal unit" because the boundaries of many geographical units are often demarcated artificially, and thus can be changed. For example, administrative boundaries, political districts, and census enumeration units are all subject to be redrawn. When data are gathered according to different boundary definitions, different data sets are generated. Analyzing these data sets will likely provide inconsistent results. This is the essence of the MAUP.

"Modifiable areal units" can emerge from two spatial mechanisms in redefining boundaries. When the number of areal units is kept somewhat constant in a given region, new boundaries can be drawn to create new zoning systems or configurations. Data tabulated according to these different zoning systems will yield inconsistent analytical results. This is known as the "zoning effect," the first sub-problem of the MAUP. Another mechanism to create modifiable areal units is through spatial (dis)aggregation or by changing the spatial resolution of the data. Smaller areal units can be merged or aggregated into larger units, but fewer in number to cover the study area. Then, the spatial resolution of the data is lowered. Or, areal units can be subdivided into smaller areal units, provided that data pertaining to the larger areal units can be reasonably disaggregated. These two processes, which operate from opposite directions, create nested or hierarchical zonal systems. The problem of obtaining inconsistent analytical results from using data gathered at different spatial resolutions is known as the "scale effect," the second sub-problem of the MAUP.

In Figure 93.1, Washington, D.C. was divided into 188 census tracts for the 2000 Census. Each census tract was further subdivided into smaller block groups for census data tabulation and mapping. The District has 433 block groups in the 2000 Census. Because block groups are nested under the tract level, different results from these two levels reflect the scale effect. Aside from using census tracts, one may use postal zip code units to partition Washington,

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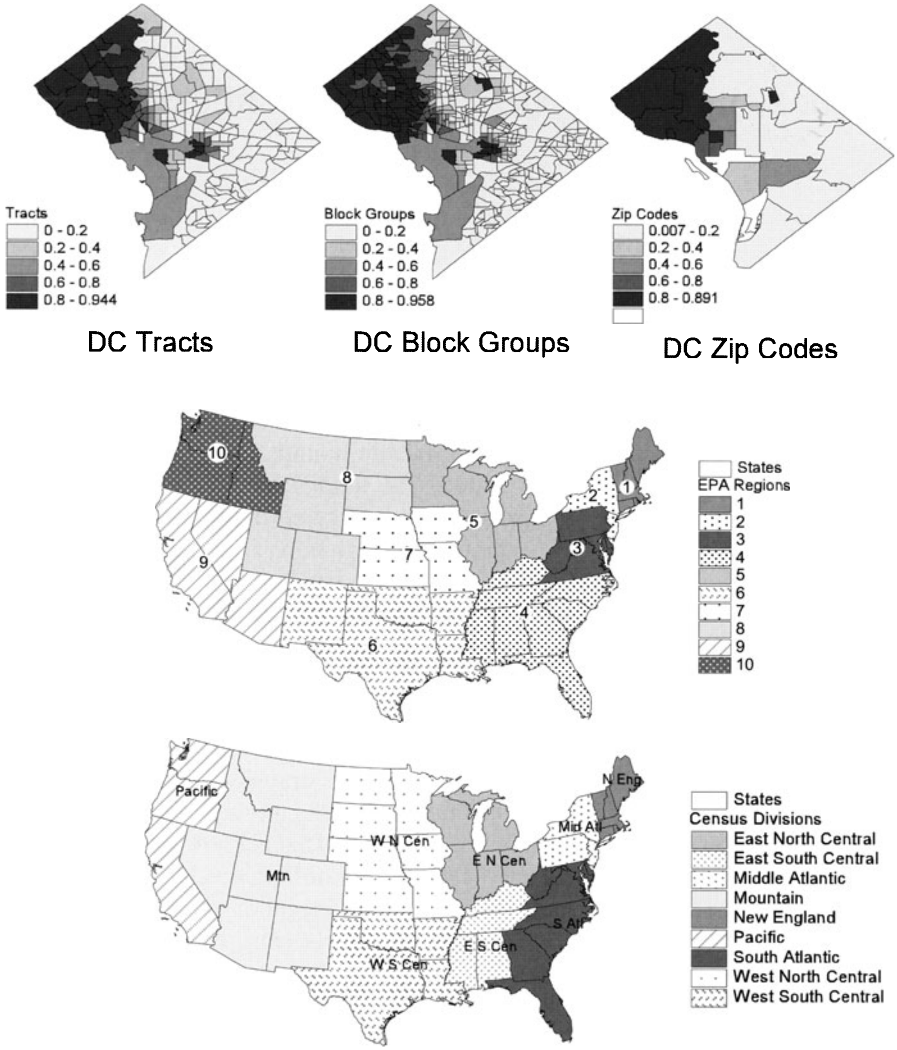

Figure 93.1. Examples of the scale effect and zoning effect of the MAUP: Washington, D.C., and the United States.

D.C. Figure 93.1 shows 27 zip code areas. Even though the number of zip code units and the number of census tracts are not identical, the two zoning systems yield different results that still can be regarded as the zoning effect. Figure 93.1 also shows two zonal systems for partitioning the United States. The Bureau of the Census divides the country into nine census divisions, while the U.S. Environmental Protection Agency uses ten administrative regions. Data gathered or tabulated according to these two zonal systems will provide different results, another example of the zoning effect.

Table 93.1. Selected Statistics for Washington, D.C.

	Proportion Non-white	Proportion Elderly (≥ 65)
Entire D.C.	0.6922	0.1222
Tract	0.7241	0.1200
Block Group	0.7181	0.1309
Zip Code	0.5613	0.1151

Notice how the proportions behave differently for the two different variables.

Table 93.1 reports on two sets of averages derived from several census variables of Washington, D.C. Proportions of non-white and proportions of elderly were computed for all census units at the census-tract and block-group levels, and averages were taken at the two levels. Results from the two census levels are not identical, even though they are not dramatically different. The same set of statistics was also derived for zip code areas, and these statistics are different from the results derived at the two census levels. The averages based on Washington, D.C. as a whole are also reported as references. The proportions of white, which are the reciprocal of the proportions of non-white, are also mapped at the two census levels in Figure 93.1 to illustrate the MAUP.

WHY DOES THE MAUP ARISE?

In the spatial aggregation process, smaller areal units within a neighborhood are merged to form larger units. If all merged units have identical values, then the aggregated unit and the disaggregated units will have the same value, and, thus, there is no MAUP effect based on scale differences. Values at the aggregated level can preserve values at the disaggregated level. Although the "First Law" of Geography tells us that closer things are more similar, we can hardly find uniform geographical surfaces in the real world. Then, when slightly different neighboring units are aggregated to form larger units, the original values are averaged or smoothed at the aggregated level. For instance, standard deviations indicate the level of variation for the proportions of non-white in Washington, D.C. at the census-tract and block-group levels of 0.3270 and 0.3436, respectively. Thus the census tract data were smoothed and lost variation captured by the block-group data.

Although changing levels of variation pertain to the scale effect, the general concept of averaging or smoothing neighboring values also helps to explain the zoning effect. Nevertheless, we cannot predict the direction of changes in the variables between different spatial partitioning schemes.

WHAT ARE THE SIGNIFICANCES OF THE PROBLEM?

The impacts of the MAUP effect are pervasive among various analytical techniques, including simple descriptive statistics (those used in the previous section), standard statistical procedures (such as various types of regression analysis), and spatial models (such as gravity-type spatial interaction models). Numerous studies have documented the impacts of the MAUP on other statistical and spatial techniques (multiple and logistic regressions, location-allocation models, and input-output models; for a review, see Fotheringham and Wong 1991). In addition, the MAUP is a concern in processing and analyzing remotely sensed data (Quattrochi and Goodchild 1997) and in handling spatial data in GIS (Tate and Aktinson 2001). In general, the MAUP is of significance in three major areas.

First, when smaller areal units are merged to form larger units, variable values are averaged. The correlations among variables for the aggregated units will likely be higher than that for the disaggregated level (Fotheringham and Wong 1991). For instance, the correlation coefficient, which has a theoretical range of –1 and +1, is 0.3247 at the census-tract level and 0.2800 at the block-group level when the number of white population counts and counts of elderly for Washington, D.C. were evaluated. But the most significant implication of the inconsistent correlation coefficient across scales is that correlations among variables are the bases of almost all statistical analyses involving more than one variable. Therefore, inconsistent correlations across scales imply that statistical results will also vary across scales.

Second, for any given study area, data with multiple resolutions or gathered according to different partitioning systems are likely available. Because of the presence of the MAUP, using different data sets for the same analysis will offer different results. Then, how should one decide which dataset to use? A related issue is to what extent the results are dependent upon the chosen dataset.

Third, at the conceptual level, most spatial data are aggregates of individuals, which can be persons or locations. Quite often, the goal of analysis is to identify patterns or systematic processes pertaining to individuals based on information derived from aggregated or ecological data. However, due to the MAUP, aggregated data for different scales or zonal systems cannot provide a consistent picture on the individual situation. It is also argued that it can be erroneous to infer individual situations based upon aggregated or ecological data. This is known as the ecological fallacy, and the MAUP is one of the sources of this fallacy.

HOW TO HANDLE THE PROBLEM?

Some scholars argue that using data representing different spatial scales should yield different results because they reflect the different processes operating at different geographical levels. In other words, they do not recognize the MAUP as a geographical problem. On the other hand, some scholars are working diligently to identify solutions to the MAUP (e.g., King 1997). But, currently, no general solutions exist. Some scholars suggest that the zoning problem is simpler because it can be treated as a data interpolation or transformation problem (Fisher and Langford 1995). For scale effect, one approach is to develop relatively scale-insensitive analytical techniques. This approach has had limited success so far and the solutions are subject-dependent (e.g., Tobler 1989; Wong 2001).

Another approach to the MAUP is to acknowledge that there can be multiple results when different data sets of the same study area are used (Fotheringham 1989). This approach recognizes that a result based on one data set is only one of many possible results, and thus the range of possible results should be reported whenever possible. To implement this approach, multiple data sets are used and the same analysis is performed on each data set such that a range of outcomes can be reported. This approach is especially feasible when data for multiple scales and for different zoning systems are stored in a geographic information system (GIS), and the same analysis can be repeated for all data sets.

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