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On the Cover
Through its widespread usage, GIS has proven that it can make our lives more efficient. The technology also has the ability to improve the quality of our lives as well. By addressing public health concerns and through numerous environmental applications, GIS has proven to be a vital but soft-spoken tool in keeping our communities safe. The geographic representation of soil sampling is helping federal, state, and municipal employees attach a pathology to a number of harmful pollutants. Early detection and containment are simplified by new technology so that these harmful toxins are eliminated before any serious health problems arise. The distribution of soil lead concentrations is the subject of an article by Daniel A. Griffith, a Professor of Geography at Syracuse University. His methods for using statistics and spatial representation to better understand polluted landscapes highlight this issue of the URISA Journal.
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The Geographic Distribution of Soil Lead Concentration: Description and Concerns

Daniel A. Griffith

Abstract: Pollution of inhabited geographic landscapes is often a public health concern. Ascertaining the degree and scope of such pollution is a difficult task and frequently involves analysis of soil samples. This article describes ways to statistically analyze the geographic distribution of soil samples to better understand polluted landscapes, in part to determine whether more samples are needed; special reference is made to lead. The soundness of this description rests on the identically distributed assumption of statistical analysis as well as attributes of soil samples supporting evaluations of constant variance; methods are outlined for assessing both. Empirical findings are summarized regarding the distribution of soil lead concentration in the environment extracted from three types of geographic landscapes: an urban area, superfund sites, and a flood plain. These regions are described in terms of the statistical frequency distribution of soil lead concentration and the nature and degree of spatial autocorrelation latent in the geographic distribution of soil lead concentration. The importance of knowing such results is demonstrated by examining three concerns: 1) why a spatial analysis of soil samples is worth undertaking; 2) the cost-effectiveness of spatial sampling; and 3) the ability to predict soil lead contamination at unsampled locations based on data from sampled locations.

Introduction

Lead (Pb; a heavy, soft, malleable, bluish-gray metal) is a ubiquitous element that is found in rocks, soil, plants, animals, and human beings; it naturally occurs in quite low levels. It is also one of the toxic heavy metals that have been geographically concentrated or whose elevated levels have been made ubiquitous in the inhabited environment because of human activities. Three principal sources of this pollution are the widespread use of lead-based paints, lead emissions in gasoline in earlier years, and lead waste from mining/commercial/manufacturing processes. Community health issues associated with this pollution, including childhood lead poisoning, are subjects of research across the nation (e.g., Spake and Couzin 1999). This research increasingly involves geographic information systems, with recent spatial analyses of pediatric lead poisoning appearing for Syracuse, New York (Griffith et al. 1998a) and Jefferson County, Kentucky (Reissman et al. 2001), and for the states of New York (Raucci 1999) and Indiana (McGarigle 2000).

Current policies aimed at reducing lead exposure are based on the assumption that the greatest lead hazard comes from lead-based paints. Mielke (1999) argues that dust is another form of lead pollution that poses a threat to the health of children. Soil, which contains tiny particles of lead, functions as a giant reservoir of lead dust in the inhabited environment. Accordingly, children face their greatest risk for exposure in yards around their houses and, to a lesser extent, in open public spaces in which they play. Mielke further contends that only an accurate and complete appreciation of the distribution of lead in the environment can help shape policies that more effectively protect the health of children. To this end, this article addresses the following general question:

How can the statistical and geographic distributions of soil lead concentration in the inhabited environment be described?

More specifically, what information do spatial statistics give us regarding georeferenced soil lead concentration measurements, and what are the implications gleaned from empirical analysis of selected landscapes for understanding soil lead concentrations in other landscapes? Answers to these questions are based on summarized findings regarding the distribution of soil lead concentration in various types of geographic landscapes: an urban area (Syracuse, NY), two superfund sites, and a flood plain. A spatial analysis methodology is described and employed to analyze four specific sites, with the goal being to establish expectations about non-geographic and geographic variability when similar environmental conditions prevail at other locations.

Data Analysis Requirements

The desired data descriptions require assessment of soil lead concentrations in terms of their landscape-wide means, their variances, their frequency distributions, and latent levels of spatial autocorrelation in their geographic distributions. To complete these assessments, proper data collection dictates that a number of protocol features are satisfied. To assess soil lead contamination across a given landscape, georeferenced soil samples are needed. To assess the identically distributed assumption of statistical analysis, attributes of soil samples supporting evaluations of constant variance are needed. Additionally, to assess the appropriateness of sample size, it is necessary to establish adequate geo-
graphic coverage of a sampling network. Failure to fulfill these requirements severely compromises data descriptions.

The statistical analytic techniques employed here are based on the normal curve theory. A bell-shaped curve is symmetric and has the data concentrated near the mean, resulting in few unusually high or low values. It is the foundation upon which much constant variance testing, model parameter estimation, and spatial autocorrelation inferences are built. Development of the geographic sample-size concept and the map hole plugger discussed in this article is based on this. In other words, the statistical frequency distribution dictates the degree to which numerical results reported in this article are meaningful.

The methodology outlined here emphasizes each of the aforementioned data collection protocol features. Four landscapes were selected because their soil samples are georeferenced; a fifth site was a superfund site; it was dismissed because most of its soil samples lack locational tags. One assessment of constant geographic variance can be achieved by comparing variation in different regions of a landscape. A convenient regionalization scheme is to partition a landscape into the four quadrants of the plane; another is to make comparisons through the use of attribute features of sample locations. Finally, adequate geographic coverage can be established in two ways: deviation of a given sampling network from a hexagonal grid can be quantified (see Stehman and Overton 1996), and an effective sample size can be computed based on the nature and degree of latent spatial autocorrelation (Griffith and Zhang 1999).

The interested reader may wish to consult Cressie (1991) and Griffith and Layne (1999) for more comprehensive discussions of the geostatistical and spatial autoregressive tools employed for the analysis summarized in this article. More conventional tools for evaluating statistical model assumptions can be reviewed in sections of the Encyclopedia of Statistical Science. Additionally, Sen and Srivastava (1990) furnish a readable treatment of Box-Cox power transformations.

**Background: Samples From Selected Geographic Landscapes**

Four geographic landscapes are explored in this study for illustrative purposes. Evidence is sought from them to address the question of what expectations can be obtained from these landscapes regarding the variability of soil lead contamination in other places.

**Site 1**

Griffith et al. (1998a) analyzed the spatial distribution of pediatric blood-lead levels in Syracuse, NY. That article presented the first choropleth-map generalization of the geographic distribution of lead concentration in surficial soil across the city, much of which was deposited by gasoline emissions. However, the map is incomplete, being constructed using 112 samples covering 50 of the city’s 61 census tracts; 139 samples were collected, but only 112 have locations within the city. Geometric means of samples were calculated for each census tract. Johnson together with Bretsch (1998) subsequently expanded the soil sampling project, augmenting the number of samples by 167 and nearly completing coverage of the city. The measures used here were obtained with a 2-mm sieve for soils 0 to 10 cm in depth, with 162 falling into the city itself, which covers an area of roughly 25 square miles.

**Site 2**

A total of 100 soil samples were collected from a roughly 1-square mile portion of the flood plain of the Geul River valley, located in the south of The Netherlands. This region is perilously polluted by heavy metals in stream sediments resulting from historic metal mining and deposited by flooding (Heuvelink 1999). Assay results for the soil samples collected from this region constitute part of the data for a pediatric lead ingestion study. These soil sample locations were determined by the play habits of children residing in campground sites for at least 3 days. Composite soil samples from the upper 5 cm of approximately 100 g were taken in duplicate, air-dried, processed through a 2-mm sieve, and powdered (van Wijnen et al. 1990, Leenaers 1991).

**Site 3**

In all, 277 surface (0-2”) soil samples were collected in and around an abandoned lead smelting facility superfund site located in Murray, Utah. This area was polluted by airborne emissions and placement of waste slag from the smelting process. Three of these samples failed to have a geocode recorded, 173 samples were collected from the superfund site itself, and 101 samples were collected from the adjacent community. The composite study area covers roughly 0.5 square mile area. Thirty-eight soil samples can be grouped into 17 clusters on the basis of their common georeference coordinates; in these samples, the juxtaposed assay results were pooled for composite measures. The result is 253 locations for which lead concentrations were measured. A single spot within the site was intensively sampled.

**Site 4**

A total of 236 surface soil samples were collected for a skeet-and-trap shooting range superfund site housed on a roughly 0.1 square mile area. The shooting positions were located along the southern boundary of the site. The measurements of lead concentration were taken in the top 6 inches of soil. A single spot within the site was intensively sampled. The sampling network used throughout most of the site reflects a square grid pattern.

**Step 1: The Statistical Frequency Distribution Description of Soil Lead Concentration**

Many environmental measures conform to a log-normal distribution (Gilbert 1987, Millard and Neerchal 2001) or empirically a frequency distribution where changing each data value to its natural logarithmic counterpart yields a set of values that conforms to a normal distribution. This frequency distribution tends
to describe pollution measures well because they are bounded below at zero and are often strongly positively skewed. Because a heavy metal such as lead occurs naturally in all soils, its lower bound may differ from zero, requiring a threshold parameter to be included in the log-normal distribution specification. Pollution is deposited in a geographic landscape by point source human activities, such as leaded gasoline emissions dispersing from cars moving along roads. Relatively small amounts are deposited in most locations, while increasingly larger amounts are deposited in fewer and fewer locations. One of the critical properties of lead is that it does not typically migrate from where it is deposited and it does not decay or biodegrade into something else; rather, it adheres to fine clay and organic matter particles, accumulating in the upper few inches of undisturbed soil. If the process depositing lead pollution is repetitive, then, with some stochastic fluctuation, each layer of pollution has the same geographic distribution resulting in new deposit amounts being proportional to existing deposit amounts at each location. Thus, the cumulative effect of many layers of small deposits is multiplicative, resulting in the log-normal distribution. This type of depositing process is the expected outcome of gasoline exhaust emissions, periodic river flooding, smelter air pollution, or even skeet shooting waste. Even if pollution were repeatedly deposited at random, following a uniform distribution, the results would be approximately log-normally distributed. The first scenario is consistent with the presence of positive spatial autocorrelation; the second scenario is consistent with the absence of spatial autocorrelation. In either case, the repetitiveness of the depositing mechanism would result in some type of patterned variance.

The functional form of the logarithmic transformation utilized here includes a translation parameter, $\delta$, rendering $\text{LN}(\text{pb} + \delta)$, where the translation term may be a function of the minimum lead concentration measure (see Griffith et al. 1998b). This translation term is a mean response for a non-linear model specification. Of note is that soil sample locations are rarely randomly selected. Regardless of whether or not they are, formal tests for normality and homogeneity of variance are based on random sampling from the lead concentration distribution rather than the set of soil sample locations. Accordingly, these attribute values are what statistical tests of the hypotheses for normality and constant variance relate to; statistical significance is established using a model-based inference framework.

For the Syracuse geographic landscape, the minimum soil lead concentration measure of 0.4 parts per million (ppm) is aberrantly low, $\delta = 3$, and the log-transformed version of the 167 measures conforms much more closely to a normal distribution (see Table 1 and Figure 1). Pooling the second sample with the first sample decreases $\delta$ to 2. Increasing the complexity of the transformation to account for this single deviant fails to dramatically improve conformity with normality. Meanwhile, two assessments of constant variance are possible with these data. Bretsch (1998) recorded the location type for soil samples using the following categories: streetside soil ($n = 74$), park soil ($n = 30$), playground soil ($n = 17$), house lot soil ($n = 30$), and vacant lot soil ($n = 17$). In addition, the geographic landscape can be arbitrarily divided into four regions by centering the soil sample geocodes; the geocodes are then grouped together according to their locations in each of the four standard quadrants of a plane. This procedure results in groups of 35, 45, and 43 soil sample locations. The Bartlett and the Levene statistics used to evaluate constant variance based on these two different schemes appear in Table 2. The Bartlett statistic requires a normal frequency distribution; the Levene statistic is relatively insensitive to departures from a normal distribution, and furnishes a reliability gauge for the corresponding Bartlett statistic.

### Table 1

<table>
<thead>
<tr>
<th>Location Type</th>
<th>pb</th>
<th>$\text{LN(pb)}$</th>
<th>$\text{LN(pb} + \delta)$</th>
<th>Residuals</th>
</tr>
</thead>
<tbody>
<tr>
<td>City of Syracuse</td>
<td>0.621</td>
<td>0.947 (&lt;0.0001)</td>
<td>0.969 (0.0008)</td>
<td>0.982 (0.0350)</td>
</tr>
<tr>
<td>Geul River flood plain</td>
<td>0.917</td>
<td>0.957 (0.0027)</td>
<td>0.959 (0.0033)</td>
<td>0.980 (0.1233)</td>
</tr>
<tr>
<td>Smelter superfund site</td>
<td>0.523</td>
<td>0.976 (0.0003)</td>
<td>0.990 (0.0819)</td>
<td>0.990 (0.0819)</td>
</tr>
<tr>
<td>Smelter superfund site: nonresidential</td>
<td>0.602</td>
<td>0.975 (0.0032)</td>
<td>0.987 (0.1047)</td>
<td>****</td>
</tr>
<tr>
<td>Skeet/trap shooting range superfund site</td>
<td>0.228</td>
<td>0.917 (&lt;0.0001)</td>
<td>0.968 (&lt;0.0001)</td>
<td>0.995 (0.5858)</td>
</tr>
</tbody>
</table>

### Table 2

Null hypothesis probabilities of homogeneity of variance assessments for log-transformed soil lead concentration measures from selected geographic landscapes. For each statistic, the null hypothesis value is 0

<table>
<thead>
<tr>
<th>Location Type</th>
<th>Bartlett’s Statistic</th>
<th>Levene’s Statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>City of Syracuse: location types</td>
<td>0.032</td>
<td>0.018</td>
</tr>
<tr>
<td>City of Syracuse: quadrants of the plane</td>
<td>0.194</td>
<td>0.345</td>
</tr>
<tr>
<td>Geul River: sides of river</td>
<td>0.644</td>
<td>0.823</td>
</tr>
<tr>
<td>Geul River: quadrants of the plane</td>
<td>0.066</td>
<td>0.123</td>
</tr>
<tr>
<td>Smelter superfund site: residential/nonresidential</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Smelter superfund site: quadrants of the plane</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Skeet/trap range superfund site: distance from gallery</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Skeet/trap range superfund site: quadrants of the plane</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>
While variability of log-lead concentration within these five groups has overlapping 95% confidence intervals, the confidence interval for vacant lots is substantially wider; the result is both a Bartlett and a Levene test statistic for homogeneity of variance that is significant. More generally, while variability is very similar for log-lead concentration in park, playground, and house lot soil, it is modestly less in streetside soil and markedly greater in vacant lot soil. Hence, the vacant lot soil samples are the primary source for a potentially statistically significant difference in log-lead concentration variances across the five categories. In contrast, variability of log-lead concentration within the four quadrants of the plane fails to exhibit a significant difference, with the four 95% confidence intervals having considerable overlap.

For the Geul River flood plain geographic landscape, $\delta = 19$, the log-transformed version of the 100 measures conforms much more closely to a normal distribution (see Table 1), with a plot very similar to that appearing in Figure 1. Again, two assessments of constant variance are possible with the data. On the one hand, no apparent difference exists between the means or variances of the log-lead concentration measures obtained for the east ($n = 46$) and the west ($n = 54$) banks of this river. On the other hand, after employing a 45° rotation of the geocoding axes in order to obtain a more uniform distribution of soil sample locations by quadrant of the plane—resulting in group sizes of 24, 23, 27, and 26—a modest difference in variances is detectable. As before, the Bartlett and the Levene statistics used to evaluate constant variance based on these two different schemes appear in Table 2. Meanwhile, the 95% confidence intervals for variability of log-lead concentration within the four quadrants of the plane overlap. Both the accompanying Bartlett and Levene test statistics suggest that the variability in log-lead concentration is roughly homogeneous across this region. A Bonferroni adjustment for simultaneous testing reinforces this conclusion.

For the smelter superfund site geographic landscape, both the minimum (i.e., 37 ppm) and the maximum (i.e., 33,000 ppm) soil lead concentration measures are aberrant ones, $\delta = -32$, and the log-transformed version of the 277 measures conforms much more closely to a normal distribution (see Table 1), again with a plot very similar to that appearing in Figure 1. As before, increasing the complexity of the transformation to account for these two extreme deviants fails to dramatically improve conformity with normality. However, restricting attention to the superfund site itself does yield a somewhat closer correspondence with a bell-shaped curve, in part because the minimum outlier value of 37 ppm is located in the residential portion of this landscape.

Inspection of Table 2 confirms a substantial variance difference between residential and non-residential regions. As one might expect, the superfund site exhibits a markedly greater level of variability. Variability again can be analyzed in terms of the four quadrants of the plane, which respectively contain 70, 65, 76, and 63 soil sample locations. Considering these groups in counterclockwise order, log-lead concentration in the fourth quadrant displays substantially less variability than do the measures in the remaining three quadrants. This finding is attributable to this set of locations mostly being in the residential area of the region. The second quadrant is a mixture of superfund site and residential sample locations, which suppresses the variability displayed by the log-lead concentration measures obtained for it. Restricting attention to the superfund site itself does not render a more favorable assessment. The group sizes are currently 41, 19, 50, and 63. While all four of the 95% confidence intervals overlap, the log-lead concentration variability displayed by the second quadrant continues to deviate markedly from that displayed in the remaining three quadrants.

The skeet-and-trap shooting range superfund site also renders a frequency distribution of lead concentration that is approximately log-normally distributed, with $\delta = 12$. The log-transformed version of the 236 measures conforms much more closely to a bell-shaped curve (see Table 1); however, even though substantial improvement is attained, the transformed values continue to deviate from normality. Comparing the log-lead concentration variability across the superfund site once more reveals nonconstant variance (see Table 2). Analysis based on the four quadrants of the plane involves subregions containing 49, 60, 68, and 49 soil sample locations. The average log-lead concentration is roughly the same in the upper left- and lower right-hand quadrants, and is markedly greater than that for the upper right- and lower left-hand quadrants, whose average log-lead levels are approximately the same. The variance for these log-lead concentration measures is approximately the same in the top two quadrants, is marginally greater than that displayed in the lower right-hand quadrant, and is noticeably greater than that displayed in the lower left-hand quadrant. Inspection of variability from the southern border of the site, where the shooting gallery was located, also suggests the presence of nonconstant variance.

In conclusion, an analyst should expect that the statistical distribution of soil lead concentration measures for geographic landscapes might be best described with a log-normal distribution coupled with a landscape-specific translation parameter. The analyst should also expect that these measures will display heterogeneous variability across heavily polluted (e.g., superfund) sites and more or less display homogeneous variability across other
types of geographic landscapes, whether this variability is based on geographic subregions or attribute-based location categories. Of note is that, while the log-transformation fails to completely equalize variance in the two superfund site cases, diagnostics suggest that it is the most suitable transformation to use. Exploratory work to date with these transformed data has failed to reveal a good weighting scheme to employ in order to compensate for any persisting nonconstant variance. Additionally, both the Bartlett and the Levene test statistics warrant inspection here, since the Bartlett test statistic is both more sensitive to deviations from constant variance and far less robust against deviations from normality than the Levene test statistic.

Step 2: Spatial Autocorrelation and The Geographic Distribution of Soil Lead Contamination

Two geographic distribution features of soil samples merit investigation. Spatial autocorrelation allows predictions of soil lead concentrations at unsampled locations. It also enables an effective sample size (the number of equivalent independent values) to be computed for data whose frequency distribution emulates a bell-shape curve. This second feature can be better understood through the calculation of an additional statistic pertaining to the spacing of soil samples. The average first nearest-neighbor distance supplies such a statistic. If the soil sample locations are randomly positioned, this statistic takes on a value of 1; if the locations are uniformly positioned, this statistic takes on a value of approximately 2.15.

A map for the Syracuse geographic landscape appears in Figure 2. The top map shows the census tracts for the city, together with their centroids and the most recent 167 soil sample locations. The bottom map shows a Thiessen polygon surface partitioning constructed with the soil sample locations, upon which the census tract centroids have been superimposed. The Moran Coefficient—a spatial autocorrelation index that is similar to a product moment correlation coefficient—based on this tessellation is 0.16663, which is both significant and indicates that a weak tendency exists for similar values of log-lead concentration measures to be in nearby sample locations. A pure simultaneous spatial autoregressive (SAR) model—$Y = \rho W Y + \epsilon$, for georeferenced variable $Y$, spatial weights matrix $W$, and random error $\epsilon$—quantifies the nature and degree of spatial autocorrelation as $\rho = 0.35196$ (on a scale of 0 to 1), which also indicates the presence of a weak tendency for similar values to cluster in the city. The most appealing semivariogram description is furnished by a Bessel function [see Figure 6; this function can be estimated following Griffith and Layne (1999) or with ESRI's Geostatistical Analyst]; parameter estimates include 0.274 for the nugget, 2.490 for the slope parameter, and 0.146 for the range parameter (based on standardized distance), with the relative error sum of squares being 0.228. Hence, the geographic distribution of soil lead concentration across Syracuse may be described in a manner that supports spatial interpolation of the surface.

The effective sample size is 43.1% of $n$; approximately 12% of the variance in log-lead concentration is accounted for by nearby values of log-lead. The distribution of the 162 soil sample points within the city is essentially random, raising the possibility of poor geographic coverage by the sampling network. In fact,
four census tracts (CTs) (i.e., CTs 15, 28, 38, and 42) are without soil samples. The semivariogram model renders the following respective $LN(Pb + 3)$ predicted values for the centroids of these four census tracts, when kriging weights are restricted to being positive: 4.99744, 4.02726, 4.04000, and 4.81637. These results suggest that only a modest amount of new information will be gained from additional soil samples and that any supplemental sample locations need to be judiciously selected.

A map for the Geul River flood plain appears in Figure 3. The left-hand map shows the river, flood plain, and 100 soil sample locations. The right-hand map shows a Thiessen polygon surface partitioning constructed with the soil sample locations. The Moran Coefficient based on this tessellation is 0.42492, which is significant and also indicates that a moderate tendency exists for similar values of log-lead concentration measures to be in nearby sample locations. A pure SAR model quantifies the nature and degree of spatial autocorrelation in this case to be $\hat{\rho} = 0.79251$, which confirms the presence of a moderate tendency for similar values to cluster in this flood plain. Again, the most appealing semivariogram description was obtained with a Bessel function (see Figure 6); parameter estimates include 0.061 for the nugget, 0.550 for the slope parameter, and 0.358 for the effective range (based on standardized distance), with the relative error sum of squares being 0.250. Hence, as was found for the Syracuse case, the geographic distribution of soil lead concentration across the Geul River flood plain may be described in a manner that supports spatial interpolation of the surface.

The effective sample size is a mere 12% of n; approximately 55% of the variance in log-lead concentration is accounted for by nearby values of log-lead. The distribution of the 100 soil sample points within the flood plain is random, with a noticeable tendency toward clustering, raising the possibility of poor geographic coverage by the sampling network. This finding is partly an artifact of the use of transects for sampling. These results suggest that considerable redundant information is contained in the soil samples already collected. Additional information can be gained from supplementary soil samples if they are collected in a non-transect fashion from those sections of the flood plain in which few samples already have been collected. Conspicuous undersampled subregions include the southwest and the northern parts of the landscape.

Finally, 253 soil samples were collected for the smelter superfund site and 236 were collected for the skeet-and-trap shooting range superfund site. A map depicting this first case appears in Figure 4. The left-hand side of the figure presents a map showing the distribution of soil samples with both the site itself and the nearby residential community. The right-hand side of the figure presents a Thiessen polygon surface partitioning for the soil samples. The Moran Coefficient based on this tessellation is 0.26588, which is both significant and indicates that a weak-to-moderate tendency exists for similar values of log-lead concentration measures to be in nearby sample locations. A pure SAR model quantifies the nature and degree of spatial autocorrelation as $\hat{\rho} = 0.53603$, which also indicates the presence of a weak-to-moderate tendency for similar values to cluster in this superfund site. Again, the most appealing semivariogram description was obtained with a Bessel function (see Figure 6); parameter estimates include 0.071 for the nugget, 2.660 for the slope parameter, and 0.132 for the range parameter (based on standardized distance), with the relative error sum of squares being 0.234. Of note is that, while the mean log-lead concentration levels for the superfund and residential areas appear to be statistically significantly different (see Table 2), adjusting for the difference of means yields a Moran Coefficient of 0.23963, which deviates little from that for the unadjusted data. Hence, as for the two preceding cases, the geographic distribution of soil lead concentration across the superfund site may be described in a manner that supports spatial interpolation of the surface.

A map portraying a Thiessen polygon surface partitioning for the skeet-and-trap shooting range superfund site appears in Figure 5. In this case the log-transformed measures yield a Moran...
Coefficient value of 0.48873, which is both significant and indicates that a moderate tendency exists for similar values of log-lead concentration measures to be in nearby sample locations. A pure SAR model quantifies the nature and degree of spatial autocorrelation as $\rho = 0.76404$, which also indicates the presence of a moderate, pronounced tendency for similar values to cluster across this superfund site. As with the preceding three empirical examples, the most appealing semivariogram description was obtained with a Bessel function (see Figure 6); parameter estimates include 0.894 for the nugget, 3.510 for the slope parameter, and 0.138 for the range parameter (based on standardized distance), with the relative error sum of squares being 0.071. Once more, the geographic distribution of soil lead concentration may be described in a manner that supports spatial interpolation of the surface.

The effective sample sizes for these two superfund sites, respectively, are 27.0% and 10.7% of their corresponding n values; their respective percentages of the variance in log-lead concentration (accounted for by nearby values of log-lead) are approximately 24 and 53. The distribution of soil sample points across each of the two superfund sites is quite different: the smelter site has a strong tendency for its sample locations to cluster, whereas the skeet-and-trap shooting range site has a strong tendency for its sample locations to be uniformly spaced. These results are due in part to: 1) a very intensively sampled section of the smelter superfund site coupled with several sparsely sampled subregions, and 2) the visibly noticeable square grid network component used in the skeet-and-trap shooting range superfund site (see Figure 5). Interestingly, considerable redundant information is contained in the soil samples already collected for the shooting range superfund site, even though its soil sample locations are more uniformly spaced, and less redundant information is contained in the samples already collected for the smelter superfund site. This outcome is partly due to the sampling intensity per unit area in the shooting range site being nearly six times that in the smelter site. Thus, little additional information can be gained from supplementary soil samples for the first site, while judiciously selected supplemental soil sample locations could yield considerable new information for the second site.

Therefore, the geographic distribution of soil lead concentration measures for these geographic landscapes may be described as containing weak-to-moderate positive spatial autocorrelation and a spatial dependency structure that may be described with a Bessel function semivariogram model. For comparative purposes, the log-transformed lead concentration measures were converted to z-scores for each of the four landscapes, with the resulting semivariogram plots appearing in Figure 6. A comparison of these plots reveals that: 1) the City of Syracuse and the Geul River flood plain display considerably more variability with increasing distance than do the superfund sites, 2) the ascending rank-order levels of autocorrelation should be for the smelter superfund site, followed by the City of Syracuse, and then roughly a tie for the top rank by the Geul River flood plain and the skeet-and-trap shooting range superfund site. The effective standardized distance ranges for these cases fall into the interval (0.08, 0.23).

Non-zero semivariogram nuggets may be attributed to measurement error, specification error, or some other unaccounted-for source of error. The nugget values reported here may relate to a geographic scale effect and/or its interaction with sampling intensity (a form of resolution), since the landscapes range in size from 0.1 to 25 square miles while their intensities range in magnitude from 7 to 2360 samples per square mile. Unfortunately,
with only four landscapes, it is not possible to determine whether or not this is the case; figures for the City of Syracuse are inconsistent with a possible trend portrayed by the remaining three landscapes.

**Exploring Concerns**

Three concerns merit attention here, all of which pertain to what has been learned from the data analyses presented in this article that is transferable to other places. The first concern focuses on why a spatial analysis of soil samples is worth undertaking. The second concern relates to cost-effectiveness of spatial sampling. The third concern centers on the ability to predict soil lead contamination at unsampled locations based on data from sampled locations.

**Pediatric Lead Poisoning: A Public Health Concern**

Mielke (1999) argues that an accurate and complete appreciation of the distribution of lead in the environment is needed. Findings reported in this article seek to establish a description of this distribution, in terms of both statistical frequency and geographic variability. The utility of this type of description may be demonstrated by employing it in observational public health studies, such as those addressing pediatric lead poisoning. For example, the combined two sets of Syracuse soil lead concentration measures were used to construct a choropleth map of soil lead levels by census tract (see Figure 7). This map is a marked improvement over the one presented in Griffith et al. (1998a), which is based only on the first soil sample set. Soil sample values within a census tract can be aggregated by summarizing them with a single geometric mean. The geometric mean is the preferred measure of central tendency when soil lead concentrations conform to a log-normal distribution, and actually represents an arithmetic mean of the log-transformed values. The combined two soil sample sets yield 57 aggregate soil concentration geometric mean values that closely conform to a log-normal distribution (the Shapiro-Wilk test statistic null hypothesis probability is 0.495), with \( \delta = 0 \), display constant variance across the four quadrants of the plane and across sample sizes (the respective null hypothesis test statistic probabilities are: for Bartlett, 0.895 and 0.422; for Levene, 0.616 and 0.643), and exhibit weak positive spatial autocorrelation (Moran Coefficient = 0.17050; \( \hat{\rho} = 0.33962 \)). Covariation between these measures and mean pediatric blood-lead levels is portrayed in Figure 8; spatial autocorrelation latent in the soil lead values allows interpolated measures to be calculated for the four tracts lacking soil samples. A conspicuous positive relationship is displayed between these two georeferenced ecological variables. Figure 8 portrays this relationship, displaying a positively sloping underlying (invisible) trend line from which the scatter of points considerably deviates.

The spatial statistical model relating pediatric blood-lead levels and soil lead concentration may be written as follows:

\[
\ln(p_{\text{blood}}) - 0.6 = 0.58948 \sum w_{ij} \ln(p_{\text{soil}}) - 0.6 - 0.93676(1-0.58948) + 0.20251 \ln(p_{\text{soil}} + 37) + e, \text{ adj-R}^2 = 0.566,
\]

where \( p_{\text{blood}} \) denotes the blood-lead level of an individual child (in micrograms/deciliter), \( p_{\text{soil}} \) denotes the geometric mean of lead concentration in soil samples (in ppm), \( w_{ij} \) denotes the geographic weight for census tracts \( i \) and \( j \) (0 \( \leq w_{ij} \leq 1; \sum w_{ij} = 1 \)), \( \ln \) denotes the natural logarithm (base \( e = 2.7182818 \)), and \( e \) is an error term.

Diagnostics associated with this equation are as follows: normality of residuals: Shapiro-Wilk statistic = 0.985 (\( p = 0.661 \)); attribute homogeneity of variance: lack of any conspicuous patterns in the 'y-versus-e' plot; homogeneity of spatial variance null hypothesis probabilities: 0.460 for Bartlett, 0.730 for Levene; and spatial autocorrelation: Moran Coefficient = -0.04785 (\( z_{MC} = -0.5 \)), GR = 1.01429.

These diagnostics imply that this equation lacks specification error due to assumption violations. However, the percentage of variance accounted for suggests that covariates may be missing from the equation.

Therefore, children living in census tracts with higher soil lead concentrations appear to be at higher risk of becoming lead poisoned than do children living in census tracts with lower soil lead concentrations. The spatial statistical analysis and methodology outlined in this article make such an assessment of an important public health problem possible.
Representative Maps: Spatial Sampling Concerns

Numerous features of sampling warrant discussion here, namely intensity, spacing, coverage, information content, and precision. As mentioned earlier, the best spatial sampling network is based on a hexagonal grid, and as such has a first nearest neighbor statistic close to 2.15. Deviations from this grid are often necessitated by factors such as cost and the feasibility of collecting a sample. Both the City of Syracuse and the Geul River floodplain samples are dramatically impacted by these considerations. In the case of Syracuse, mostly public locations have been sampled because of permission and access constraints. In the case of the Geul River, transects were used to help reduce costs and because campgrounds were of interest. Some transect sampling appears to have occurred in the smelter superfund site as well (see Figure 4).

Meanwhile, as the intensity of sampling increases, spacing will decrease, resulting in an increase in the degree of spatial autocorrelation for sample values. In turn, incremental information content decreases. Both of the superfund site samples are impacted by this consideration. When hot spot subregions were detected in these sites, the subregions were intensively sampled in order to confirm their elevated pollution status. Both sites have one subregion that has been intensively sampled. While the replicate information is redundant, it also is confirmatory, illustrating one of the values of securing duplicate information during sampling.

In other words, the effective sample size is helpful—as is the first nearest neighbor statistic—when assessing coverage of a landscape, especially in cases where supplemental sampling is expected to occur. Knowledge of the effective sample size informs a scientist about where new samples should be taken, in an attempt to obtain as representative a geographic coverage as possible. If intensity is great enough, little beyond confirming previous sample results will be gained by securing new samples. If subregions are more intensively sampled, little will be gained by securing new samples from them; rather, more new information can be gained by securing new samples from the least intensively sampled subregions. By doing so, the sampling grid would undergo a modification that would move it closer to the uniformly spaced hexagonal grid.

Precision of a sample statistic is important as well. This precision is achievable in a conventional random sampling context by increasing the sample size, with the minimum necessary sample size being in the interval (30, 100). Costs associated with satisfying this requirement more than likely will be prohibitive for geographic landscapes. For example, stratifying by the 61 census tracts of Syracuse would require at least 1830 soil samples. Furthermore, the effective sample size resulting from latent spatial autocorrelation in soil lead concentrations means that this number would need to be much larger. Regardless of spatial autocorrelation effects, issues of precision still need to be addressed. Consider the scatterplot comparison of the two samples for Syracuse presented in Figure 9. Not only does the displayed scatter of points deviate too much from a straight line, but three census tracts (i.e., CTs 8, 16, and 33) have estimate pairs that dramatically differ. Increasing sample sizes within these tracts, even at the expense of securing redundant information, would help circumvent this problem. Similarly, the scatterplot comparison of replicate samples for the smelter superfund site presented in Figure 9 suggests a relationship between arithmetic mean lead level and standard deviation; good precision would be accompanied by a standard deviation close to zero at all concentration levels. Of the 17 replicate locations, four are triplicated and 13 are duplicated. Again, a lack of precision is indicated by these replicates.

Therefore, even when considerable spatial autocorrelation characterizes a set of soil samples, the sampling distribution variability of mean surface maps for a landscape must be controlled with adequate sample size. Spatial autocorrelation can be used to help bolster precision; however, using it to decrease sample size too much may compromise precision.

Maps With Holes: Missing Data Concerns

Another salient concern stems from the failure to have adequate geographic coverage after post-stratifying a sample. In the Syracuse, NY, example included in this article, 297 soil samples—

![Figure 9: Left: Pairs of Soil Lead Geometric Means for 49 Census Tracts Appearing in Both of the Syracuse, New York, Samples. Right: Duplicate Soil Samples for 17 Locations in the Smelter Superfund Site.](image-url)
some of which fall outside the city limits—are post-stratified into 61 census tracts, resulting in four tracts failing to contain any of the soil sample locations. Of course, one remedy is to secure a supplemental set of soil samples specifically from the four census tracts in question; of note is that a stratified random sampling design would avoid this problem. A much cheaper solution is to interpolate the missing data. Interpolation exploits latent spatial autocorrelation by borrowing duplicated information from nearby measures and emphasizes the normality assumption.

Use of the Box-Cox transformation, $LN(Pb + δ)$, allows one to work with soil lead concentration measures that more closely mimic a normal curve. In turn, normal curve theory states that the expected value of Pb, say $E(Pb)$, is a function of the mean and the variance of $LN(Pb + δ)$. More specifically, $E(Pb)$ is given by $\frac{δ}{δ + EXP[LN(p + δ)]H[ω(σ^2_{LN(p+δ)/2})]}$, where EXP denotes the anti-logarithm for $LN$ and the back-transformation correction factor $ψ_n$ is defined by Gilbert (1987). When spatial autocorrelation is present, the mean response also contains an autoregressive term. The SAR interpolation is used in rendering interpolated values differ considerably from those obtained through kriging with the fitted Bessel semivariogram model. The effective range for this model is given by 4 times the range parameter $r$, which equals 0.584 units of standard distance in this case. Restricting attention to the local neighborhood of each of the four census tract centroids (which is operationalized as a circle of radius 0.070 to 0.085 units of standard distance in order to avoid negative kriging weights) renders 164.7 ppm for CT 15, 59.0 ppm for CT 28, 60.7 ppm for CT 38, and 139.5 ppm for CT 42. Of note is that the back-transformation correction factors associated with these values range from 1.004 to 1.011, factors that are negligibly different from 1.

These interpolated values differ considerably from those obtained through kriging with the fitted Bessel semivariogram model. The effective range for this model is given by 4 times the range parameter $r$, which equals 0.584 units of standard distance in this case. Restricting attention to the local neighborhood of each of the four census tract centroids (which is operationalized as a circle of radius 0.070 to 0.085 units of standard distance in order to avoid negative kriging weights) renders 164.7 ppm for CT 15, 59.0 ppm for CT 28, 60.7 ppm for CT 38, and 139.5 ppm for CT 42. Extending the radius to the range in all four cases, and hence accepting negative kriging weights, modifies these numbers to 152.6, 74.3, 57.0, and 151.1, respectively. Because the SAR interpolation is based on averages as well as the combined samples, whereas the kriging results are based on individual measures contained in the second sample, the SAR interpolations may be more reliable. Unfortunately, little work has been completed to date comparing these two interpolations.

Conclusions

An answer can be put forth now to the question asking how the statistical and geographic distributions of soil lead concentration in the inhabited environment can be described. The statistical frequency distribution (or more formally, the statistical probability density function) appears to be a three-parameter log-normal distribution. Spatial statistical analysis reveals that the most appropriate semivariogram model appears to be the Bessel function, which links directly to the SAR spatial statistical model. The necessary geographic sampling design supporting estimation of these models needs to furnish good coverage of a landscape, with a sufficiently large sample size to ensure adequate precision of results. All of these findings should be transferable to places other than the four landscapes explored in this article. Furthermore, the methodology outlined here establishes expectations about geographic and non-geographic variability of soil lead concentrations in other landscapes, and furnishes a guide for quantifying and analyzing this variability in these other landscapes.

The importance of these findings is reflected in societal concerns such as pediatric lead poisoning. Being able to describe the statistical and geographic distributions of soil lead concentration in the inhabited environment furnishes a tool that can contribute to the solving of such problems. Scientific concerns contributed to by the knowledge of statistical and geographic distribution of soil lead concentration include methodological contributions for evaluating important quality features of a geographic sample and for plugging holes in maps.

About The Author

Daniel A. Griffith is a professor of Geography at Syracuse University. His most recent work concerning pediatric lead poisoning in Syracuse was the topic of a feature article in the Syracuse Herald-Journal. He has published numerous spatial statistics articles in the geography, regional science, statistics, and mathematics literature. He has been a Fulbright Fellow, an American Statistical Association Research Fellow, and a Guggenheim Fellow. His biographical profile is listed in the Marquis Who’s Who in the World.

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Acknowledgments

The Syracuse, NY soil lead concentration data have been made available to the author by Dr. David L. Johnson, Department of Chemistry, SUNY College of Environmental Sciences and Forestry, who with Ms. Jennifer K. Bretsch collected them. The floodplain soil lead concentration data have been made available to the author by Dr. Gerard Heuvelink; these data were originally collected by Dr. H. Leenaers, with financial assistance from the Department of Physical Geography, Utrecht University, the Dutch National Research Foundation NWO, and the Province of Limburg (NL). The superfund site soil lead concentration data have been made available to the author by Dr. Philip E. Goodrum, Research Scientist, and Mr. William C. Thayer, Syracuse Research Corporation. Dr. Susan Griffin, U.S. Environmental Protection Agency Region 8, furnished data on the original Murray superfund site.

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Lessons Learned from Case Studies on the Implementation of Geospatial Information Technologies

Claude Caron and Yvan Bédard

Abstract: It is difficult to evaluate when geospatial information technology (GIT) is considered an efficient solution in an organization because it is hard to know the "real" pathway of a given GIT implementation project (as opposed to the "official" pathway presented externally) or the motivations of all of the participants. In fact, behind success stories are frequent indications that newly implemented systems do not always help to reach the formal objectives of the organization. Moreover, close analysis reveals that GIT projects usually do not unfold the way prescribed by formal system development methods (even when presented as such).

The goal of this article is to present the result of a research project aiming at better understanding the implementation processes of GIT within organizations. Based on concepts found in Management, Sociology, Psychology, and Geomatics, our methodology involved three detailed case studies in three municipalities. These case studies included several in-depth interviews and analysis of archived administrative documents. The results of this theoretical research, which took place in 1997, were then validated over 3 years in the field by the principal author during major projects in Canada and Europe. Findings showed that GIT implementation projects can be presented as having an organizational perspective, being very "rational," in sync with formal system development methods, and being a "success" while in fact such projects follow a narrow perspective, are perceived as non-efficient, follow an unforeseeable implementation pathway, and are driven by the technology.

Introduction

Geospatial information technology (GIT) has rapidly evolved during the last two decades. At the same time, software engineering and system design methods have penetrated the implementation process of information technology (IT) within organizations. However, the demonstration that implemented IT or GIT meet organizational needs is still equivocal. Informal discussions allow us to suppose that the reality is not at par with the expectations. Sometimes, these technological solutions appear disappointing, as they mostly constitute a means to improve operational tasks (e.g., replacing manual drawing by digital mapping) rather than a way to improve the global efficiency of an organization (Clark 1990, Hammer and Champy 1993, Onsrud and Pinto 1993, Campbell 1997, Caron and Roche 1997). Often, they are seen as "technology-driven" expensive projects with long-to-come benefits and an uncertain implementation process; in other words, they are perceived as risky ventures (Quebec Government 1993, Pornon 2000). Despite these difficulties, conference proceedings and specialized magazines continue to show describe development projects and successes with few problems (Caron and Benda 2001).

We believe that the current difficulty in assessing the adequacy between GIT and organizational needs is in part caused by incomplete knowledge of the pathway by which these technologies are implemented in organizations. Recent studies on this topic have been conducted in parallel, and interesting and complementary frameworks have been proposed to describe GIT projects (Chan and Williamson 2000, Pornon 2000). However, we still lack knowledge concerning the motivations, objectives, implementation pathways, and benefits related to GIT implementation. To better understand these elements of the GIT implementation process, we have divided GIT projects into a pathway and into a perspective.

The project pathway is generally a succession of steps that may or may not be based on a structured system development method. Although small GIT projects that are not formally planned and that follow unstructured, informal, and undocumented steps are still seen, most GIT projects are large and complex and cannot succeed without formal planning and well-documented procedures. For example, the Rational Unified Process suggests four major steps (inception, elaboration, construction, and transition) and plans several substeps that use a modeling language that has become standard, i.e., the Unified Modeling Language (Booch et al. 1999). Ideally, all should follow such steps and use this formula. Even those adept at extreme methods follow rigorous rules and formally plan the development stages (Beck and Fowler 2001). Such pathways are considered "rational," starting with the problems and needs to be analyzed in the organization, followed by the design and development of an appropriate solution, and ending with implementation of the solution. Along this pathway, formal documents are produced to develop the system, to facilitate its maintenance, or to facilitate contractual arrangements. However, in practice, projects do not always follow this "theoretically good-practice"
scenario and the pathway may initially seem “irrational” (Roche et al. 1996, Pornon 2000).

The perspective of a GIT project varies and may differ considerably from the perspective generally allowed for such projects. For instance, the presented perspective might include “doing more with less,” speeding up data acquisition, facilitating data access, etc. However, unofficial motivations could include (Roche et al. 1996, Caron and Roche 1997) the following:

- spending a budget before a given date;
- using a governmental subsidy;
- reducing the number of employees in an organization;
- acquiring more prestige by the use of leading-edge technology (March 1991a, Roche et al. 1996); and
- following current trends regarding GIT.

In light of the above possibilities for the pathway and perspective, we decided to investigate in detail three municipal GIT projects to better understand how they evolved. We wanted this study to be purely descriptive and to provide explanations rather than being prescriptive and suggest new ways of implementing GIT. Accordingly, this article raised a general research question:

What are the similarities and the differences among pathways and perspectives relative to GIT implementation projects?

In the next sections, we present the theoretical background of our descriptive research, our methodology, and the results obtained. We then discuss the outcomes of this study and suggest directions for future research.

**Theoretical Background**

**Components of the Theoretical Framework**

Since the literature concerning organizations and IT is spread into different scientific fields and theoretical paradigms (Ebers and Ganter 1991, Moessinger 1991, Crowston and Malone 1994), we have created a pragmatic model of GIT projects based on an eclectic approach. First, the proposed model is founded on a development process that is a particular type of decision-making process (Chevallier 1992). This process is characterized by:

1. a stimulus that starts the project,
2. a particular pathway, and
3. a solution as a result (Mintzberg et al. 1976). Some authors add a global evaluation as a final step (Beaudouin 1984, QuÊbec Government 1993). Accordingly, GIT projects can be described with four elements: the initial impulse, the general process, the final solution, and the multiple evaluations (according to different individuals or groups) (Figure 1).

In addition, GIT projects are influenced by their organizational context (Roche 2000); this adds external factors that must be taken into consideration as well as the development process per se (Onsrud and Pinto 1993). Different organization models exist that may be used to describe this context (Mintzberg 1981, Morgan 1993). We used the traditional three-level pyramid: strategic, tactical, and operational (technical) (Anthony 1965).

The theoretical framework we adopted for this study is based on five components (Figure 2), as follows:

1. the project impulse;
2. the project pathway (i.e., the general decision-making process);
3. project relationships with the objectives of the organization;
4. the solution resulting from the project; and
5. evaluations of project success.

Once the theoretical framework was established, we formulated our main research hypothesis as:

Even if a GIT project is presented as having followed a "rational" pathway, an organizational perspective, and a success, it is in fact generally characterized by a pathway not actually "rational" by a perspective limited to the technology and may be considered a mitigated success (these elements vary during the project).

In the following paragraphs, we explain the five components of our theoretical framework while the next sections explain the research methodology and the findings.

**Project Impulse**

The project impulse is the event starting the GIT development process in the organization, the kick-off event. To create a spectrum of impulse types, some authors have used the following values: opportunity decisions, problem decisions, and crisis decisions (Mintzberg et al. 1976).

Decisions may be categorized by the stimuli that evoked them along a continuum. At one extreme are opportunity decisions, those initiated on a purely voluntary basis, to improve an already secure situation.... At the other extreme are crisis decisions, where organizations respond to intense pressures. Here a severe situation demands immediate action, for instance, seeking a merger to stave off bankruptcy. Thus, opportunity and crisis decisions may be considered to form the two ends of the continuum. Problem decisions may then be defined as those that fall in between, evoked by milder pressures than crisis. (Mintzberg et al. 1976, p. 251)

This classification of project impulses into opportunities, problems, and crises has been used by several authors (Nutt 1984, Hammer and Champy 1993) and was adopted in this study. An opportunity is defined as a feeling that it is time to acquire a new
technology or to start a development project, without any specific problems to solve in the organization. A problem is a gap, a perceived difference between what is desired and what exists (Beaudoin 1984, Kepner and Tregoe 1985). It is heavily influenced by one’s perception and has a fundamentally subjective nature. In fact, a problem cannot exist without an observer perceiving a gap between the desired and the existing situations (Beaudoin 1984). Finally, a crisis is considered an important gap.

### Project Pathway and the Types of Decision-making Process

Until the middle of the 1950s, the main decision-making paradigm was the “rational” approach (Butler 1991). This approach presents the process as a series of logical steps leading to a choice. Herbert Simon highlighted the limitations of this approach and proposed the “bounded-rational” approach. In practice, an optimal decision is difficult to reach and, most of the time, we accept a “satisfying” solution (Simon 1960). Both the “rational” and “bounded rational” approaches view the decision-making process as being a context of “problems looking for solutions;” however, we retained only the bounded-rational approach as a realistic pathway for this context.

Contrary to this vision, the “garbage-can” approach introduced in the 1970s (Cohen et al. 1972, Cohen et al. 1976, March and Olsen 1976) considered the problems, solutions, participants, choices, and decision-making contexts together. It may be explained as follows: “Suppose we view a choice opportunity as a garbage can into which various problems and solutions are dumped by participants. The mix of garbage in a single can depends partly on the labels attached to the alternative cans; but it also depends on what garbage is being produced at the moment, on the mix of cans available, and on the speed with which garbage is collected and removed from the scene” (Cohen et al. 1976:26). This perspective of decision-making implies that in a specific organizational context, one may find “collections of choices looking for problems, issues and feelings looking for decision situations in which they might be aired, solutions looking for issues to which they might be an answer, and decision makers looking for work” (Cohen et al. 1972, p. 1).

Considering the lack of a unified theory of decision-making, we decided to contrast the “bounded-rational” model (March and Olsen 1991, March 1991b) with the “garbage-can” model (Table 1) because these models are at near opposite ends along a spectrum of several models. In one sense, the two models complement each other, with the gaps in each model filled by contributions from the other. However, the two models have sufficient differences to view them as being the extremes of a spectrum where one model might perform very differently from the other in a specific development situation (Bass 1983).

### Table 1 Some characteristics of “bounded-rational” and “garbage-can” models

<table>
<thead>
<tr>
<th>Bounded-Rational Model</th>
<th>Garbage-Can Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process with specific steps</td>
<td>Process without any steps (March and Romelear 1976)</td>
</tr>
<tr>
<td>“Economical” theory (Bass 1983)</td>
<td>“Behavioral” theory</td>
</tr>
<tr>
<td>“Prescriptive” approach (Bazerman 1990)</td>
<td>“Descriptive” approach (Landry 1992)</td>
</tr>
<tr>
<td>Link between problems and solutions</td>
<td>Temporal and space closeness of solutions, problems, decision makers, and choice contexts</td>
</tr>
<tr>
<td>Operational/tactical decisions</td>
<td>Tactical/strategic decisions</td>
</tr>
</tbody>
</table>
Relationships between the Project and the Objectives of the Organization

We mentioned earlier that a GIT project may be geared toward strategic objectives, tactical objectives, or technical objectives. While the technical objectives can be easily defined, that is not the case for the top of the pyramid, as there seems to be little agreement as to what strategy means. Nevertheless, several researchers have explored the relationship between IT and the strategic goals of organizations (Blenker and Pontiggia 1991, Wassenar 1991, Raymond et al. 1993, Henderson and Venkatraman 1994, Hendriks 1998). Many authors emphasize that the real benefits of IT come from the capacity of organizations to plan, implement, and use IT, and to “align” IT to organizational strategies (Scott Morton 1991, Bartholomew and Caldwell 1995). However, many practitioners report that IT activities seem sometimes “disconnected” from the organization aims (Hammer and Champy 1993).

In our research, we considered that, at one extreme of a spectrum, IT may be not planned at all (Vitale et al. 1986) or may be considered as being an end in itself (Caron 1997), while at the other extreme of the spectrum, IT may contribute strategically to global performances and organizational efficiency. Despite a continuum between these extremes, we have created a dichotomy and contrasted a “business” view versus a “technical” view of GIT in organizations (Table 2).

Table 2: Some distinctions between “business” and “technical” views

<table>
<thead>
<tr>
<th>Business View</th>
<th>Technical View</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business issues</td>
<td>Technology issues</td>
</tr>
<tr>
<td>Main force: strategy driven</td>
<td>Main force: technology driven</td>
</tr>
<tr>
<td>Top-down approach</td>
<td>Bottom-up approach</td>
</tr>
<tr>
<td>Leaders: managers and administrators</td>
<td>Leaders: technologists and operators</td>
</tr>
<tr>
<td>Formal hierarchy of organizational goals</td>
<td>Informal arrangement of goals (“organizational slack”)</td>
</tr>
<tr>
<td>Adoption process of technology: complex</td>
<td>Adoption process of technology: simple</td>
</tr>
<tr>
<td>Implementation decisions: strategic/tactical</td>
<td>Implementation decisions: operational/tactical</td>
</tr>
</tbody>
</table>

Different Types of GIT Solutions

A few researchers have classified technological solutions in the wider field of IT as well as in the more specific field of GIT (Nolan 1979, Huff et al. 1988, Chrisman 1997). No general classification of GIT solutions exists that is useful or relevant to all situations; however, Chrisman (1997) proposed a key schema presenting the different issues related to geographic information. We adapted this framework to categorize GIT solutions into four levels of sophistication beginning with simple tools, such as computer-assisted design (CAD) or geographic information system (GIS), and including global information and management concepts (Caron and Vallière 1995, Caron 1997). Based on an expansion of solution possibilities (same criteria as Huff et al. 1988), these four levels of solutions integrate themselves (Figure 3) as explained in Table 3.

Evaluation of the Success of a GIT Project

The last component of our theoretical framework is the result of the successful evaluation of a GIT project. Success is difficult to measure since different points of view exist to evaluate success: “[...] it is likely that success will be measured in different ways not only by different organizational members but also by different organizations and even by the same organization in different points in time.” (O’Connor 1993)

Many studies have been conducted to establish the best way to measure the success of an information system in an organization and many have attempted to create a unique and global model (DeLone and McLean 1992, Pitt and Watson 1994).

In practice, however, the diversity of viewpoints among those in an organization makes it difficult to measure the organization efficiency. Different criteria used include customer satisfaction, team project satisfaction, schedule respect, cost respect, solution performance (technical and organizational), and solution use (Doll and Torkzadeh 1988, Melone 1990, Smith 1991). Even when instruments for measuring seem similar, authors often use different definitions. This creates difficulties to compare results and to integrate theories (Campbell and Masser 1995). Based on the model of Pitt and Watson (1994), we established the following classification:

1. Organization performances (criteria determined by the strategic planning of IT)
2. Technological performances
   - improvement of IT (criteria determined at the beginning of the project),
   - user satisfaction toward the technological solution, and
   - whether a technological solution was used or not.

3. Project performances
   - budget respect,

Geographic Information System
- A GIS solution (concept derived from the MIS concept) is different from the previous level by the fact that management considerations become more important than simply regarding hardware and software issues.
- In practice with this solution, many of the following aspects are considered: redefining many tasks, restructuring communication channels (information and decision), reshaping human resources (training, hiring, suspending, etc.), redistributing power in the organization (job title, responsibilities, etc.), creating a common cartographic basis in the organization, planning a coordinated (federated) plan for GIT developments, and verifying that managers perceive only one global GIS.

Generally, a GIS project implies rethinking one or many organizational processes regarding the management and the use of geospatial data.

Global Geography-Enabled Organizational Solution
- The implementation of GIT is part of a more global concept concerning the entire organization (objectives, structure, processes, resources, etc.)
- In this context, the strategic competitive advantage through the introduction of GIT in the organization is considered.
- GIT is a stimulus for a major reorganization or an important support of all organizational processes.

To sum up our theoretical framework, the five variables used in our study and their possible values are presented in Table 4. These values may appear too clear cut and almost to represent a caricature, but they are intentionally contrasted to better highlight the characteristics of each case study. While it may mean forcing some choices, it will be clear later on that, in some cases, the variables can take on more than one value at a time (e.g., problem and opportunity). Furthermore, we will add nuances and comments on these values when needed.

Research Hypothesis and Postulates
Once the theoretical framework is established, the main hypothesis is divided into five sub-hypotheses: H1 to H5.

H1. A development project of GIT may be classified by its pathway (route) and its perspective (target). These two characteristics may be used to generate the axis of a classification matrix (Figure 4), thus defining four poles or project types. This matrix allows us to classify all GIT development projects.

H2. In general, GIT development projects have an “unforeseeable” pathway and are conducted with a “technological” perspective.

H3. During a project, some “recentering” of the perspective and the pathway may occur; for example, an “unforeseeable technological” (UT) project may become an “algorithmic organizational” (AO) project, or vice versa. Despite recentering and in coherence with H2, a project will be of a UT type most of the time.

H4. GIT projects may have a blocked pathway and perspective. Therefore, we make a distinction between the official and unofficial types of a project. For example, there may be a situation where the acquisition of leading edge technology is simply a “symbol.” In such a context, the technology contributes to the image of modernity of the organization. How-
ever, managers of the organization probably will not easily acknowledge this kind of motivation.

H5. GIT projects tend to be publicized as having as many characteristics of an “algorithmic” pathway and an “organizational” perspective as possible, determined by what is officially justifiable.

**Research Methodology**

The aim of this research project is to conduct a qualitative analysis of GIT development projects that were completed by the end of the 1990s. Since it is an organizational phenomenon *in vivo*, we decided to choose the case study as the main research strategy. Moreover, this technique is often used to study organizations (Lee 1989, Onsrud et al. 1992, Campbell and Masser 1995).

In concrete terms, we conducted interviews with different persons in the studied projects. These interviews allowed us to discover non-written characteristics of projects (Mintzberg et al. 1976, Yin 1989). As a complementary research technique, we used archive analysis (i.e., an analysis of all kinds of official documents regarding a specific project). In this way, we were able to “triangulate” different information sources (Bass 1983) and confirm or not the information collected from interviews.

From a methodological point of view, generalization from case studies is still a controversial and misunderstood action. Nevertheless, we maintained our methodological approach (subsequent experiences by the main author support the findings of this research). Yin (1989:21) explained the subject by making a clear distinction between statistical generalization and analytical generalization:

> A ... common concern about case studies is that they provide very little basis for scientific generalization... case studies, like experiments, are generalizable to theoretical propositions and not to populations or universes. In this sense, the case study, like the experiment, does not represent a “sample,” and the investigator’s goal is to expand and generalize theories (analytic generalization) and not to enumerate frequencies (statistical generalization).

**Choice of Case Studies**

As mentioned earlier, we planned to study GIT development projects within organizations. Furthermore, we wished to confirm, through an analytical generalization process, the validity of research conclusions in other contexts (replication). Thus, three case studies, chosen with the following criteria, were undertaken:

- cases involving GIT development projects,
- cases conducted in the public municipal sector in the Province of Quebec,
- cases that have a long history for which some conclusions have been publicized over the years (i.e., that started in the beginning of the 1980s),
- cases in which the size corresponds to the following categories:
  - Small (population below 25,000 inhabitants)
  - Medium (population between 25,000 and 75,000 inhabitants)
  - Large (population above 75,000 inhabitants) for which leaders accept a case study process and who are open to let different persons of their organization be interviewed,
- and cases that give access to all relevant archives (documents and artifacts) related to their project.

We decided to control the size of organizations to study because we believed that this parameter (implying different structures, functioning, and amounts of resources) might impact the development process. Furthermore, criteria were determined to select the most appropriate persons to be interviewed in order to describe each project from official and unofficial perspectives. The interviews and identification of the cities were guaranteed to remain confidential. For each case study, the following criteria were used when choosing persons to be interviewed:

- members of the “project group” vs. non-members,
- project protagonists vs. opponents,
- strategists, tacticians, vs. technicians, and
- developers vs. end-users.
To validate our hypothesis in a practical way, we needed to go into more details with our five variables (Table 4) and to define indicators. Based on accuracy, reliability, and validity criteria, we established indicators that allowed us to distinguish the unofficial from the official aspects of the projects for each of the five variables describing the pathway and the perspective (Table 5).

**Table 5** Indicators for each variable regarding unofficial and official aspects

<table>
<thead>
<tr>
<th>Variable</th>
<th>“Unofficial” Aspects</th>
<th>“Official” Aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impulse</td>
<td>Perception of the project impulse</td>
<td>Project impulse as publicized</td>
</tr>
<tr>
<td>Process</td>
<td>Perception of the decision-making process</td>
<td>Decision-making process as publicized</td>
</tr>
<tr>
<td>Strategy</td>
<td>Existence of strategic planning in the organization</td>
<td>Mention of the link in what is publicized</td>
</tr>
<tr>
<td></td>
<td>Consideration of the existence of a link</td>
<td></td>
</tr>
<tr>
<td>Solution</td>
<td>Solution in itself, including internal documents that describe it</td>
<td>Solution as publicized</td>
</tr>
<tr>
<td>Evaluation</td>
<td>Perception of project failure or success</td>
<td>Global qualifier for the project, as publicized</td>
</tr>
<tr>
<td></td>
<td>Criteria used internally to consider that it is a success</td>
<td>Criteria used to publicize that it is a success</td>
</tr>
</tbody>
</table>

**Analysis Process**

As recommended by Yin (1989), we specified how the data would be analyzed before collected in the field (Table 6). This approach limited the amount of data to collect, minimized potential analysis deviations, and contributed to establishing a rigorous manner in which to analyze data for the validation (or not) of the research hypothesis.

**Findings**

The progress for each case study was in all respects consistent with the predefined experimental framework. We collected data “in the field” through a total of 40 interviews for case studies and by the analysis of multiple archives. Each interview was recorded and lasted an average of 30 minutes. All interviews were transcribed, generating more than 600 pages of text. Hereafter, we detail our findings for each distinct city: “Small,” “Medium,” and “Large.”

**Project in the City of Small: Data Synthesis and Analysis**

The municipal organization of the City of Small is among the small to medium-size cities in Canada, its population being under 25,000 inhabitants. This municipality has a relatively simple
Table 8 Project phases for the City of Small

<table>
<thead>
<tr>
<th>Phase</th>
<th>Summary</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year “0”</td>
<td>Absence of geomatics tools in the city. The city is nevertheless interested in the general effervescence in geomatics.</td>
<td>I: problem and opportunity&lt;br&gt;P: bounded rational&lt;br&gt;S: non-existent&lt;br&gt;O: concrete GIT&lt;br&gt;E: inapplicable</td>
</tr>
<tr>
<td>I. 2 years</td>
<td>The project impulse seems to be a problem (unreliable and inaccessible data) and an opportunity (new technologies) at the same time. During this period, the city uses the article version of the cadastral map. There is no long-term strategic planning.</td>
<td>I: opportunity&lt;br&gt;P: garbage can&lt;br&gt;S: non-existent&lt;br&gt;O: concrete GIT&lt;br&gt;E: inapplicable</td>
</tr>
<tr>
<td>II. 4 years</td>
<td>During this long period, mandates are given to external firms for the digitizing of data for different objectives, even though the city still uses the article version. The new water and sewer networks are the subjects of systematic reports by surveying firms. The city starts to seriously consider the new geomatics technologies (visits to other cities, symposiums, conventions, etc.) with the objective of evaluating the pertinence of the in-house purchase of these technologies.</td>
<td>I: opportunity&lt;br&gt;P: garbage can&lt;br&gt;S: non-existent&lt;br&gt;O: concrete GIT&lt;br&gt;E: inapplicable</td>
</tr>
<tr>
<td>III. 1 year</td>
<td>The map-drawing activity increases and the city wishes to acquire in house knowledge of CAD in relation to town planning and civil engineering. The aqueduct and sewer networks are still the objects of costly reports by surveying firms. The city develops plans to acquire and implement geomatics solutions considering their technical aspects as well as the cost. It chooses to acquire CAD software and a total station.</td>
<td>I: opportunity&lt;br&gt;P: garbage can&lt;br&gt;S: non-existent&lt;br&gt;O: concrete GIT&lt;br&gt;E: inapplicable</td>
</tr>
<tr>
<td>IV. 6 months</td>
<td>Mandates are given to external consultants to evaluate the city’s current cartographic data. They are asked to propose appropriate technologies and to establish a master plan of geomatics implementation. Following this report, the city chooses a cartographic specific technology.</td>
<td>I: opportunity&lt;br&gt;P: garbage can&lt;br&gt;S: non-existent&lt;br&gt;O: concrete GIT&lt;br&gt;E: inapplicable</td>
</tr>
<tr>
<td>V. 6 months</td>
<td>The city hires a permanent technician who will be responsible for geomatics. It continues to offer digital cartography classes to technicians already in the town planning and engineering department. The city acquires geomatics equipment, including digital cartography software and the total station already chosen, to make reports in the context of water purification.</td>
<td>I: problem and opportunity&lt;br&gt;P: bounded rational&lt;br&gt;S: non-existent&lt;br&gt;O: combination of GIT and spatial information system&lt;br&gt;E: undetermined</td>
</tr>
<tr>
<td>VI. 3 years</td>
<td>The city acquires a second digital cartography workstation. Different subjects are put into place, adding to the base and cadastral maps. The procedures and work methods used are improved upon. The impulses pushing geomatics at this point are opportunities to be seized. The general development of the project consists of a series of different opportunities with very little planning. There is still no strategic geomatics planning. Many people involved in geomatics for the city find that there is an important lack of leadership in the field. The atmosphere does not encourage synergy. Geomatics advances at a snail’s pace and lacks resources. Budgets allocated to geomatics stagnate and decrease.</td>
<td>Unofficially&lt;br&gt;I: opportunity&lt;br&gt;P: garbage can&lt;br&gt;S: non-existent&lt;br&gt;O: combination of GIT&lt;br&gt;E: project and technical performance&lt;br&gt;Officially&lt;br&gt;I: problem and opportunity&lt;br&gt;P: bounded rational&lt;br&gt;S: non-existent&lt;br&gt;O: combination of GIT and spatial information system&lt;br&gt;E: undetermined</td>
</tr>
</tbody>
</table>

I: Impulse<br>P: Process<br>S: Strategy<br>O: Solution<br>E: Evaluation

Based on the classification matrix (Figure 4) and the values for each variable of the project phases, we have created a synthetic image of the project’s chronological events (Figure 5). On this diagram, the size of the different bubbles is proportional to the duration of each project phase.
organizational structure. The fictitious names of the persons interviewed are synthesized in Table 7.

The project was divided into six phases based on orientation changes and on the beginning of important new activities during the project. Therefore, a phase has activities that are relatively homogeneous. Table 8 presents the entire project by its successive phases, summarizes significant facts for each phase, and indicates values for each variable.

The following excerpt, taken from an interview with a tactician from the Town Planning and Engineering department of the City of Small, reveals the approach taken by the city, which is clearly reflected in the classification matrix:

The City of Small’s approach can be summarized by the phrase “City of Small, one step at a time.” It was imposed by the available funds allocated to digital cartography but also by our concern for the development of our in-house expertise. The gradual development by objectives also allows us to validate and adjust our way of managing digital data as we go along.

Project in the City of Medium: Data Synthesis and Analysis

The municipal organization of the City of Medium is among medium-sized cities in Canada, its population being between 25,000 and 75,000 inhabitants. This municipality has a more complex organizational structure than the City of Small. The fictitious names of the persons interviewed are synthesized in Table 9.

The project was divided into five phases based on orientation changes and on the beginning of important new activities during the project. Therefore, a phase has activities that are relatively homogeneous. Table 10 presents the entire project by its successive phases, summarizes significant facts for each phase, and indicates values for each variable.

Based on the classification matrix (Figure 4) and the values for each variable of the project phases, we have created a synthetic image of the project’s chronological events (Figure 6). On this diagram, the size of the different bubbles is proportional to the duration of each project phase.

This figure allows us to easily discover that: 1) the project

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**Table 9** Types of persons interviewed in the City of Medium

<table>
<thead>
<tr>
<th>Department</th>
<th>Brief description</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administration</td>
<td>General management of the city, planning, finance, management, litigation, management of municipal buildings, etc.</td>
<td>1 at the strategic level</td>
</tr>
<tr>
<td>Computers</td>
<td>Implementation of computer networks and of resource infrastructures and basic software.</td>
<td>1 at the tactical level</td>
</tr>
<tr>
<td>Engineering</td>
<td>Elaboration of different construction or repair projects for the city: streets, underground infrastructures, etc.; in charge of the topographic map and of the geodetic network; field reports; use of the digital videoplotter, total stations, etc.</td>
<td>1 at the strategic level 1 at the tactical level 1 at the technical level</td>
</tr>
<tr>
<td>Civil Engineering</td>
<td>Snow removal, construction, and maintenance of the aqueduct and sewer networks, household garbage collection, etc.</td>
<td>1 at the tactical level 2 at the technical level 1 at the technical level</td>
</tr>
<tr>
<td>Town Planning</td>
<td>Elaboration of the urban zoning and updating, construction and renovation permits, etc.</td>
<td>2 at the tactical level 1 at the technical level</td>
</tr>
<tr>
<td>External consultant</td>
<td>Advice, subcontracting, realization of different studies, etc.</td>
<td>1 external consultant</td>
</tr>
</tbody>
</table>
Table 10: Project phases for the City of Medium

<table>
<thead>
<tr>
<th>Phase</th>
<th>Summary</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year “0”</td>
<td>Absence of computer equipment in the organization. Beginning of a more intensive period for the development of GIT in the Province of Quebec. Managers of the city are on the watch.</td>
<td>I: opportunity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P: inapplicable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S: non-existent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>O: concrete GIT</td>
</tr>
<tr>
<td>I. 2 years</td>
<td>Participation of managers in conventions, symposiums, visits to other cities... Isolated acquisitions of equipment in some departments. Increasing interest of some managers in GIT and follow-up of the evolution of these technologies.</td>
<td>I: opportunity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P: inapplicable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S: non-existent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>O: concrete GIT</td>
</tr>
<tr>
<td>II. 1 year</td>
<td>Creation of an “IT” department in the city. Development of an IT strategic plan by a consultant, which integrates GIT concerns. Beginning of a wide reflection concerning the use of GIT in different departments of the city.</td>
<td>I: problem and opportunity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P: bounded rational</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S: existent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>O: spatial information system</td>
</tr>
<tr>
<td>III. 1 year</td>
<td>Creation of an informal group on GIT, then official creation of the “GIT Committee.” Prospective analysis conducted by this new group regarding GIT.</td>
<td>I: problem and opportunity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P: bounded rational</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S: existent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>O: GIS and combination of IT</td>
</tr>
<tr>
<td>IV. 1.6 years</td>
<td>Mandate given to an external consultant to evaluate implementation opportunities of GIT in the city. Based on an intuitive approach, acquisition by the Engineering department of the GIS “XYZ.” The consultant proposes a long-term development strategy of GIT and prioritizes some short-term projects.</td>
<td>I: problem and opportunity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P: bounded rational</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S: existent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>O: spatial information system</td>
</tr>
<tr>
<td>V. 4 years</td>
<td>Acquisition and development of GIT in the city. <em>Unofficially.</em> Projects are started from opportunity impulses. There is no long-term planning. The global solution is basically made of small systems that are “loosely coupled” instead of being a unique “federated” system.</td>
<td>I: problem and opportunity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P: bounded rational</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S: non-existent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>O: combination of GIT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>E: technical and project performance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unofficially</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I: opportunity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P: garbage can</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S: non-existent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>O: combination of GIT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>E: technical and project performance</td>
</tr>
<tr>
<td></td>
<td><em>Officially.</em> Projects are presented as solutions to existing problems. Managers maintain that all developments are conducted under long-term planning.</td>
<td>I: problem and opportunity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P: bounded rational</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S: non-existent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>O: combination of GIT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>E: organizational and technical performance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Officially</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I: problem and opportunity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P: bounded rational</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S: non-existent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>O: combination of GIT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>E: organizational and technical performance</td>
</tr>
</tbody>
</table>

was of a UT type at the beginning, became of an AO type, and finally returned to a UT type, and 2) there is a difference between what is official and what is unofficial as of phase V. During this phase, while the project is officially of an AT type, it is in fact unofficially of a UT type.

The following three quotes, taken from discussions with different participants during the case studies, clearly demonstrate the situation observed in the City of Medium:

**Excerpt of an Interview with a Computer Tactician**

**Q: It's an opportunity?**

A: That’s right. We go from one opportunity to another. What do you expect when you only have $100,000 or $150,000 per year to make everything work! ... The thing is, deep down, what pushes geomatics forward are more the personal initiatives of individual people and a little tendency to follow the trends like other cities. So, it depends a lot on the personal initiative of people who wanted to improve their situation.... And what is crystal clear is that it didn't come from higher up; it isn't the boss that said “From now on guys, I have a great idea on how to push geomatics forward: this is what we are going to do!” Personal initiative is much more important.

Excerpt of an Interview with an Administration Strategist
According to the current practice in the City of Medium, presenting a project where you plan on spending $1 million per year for 5 years to get what you want has never worked. No matter what field, whether it is in recreation, parks, or informatics, we have already done the same type of practice.... The flexibility that the City of Medium has in its immobilization plan is relatively limited. It is a city where the financial situation varies little. So, from one year to another, or from one committee to another, the trends change too much to allow such a huge sum of money to be spent on major geomatics projects.... Therefore, it’s more of a dynamic program planning approach. Which means that there is no pre-established target; it is re-adjusted as the project goes along.

Excerpt of an Interview with a Computer Tactician

In my opinion, they are systems that are nonetheless “loosely coupled” enough. It means that they are independent enough but it’s not the big integrated system. And once again, we can’t afford it. It’s good that way. It has some big disadvantages, but it also has some big advantages such as the fact that, in the end, some people are happy with their little world. And then, we have a mechanism of minimal coordination, which is the geomatics committee. All we make sure of is that one of the negative impacts, the redundancy of the work or data, is minimized.... However, there are other negative impacts such as the global vision of the project (not many people have it).... And, there is also the vulnerability of the systems. If tomorrow, two or three people leave who really know a part of the system, it’s over! Nobody is up to speed...

![Figure 6: Classification Matrix Showing the Project Events for the City of Medium.](image)

<table>
<thead>
<tr>
<th>Department</th>
<th>Brief</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administration</td>
<td>Realization of social and demographic studies, planning, finance, management, litigation, management of municipal buildings, etc.</td>
<td>2 at the tactical level, 1 at the technical level</td>
</tr>
<tr>
<td>Surveying</td>
<td>Maintenance and updating of the digital topographical map (1:1000), of the cadastral map, and of the geodesic network; field reports; use of the digital videoplotter, of total stations, etc.</td>
<td>1 at the strategic level</td>
</tr>
<tr>
<td>Informatics</td>
<td>Implementation of computer networks, development of applications in charge of implementation of a corporative geomatics tool (for the entire city) for digital cartography and spatial analysis (GIS software).</td>
<td>2 at the strategic level, 2 at the technical level</td>
</tr>
<tr>
<td>Engineering</td>
<td>Elaboration of different construction or repair projects for the city: streets, underground infrastructures, etc.</td>
<td>1 at the tactical level</td>
</tr>
<tr>
<td>Civil Engineering</td>
<td>Snow removal, construction, and maintenance of the aqueduct and sewer networks, household garbage removal, etc.</td>
<td>1 at the tactical level, 1 at the technical level</td>
</tr>
<tr>
<td>Town Planning</td>
<td>Elaboration of the urban zoning and updating, construction and renovation permits, etc.</td>
<td>2 at the tactical level, 1 at the technical level</td>
</tr>
<tr>
<td>External Consultant</td>
<td>Advice, subcontracting, realization of different studies, etc.</td>
<td>1 external consultant</td>
</tr>
<tr>
<td>External City Source</td>
<td>Person close to one or more of the participants able to give his/her appreciation of the project.</td>
<td>1 external consultant</td>
</tr>
<tr>
<td>Phase</td>
<td>Summary</td>
<td>Variables</td>
</tr>
<tr>
<td>-------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Year “0”</td>
<td>As a way to eliminate some of the redundant work related to cartography being done in different departments (e.g., they were able to redesign in Engineering portions of the plans already prepared by Surveying) and facilitate the creation of maps by superimposable layers, which allows the use of the same map background in each department.</td>
<td>I: opportunity P: inapplicable, S: non-existent O: concrete GIT E: inapplicable</td>
</tr>
<tr>
<td>I. 4.6 years</td>
<td>Start of reflections on geomatics, especially the tools for CAD. Participation in symposiums, conventions, etc. Visits to other cities in North America where digital tools are starting to be used. Increasing interest in the field of geomatics and the evolution of its technology.</td>
<td></td>
</tr>
<tr>
<td>II. 1.6 years</td>
<td>Formation of a working group in charge of evaluating the opportunity of implementing a GIS concept in the city. In-house realization of a report (an opportunity study) recommending the elaboration of a GIS. Refusal by the high-level city managers to follow the recommendations of this report. The principal reasons: the report was in-house and the technology too expensive.</td>
<td></td>
</tr>
<tr>
<td>III. 2 years</td>
<td>Increasing the use of manual cartography by superimposable layers with photogrammetry, for singular needs or in order to create maps comprising data from several departments.</td>
<td>Unofficially I: opportunity P: garbage can S: non-existent O: combination of GIT E: technical and project performance Officially I: problem and opportunity P: bounded rational S: non-existent O: combination of GIT E: technical performance</td>
</tr>
<tr>
<td>IV 1.6 years</td>
<td>Memorandum of an agreement so that the municipality can participate in the provincial cadastral reform program. Decision of the city to use the digital version of the topographic map (1:1000) and of the revamped cadaster.</td>
<td>Unofficially I: opportunity P: garbage can, S: non-existent O: combination of GIT E: project performance Officially I: problem and opportunity P: bounded rational S: existent O: spatial info. system E: organizational performance</td>
</tr>
<tr>
<td>V. 1.6 years</td>
<td>Realization of a functional analysis as always done by the same consulting firm, containing very detailed specifications concerning the future cartography system.</td>
<td>Officially I: problem and opportunity P: bounded rational S: existent O: spatial information system E: organizational performance</td>
</tr>
</tbody>
</table>
Q: There is no central vision?
A: No vision. It's small worlds that are a little isolated. But, it's that or nothing! And I think that for us, it's better than nothing.

Project in the City of Large: Data Synthesis and Analysis

The municipal organization of the City of Large is among the major cities in Canada, its population being over 75,000 inhabitants. This large municipality has a complex and ramified organizational structure. The fictitious names of the persons interviewed are synthesized in Table 11.

The project was divided into eight phases based on orientation changes and on the beginning of important new activities during the project. Therefore, a phase has activities that are relatively homogeneous. Table 12 presents the entire project by its successive phases, summarizes significant facts for each phase, and indicates values for each variable.

Based on the classification matrix (Figure 4) and the values for each variable of the project phases, we have created a synthetic image of the project’s chronological events (Figure 7).

This illustration is revealing and allows us to determine that the four most predominant phases in terms of length are I, VIII,
VI and, to a certain degree, III. The project seems to split in two after phase II, with the unofficial development being different from the official one. It can be said that there were differences between the unofficial and official versions for a big part of the project. Overall, the unofficial project seems to be of a UT type, while the official project seems to be of an AO type. The official version was, in general, fairly constant in its characteristics (phases II as well as IV, V, VI, VII, and VIII being of an AO type), while the unofficial version varied much more. Phase V is only in the official version of the project (no unofficial realization).

On the whole, if we look at the development of the unofficial version of the project, we realize that this version successively adopted the following types: UT - AO - UT - UO and finally UT. We could then say that there were two roundtrips between the lower left-hand corner and the upper right-hand corner of the matrix.

The following citations, taken from discussions with different participants during the case studies, clearly demonstrate the situation observed in the City of Large:

Q: In your department, was there a strategic or developmental plan that said you had to reach a certain productivity level using geomatics?
A: No, it was more informal.

Excerpt of an interview with a Surveying Strategist

Q: Is it fair to say that, in the end, your department was a bit pushed aside in the general geomatics development process?
A: Yes, pushed aside of, how could I say it, the synergy. We sold hardware to the city’s different departments. It’s great to have a sophisticated car; you can do lots of things with it but if you aren’t able to use it and you don’t use it everyday, it’s too bad, isn’t it?

Excerpt of an interview with a Surveying Strategist

We don’t care about informatics: when we want something, we develop it, program it, and organize it. Take for example, the report cards that come from the field, the GPS receptors and everything. We developed them ourselves. We organized a way of doing things and we didn’t bother with informatics.

It angers me a little because our project got off on the right foot. And now, I find that the project is coming to a standstill. You know, the geomatics project is really boring now! When people asked me every year to tell them what we had added in geomatics to the department, besides hardware and some new software, there wasn’t much to tell!

Excerpt of an interview with an Administration Tactician

Q: Can the fact that there isn’t that synergy between the Surveying and Informatics department contribute to stop the progress of the project?
A: Well, maybe. Well, probably. [silence] Because if one has to take care of the relationship with the users and the other is more into development, and deep down, they don’t have the same vision, the one who ends up paying is the client, the user.

Excerpt of an interview with a Surveying Strategist

I consider the project a success. Yes. A success on the technical level because our foundation is good, and our approach correct. Although I have to add something. I tell myself that, at one point, we could have been more successful, technically speaking, than we are now. We could have rated higher on my success scale than we are now.

Excerpt of an interview with an Administration Tactician

Combined Analysis of the Three Case Studies

Since values for each indicator are specified respectively for each case study, it is possible to combine these values to determine the validity of postulates and sub-hypothesis. Therefore, for each statement, we have to specify one of the following conclusions:
- supported: collected data indicate support of the statement,
indeterminate: collected data are insufficient to either support or falsify the statement, or
falsified: collected data indicate that the statement is false.

The conclusion for each sub-hypothesis is explained in the paragraphs below. These paragraphs are structured in accordance with the research sub-hypothesis already presented in the theoretical background. For many statements, we refer to endnotes to clarify the assertions.

**H1: supported.** The project impulse is unofficially of the opportunity type, and the decision-making process is unofficially of the garbage-can type. The link between organizational strategies and IT is unofficially non-existent, and the project impulse is unofficially of the opportunity type. The link between organizational strategies and IT is unofficially non-existent, and the solution is unofficially of a concrete GIT type. The project is unofficially and officially considered as a success. The link between organizational strategies and IT is unofficially non-existent, and the success is officially measured according to project performances and technological performances.

**H2: supported.** For the three case studies, project impulse is unofficially of the opportunity type and the decision-making process is unofficially of the garbage-can type. The link between organizational strategies and IT is unofficially non-existent. The solution is unofficially of a concrete GIT type for all case studies. The success is unofficially measured according to project performances and technological performances for all case studies.

**H3: supported.** Unofficial Pathway: unforeseeable (the project impulse is unofficially of the opportunity type, and the decision-making process is unofficially of the garbage-can type). Unofficial Perspective: technological (the link between organizational strategies and IT is unofficially non-existent, and success is unofficially measured according to project and technological performances, and the solution is unofficially of a concrete GIT type). Unofficial Project Type: UT (for all case studies).

**H4: supported.** Official Pathway: algorithmic (for all case studies). Official Perspective: organizational (City of Large) and technological (cities of Small and Medium). Official Project Type: AO (City of Large) and AT (Cities of Small and Medium).

**H5: supported.** The impulse is unofficially of an opportunity type and officially of a problem/crisis type and an opportunity type. The decision-making process is unofficially of a garbage-can type and officially of a bounded-rational type. The link between organizational strategies and IT is unofficially non-existent and officially existent (for the City of Large); on the other hand, it is non-validated for the cities of Small and Medium. The solution is unofficially of a concrete GIT type and officially of an abstract concept of an organization type (for the Cities of Small and Large); however, it is non-validated for the City of Medium (the solution is unofficially and officially of a concrete GIT type). Success is officially measured according to organizational and technological performances and unofficially measured according to project and technological performances.

Finally, it is possible to confirm the unofficial type of the projects for each of the three case studies by generalizing their representation in the classification matrix (Figure 8).

These representations allow us to determine the preponderance of the “unofficial” UT type for each of the three projects, while the “official” types are AT (two cases) and AO (one case).

**Discussion**

We were in a position to establish that, during a project, GIT may be an operational mean and may then become a strategic mean, or vice versa. In general, GIT is perceived as a tactical or an operational mean in most cases. Nearly all interviewed indicated their project as being a “success,” even those who have highlighted many negative issues regarding the project in their city. We were
able to discover that, officially as much as unofficially, “problem/crisis” and “opportunity” impulses are not mutually exclusive in the same project, even if an impulse type prevails over the other. Officially, even if someone “sells” GIT to decision-makers in the city as a solution to some existing problems, the fact that it is also a technological opportunity to obtain is not hidden.

It seems that when managers have “sold” their project to decision-makers of a city according to “organizational performances” criteria, they then have to keep this type of criteria in order to measure success. Instead of this constraint, we observed that managers are much more flexible in their choice of criteria to measure this organizational performance. Through our analysis of the project at the City of Large, we showed that a link between a problem and a solution could be created a posteriori. In fact, organization members may find that the new GIT solution is an unexpected answer to a latent or hidden problem that they have forgotten to solve. In such a situation, we “rationalize” a posteriori the congruence of a technology by the creation of a logical link between a solution and a problem. Therefore, we tend to reconstruct the project’s chronological events, consciously or not, creating a reality that is more logical and more consistent (Loftus 1983).

Our study shows that the projects assessed mostly followed a “garbage-can” process and that solutions are concrete GIT applications with little or no relation to organizational corporate strategies. Solutions are technology-driven and looking for problems to solve, and an a priori identification of possible solutions seems to determine the problem formulation (Nutt 1984, Caron 1997).

In fact, ambiguity was inherent to the organizations assessed. Strategic intents and objectives are often not consistent or stable. The causality that is supposed to relate means and ends, solutions and problems, and policy and actions is often very ambiguous (Olsen 1976, March 1991c, Martinet 1991). This is the same situation for the causal link between strategic objectives and the use of technologies (Blenker and Pontiggia 1991). We observed that organizational issues seem most of the time to be characterized by complexity (Zeleny 1981, Bass 1983). A complex situation is characterized by many of the following characteristics (Landry 1980): fuzzy, changeable, and ill-structured, presence of multiple persons and “roles,” presence of many performance criteria at the same time, difficulty to quantify, absence of consensus on the nature of the problem, and importance of different persons’ values. Some empirical studies show that, during the implementation of IT in an organization, the complexity of the process is generated not only by pure technical aspects, but also by many human and organizational factors (Smith 1991, Bellier-Michel 1998, Sainsaulieu 1998).

Through our case studies, we have found that an unforeseeable pathway predominates in GIT projects. As underlined by March (1991a), it seems that change is less often induced by problems than by solutions (opportunities). Nutt (1984:443) mentions that “managers don’t know what they want until they see what they can get.” The fact that managers often face ill-defined and complex problems — therefore difficult to structure (“ill-structured”) (Simon 1960, Bass 1983) — may explain the unforeseeable pathway of projects.

The development projects assessed seem to follow a perspective that is strictly technological (and not organizational). A possible and interesting explanation to this situation is the will to reduce uncertainty and risks. Minimizing risks induces projects that consist of “laying on” new technologies over old organizations without rethinking these organizations.

Our study highlighted a real distinction between what is unofficial and official during GIT projects. Like other researchers (Chrisman 1987, Harvey and Chrisman 1998, Tulloch et al. 1998), we think that characteristics inherent to occidental societies have an important influence on this situation. Therefore, concepts of “success image” and “rationality symbol” seem to incite organizations to give an official version of their project that is as favorable as possible (Marchand 1988). In the case where a new technology is acquired because it is a “symbol of modernity” or more simply to “do like others” (Danziger and Kraemer 1986, Campbell and Masser 1995, Roche et al. 1996) — which may be totally justified — we may understand that organization managers will not want to easily admit this kind of motivation.

Based on the model of Pitt and Watson (1994), our measurements of project success shows that it is somewhat “adaptable,” where organization members manipulate success criteria. Furthermore, our study underlines that the project pathway determines criteria that will be used for the measurement of success. Many authors point out that it is normal for criteria used to measure success differ from one person to another (technical aspects, management aspects...) (Smith 1991). Some persons evaluate the project pathway, while others evaluate project results (Watson and Buede 1987). The ambiguity related to objectives makes the concrete meaning of the terms “success” and “failure” ambiguous (March and Olsen 1991). This ambiguous context allows someone to use the most appropriate criteria to justify and publicize the success of the project.

Another important issue regarding the measurement of success is the fact that the evaluation of success not only varies from one person to another, but also may change with time. In this sense, one may assess some of the basic issues of budget and schedule right upon completion of the project, but other issues are more problematic and can take months to be correctly evaluated (e.g., the measurement of global organizational performances). Therefore, our research methodology did not take into account the moment of the measurement of success regarding the end of each project. This aspect should be more deeply considered in further research activities.

Finally, what to think of the fact that GIT projects are more often of an “unforeseeable technological” type (UT)? Is it a negative thing in itself? Like many citations have shown, we think that this situation is more or less normal in the municipal sector. In fact, our three case studies show that:

- The cities’ role is to manage their territory and citizen services, while the GITs support that role. Many cities have
limited budgets and investment decisions are often made based on emergencies; these are not generally at the geospatial information level. It is hard to invest heavily in a generalized way when you can only use a small piece of the budget pie.

- Major GIT projects require a sustained long-term effort, notably because of the time needed to structure and fill the geospatial databanks, which are the basis of geographical information systems. However, this long-term perspective is often dependent on political imperatives that require short-term results, which can be incompatible.

- GITs are known to the people working on the operational and tactical levels, and a lot less known among the strategists (especially the municipal elected officials), those that control the money. Therefore, it is not clear that it is possible and pertinent for these strategists to align GIT with municipal organizational strategies.

- The objectives sought after by one department or another within the same municipality are often very different (e.g., Town planning, Civil engineering, Informatics), and can sometimes be the cause of power struggles. It can then become very difficult to assemble these sometimes different interests around a coherent and federated GIT project, which favors the creation of multiple loosely coupled projects.

It is possible that the fact that GIT projects are more often of the “unforeseeable technological” type simply constitutes the reflection of a particular situation in the municipal sector. This does not in any way imply that the management in place is not rational and that they do not apply the classical rules of good, healthy management. It may simply be the time to revise our way of perceiving GIT projects in the urban sector and, consequently, rethink the usual methodological principles and the project management approaches.

Conclusion

The five sub-hypotheses H1 to H5 were supported by the cases assessed in this study. This allows us to conclude that our primary hypothesis is also supported. Additional activities should follow this one to bring a better understanding of social, organizational, and human factors that may influence GIT projects.7 A few other interesting research topics include: conducting such research in context other than municipal; conducting quantitative research instead of qualitative research (with the same theoretical framework); determining whether it is relevant and possible to create a typology of implementation contexts; developing a contingent approach for GIT project types; and verifying whether these research findings are also valid in the world of IT.

For practitioners and researchers, our recommendations are to encourage some adaptations of the current development prescriptive precepts to the observed reality. In fact, it would be important to revise system development methods and techniques to take into account the findings of the current study. For example, although we often hear people preaching that IT should be linked to strategic planning and that it should allow for the rethinking the organization, could we accept other ends such as simply “laying on” GIT over an old organization? One often preaches that IT should contribute, directly or not, to improve organizational performances! But why could not IT have “other” ends that are socially or economically less acceptable, but nevertheless valid? One often preaches that the implementation of GIT in an organization should be conducted in a structured, logical, and rational manner! Why? Is it more successful? This still must be demonstrated.

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Acknowledgments

The authors would like to thank the Natural Sciences and Engineering Research Council of Canada and the Fonds pour les Chercheurs et l’Aide à la Recherche of the Province of Quebec for their financial support with this study. Finally, we would like to thank those persons and cities who participated in this study and the reviewers of this article for their constructive comments.

References


**Endnotes**

1 This article is mainly based on the Ph.D. research of the first author (Caron 1997) under the advisorman of the second author, on subsequent research activities, and complementary discussions and practical experiences in the industry in different countries.

2 The initial impulse of the project in the City of Small is at the same time an *opportunity* and a *problem/crisis*. Nevertheless, this situation validates the postulate H2a), but indicates that both impulse types can coexist in the same project. We may conclude from this case that the opportunity is always present as a project impulse, but that does not exclude some problems to be solved.

3 Concerning the project in the City of Large, GIT has been considered an organizational abstract concept during a few years. Therefore, we may state that the solution type may change during a project, in accordance with the sub-hypothesis H3.

4 This sub-hypothesis is validated for the three projects, because at least one characteristic of the pathway is officially algorithmic and at least one characteristic of the perspective is officially organizational. In fact, we established the following analysis rule to validate H5: [H5a) or H5b)] and [H5c) or H5d) or H5e)]. To measure only a “tendency,” it would have been too demanding to have a sub-hypothesis requiring that the official version of a project should be different from the unofficial version for all five variables at the same time. For the City of Medium, postulates H5a) and H5b) concerning the pathway are validated and the postulate H5e) concerning the perspective is validated. Concerning these two projects, it has been officially admitted that the project impulse is partly an opportunity. However, GIT has been “sold” (exact term used by interviewed persons) as a solution to a problem regarding cartographic production in the organization.

5 Collected data do not allow us to *validate* this postulate for the cities of Small and Medium, nor does it allow us to *invalidate* it.

6 It is worthwhile to mention that some researchers study the inverse relationship, i.e., the influence of GIT on organizations, society, and culture (Chrisman 1997, Tulloch et al. 1998).
An Object-Oriented Approach for Modeling Urban Land-Use Changes

Ale Raza and Wolfgang Kainz

Abstract: Where to get data for urban planning and management is one issue, but how to manage these data is still a challenging task. This article focuses on the technical issue of managing data. The core data for urban planning are land-use data, which, if updated frequently, raises the issue of structuring, storing, querying, and displaying the data. Modeling, querying, and displaying changes in land-use data have been a challenge for many designers and urban planners. We propose a novel approach to model land-use changes based on object-oriented concepts and a mathematical theory of cell complexes. For object-oriented concepts, the Unified Modeling Language is used. Each land use is considered as an object. This object is an instance of the SpatioTemporalAttributeClass, which is the aggregation of SpatialClass, TemporalClass, and AttributeClass. The AttributeClass is a metaclass of LanduseClass and EvidenceClass. This article focuses on the AttributeClass (land use). The two types of land uses considered here are detailed and general land use. Detailed land use is recorded at the parcel level, while general land use does not require parcel information. Parcel-level land use is indispensable for many operational and strategic planning exercises. An object-relational approach is employed to achieve the model at the logical level. This approach may help alleviate the accessibility problem of land-use data in an urban environment. Through Structured Query Language, it is demonstrated how the spatiotemporal queries can be made.

Introduction

The importance of land-use data in urban planning and management has been recognized by many researchers and planners (Douglas 1994, van Helden 1994, Kaiser et al. 1995). Conventionally, land-use data are collected through field surveys and are administered at the parcel or plot level. Attempts have been made to update land-use data through remote sensing, but with little success in urban areas at the parcel level (Martin et al. 1989). Normally, remote sensing is useful for general land use. Another approach to update urban land-use data at the parcel level is through an operational planning process, such as building permits (Brail 1989, de Bruijn 1990). Regardless of how and from where the time series land-use data are collected for urban planning and management, the issue of data management remains unresolved. Without going into details of the sources of data for updating, this article focuses on updating land-use data through field survey at the parcel level (i.e., detailed land-use change). Detailed land use is registered at the parcel level; therefore, spatiotemporal aspects of parcel objects are also discussed. Parcel-level land use is indispensable for many operational and strategic planning exercises (e.g., utilities, health, education, and environmental impact assessment). The majority of urban functions are dependent on these data (van Helden 1994).

In this article, we focus on management issues, i.e., issues that pertain to the structuring, storing, querying, and displaying of land-use data. Land-use change is a complex process. An object-oriented (OO) approach has been employed to update land use in which each land-use category is considered as an object. The model for land-use change is applied to earlier work by the authors on the unified cell tuple-based spatiotemporal data model (Raza and Kainz 1999, 2000). This model and types of spatiotemporal queries are briefly introduced in the following section. This is followed by modeling parcel and land-use change, logical schema, and examples of scanning land-use history. Differences between this model and other models, such as the space-time composite or simplicial complex approach introduced by Worboys (1994), are also discussed. The article concludes by pointing out some of the limitations and advantages of the adopted approach. Time series land-use data of Karachi are used for prototyping.

Cell Tuple-Based Spatiotemporal Data Model

The conceptual schema for the unified cell tuple-based spatiotemporal data model (CTSTDM) is presented using Unified Modeling Language (UML). UML is a conceptual schema language for designing the model. A description of UML can be found online at http://www.uml.org. The parcel-land-use object is an instance of the SpatioTemporalAttributeClass, which is the aggregation of SpatialClass, TemporalClass, and AttributeClass (three components of reality). The time is fused to SpatialClass and AttributeClass. The SpatialClass and TemporalClass are aggregated to form the SpatioTemporalClass, and AttributeClass and TemporalClass are aggregated to form an AttributeTemporalClass. A change in land-use object causes either change in the objects of SpatioTemporalClass, AttributeTemporalClass, or both classes, simultaneously.

The conceptual schema for CTSTDM is presented in Figure 1. SpatialClass has one PointClass (subclass). A SpatioTemporalClass is a superclass of three classes (i.e., ZeroTCellClass, OneTCellClass, and TwoTCellClass). The objects of these classes are ZeroTCell (ZTC), OneTCell (OTC), and TwoTCell (TTC), respectively. The object of SpatioTemporalClass can be defined as an (open) n-tcell in a to-
A ZTC is a temporal node, an OTC is temporal arc, and a TTC is a temporal polygon/area. ZTC, OTC, and TTC are members of the temporal cell complex (TCC). Three dimensions of time are incorporated as three specialized classes of LinearTimeClass (i.e., DataBaseTimeClass [DBT], WorldTimeClass [WT], and SystemTimeClass [ST]). ST reflects the time at which spatial changes occur in the system; it is explicitly associated with the spatial object and is independent of DBT and WT. It is different from DBT in the sense that the latter represents the updating of the spatial temporal attribute object in the database, while the former indicates the updating of the spatial object. In a LinearTimeClass, two data types are defined: PointTime [0-T] and IntervalTime [1-T].

Accessing spatiotemporal data demands temporal (e.g., when, now, before, after, and meet) and spatial (e.g., left, right, inside, and meet) operators. Theoretical work on temporal relational databases by Allen (1983, 1984), Gadia and Nair (1993), and others is not fully implemented in commercial databases such as Oracle, DB2, or Informix. None of the commercial GIS soft-

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Figure 1: Conceptual Schema for Cell Tuple-Based Spatiotemporal Data Model.
ware products store all of the spatial data (topological) in a relational form.

Spatial operators in Oracle are dedicated to the spatial data model called Spatial Cartridge, which is a nontopological model. These functions may not be utilized for a cell tuple-based spatiotemporal data model. Without going into details of these functions, we demonstrate the retrieval of spatiotemporal data through "entry-level SQL92," which is implemented by Oracle. A conforming Structured Query Language (SQL) implementation must support at least entry-level SQL (Oracle8 1998). Langran (1992) indicated four types of queries in spatiotemporal databases.

- Simple temporal query: What was the state of object(s) at time \( t_i \)? In this type of query, point time is given.
- Temporal range query: What was the state of the object(s) during the time interval \( t_i \) to \( t_j \)? In this type of query, interval \( 1-T' [t_i, t_j] \) time is given.
- Simple spatiotemporal query: What was the state of the objects at time \( t_i \)?
- Spatiotemporal range query: What was the state of the objects during the time interval \( t_i \) to \( t_j \).

The last two types of queries need windows to define space. These queries are not discussed in this article.

**Simple Temporal Query**
The parcel-land-use object is embedded by interval time; the point time \( t_i \) (0-T) could relate with 1-T in various ways. Consider the case in which \( t_i \) is covered by 1-T. In such cases, three possibilities could exist: \( t_i \) is in between the time interval (1-T), \( t_i \) is a lower bound of 1-T, or \( t_i \) is an upper bound of 1-T (Figure 2).

**Temporal Range Query**
In this type of query, the given time interval 1-T’ may relate to 1-T in several ways. Allen (1983, 1984) compares these two intervals. Various spatiotemporal queries can be made based on these temporal relations. Here we consider four types of relations; i.e., when 1-T’ is within 1-T (Figure 3):

- 1-T left covers 1-T’,
- 1-T covers 1-T’,
- 1-T right covers 1-T’, and
- 1-T equals 1-T’.

The way to achieve simple temporal and temporal range queries is demonstrated in the section on scanning land-use history.

**Parcel-Based Land-Use Change**
While observing land-use changes at the parcel level, Huxhold (1991) indicated the following potential sources of changes:

- Buildings are built and demolished
- Existing buildings are renovated (conversion of house into commercial enterprise without demolishing it and rebuilding)
- Boundaries of parcel change
- A new subdivision is created
- Resize or relocation of public right-of-way
- A street is vacated
- Property outside the jurisdiction is annexed
- Errors are detected and corrected

Basically, the two types of changes are attribute and spatial changes. Some changes are attribute changes (e.g., 1, 2, and 6) and others are spatial changes (e.g., 3, 4, 5, and 7); eight changes could be either one or both. Although Huxhold used these changes in the building context, they are also applicable to the parcel or land-use object.

Four key issues are the cores of OO modeling for spatiotemporal data (parcel or land use): the concept of change, object identity (ID), properties of object, and operations of object. Does any change in an object create a new object? The answer is yes and no, depending on application and design. The concepts of object and version are important at the designing stage. By introducing the versions, object creations can be restricted to the changes in the core concept of the objects. Objects are the concepts that are semantically different from the other objects.
ever, versions are semantically equal to objects; they are merely another state of an object. If we consider that any change in an object triggers an object, then a database will be populated with a large number of objects instead of versions. In the following session, we first define the properties of parcel and land-use objects and the concept of change in each object; this is followed by modeling of the spatiotemporal changes. The properties (spatiotemporal and attribute-temporal) can be categorized into two types: essential (core concept) and non-essential (Raza et al. 1998). A change in essential property or core concept triggers a new object, while a change in non-essential properties creates a new version. Based on these notions, a unique approach is adopted in this article. Parcel and land use together constitute an object of the ParcelLanduseClass. The essential and non-essential properties of these objects are defined. These properties provide the basis to identify the objects and their versions.

**Parcel Class**

Parcel itself is a spatial-temporal attribute object that has spatial, temporal, and attribute components. Spatial-temporal extent is defined by a two-dimensional spatiotemporal object, which is the set of TTC objects. Attribute-temporal is described by its category, area, perimeter, address, owner, and so forth. In the OO approach, each object has a unique identification, certain properties (attributes in UML), and operations. Fundamental operations such as create, delete, kill, and destroy are not discussed in this article. These operations are associated with the SpatioTemporalClass and are discussed in Raza and Kainz (2000). The essential properties of the parcel are defined by its address that, when changed, creates a new parcel object. The non-essential properties are described by area, shape, perimeter, planning zones, TTC objects, and so forth.

Attributes (or data members or properties) of a ParcelClass are shown in Figure 4. These properties are defined in the section on scanning land-use history. A parcel object resembles a cadastral object, commonly known as a "plot" in Pakistan. "A plot means any size of land capable of being described with such definiteness that its locations and boundaries may be established which is designated by its owner or developer as land to be used or developed as a unit, or which has been used or developed as a unit" (Town Planning Regulations 1979, p. 5). The unique combination of land-use category, parcel number, block number, and scheme number determines the parcel identification (ID) (essential property) of the parcel. However, for modeling and implementation purposes, a unique combination of land-use category and parcel number (shown as bold in Figure 4) is considered an address (i.e., parcel object ID). Therefore, a parcel is defined by a unique combination (ID) of category and number (e.g., A-1, ST-10, and FL-20). Categories indicate the type of land use; for example, A is residential, ST is amenities, and FL is apartment. The same parcel ID is used by many urban applications; for example, a land registration department uses this for recording ownership, building control uses this for issuing building permits, and a planning department uses this for planning purposes and for registering the land use.

Considering parcel as an object, a single parcel can appear, disappear, transform, or change size, position, and shape (Figure 5). In the case of two or more parcels, parcels can be subdivided or amalgamated (Figure 5).

Parcels A-1, A-2, and A-3 are amalgamated to form parcel A-1 or A-4. Parcel A-1 is subdivided into either A-1 and A-2 or A-3 and A-2. Therefore, parcels also have mutations called versions. A version is a state of the same object triggered by a non-essential change. We consider a parcel to be the same as long as its category and parcel number are the same (i.e., address of the parcel). Therefore, the cases listed (except transformation) in Figure 5 are the illustration of mutation or version of parcel A-1, where a change in size, shape, position and so forth triggers a new version of the same parcel. A change in a category and/or parcel number creates a new parcel (e.g., transformation [A-1 to A-2]). In the case of amalgamation, the amalgamated parcel can be a new version or a new object (e.g., A-1 or A-4, respectively).

Similarly, in the case of a subdivision, a subdivided parcel can be a new version or new object (e.g., A-1 or A-3, respectively). In this article, we focus on modeling detailed land-use change in which a parcel object is one of the fundamental components.

Different planning agencies or counties may have a different definition of parcel and the concept of change in parcel. Figure 5 is based on the concept of parcel and its change being practiced in Karachi. These parcel changes can be explained by the example shown in Figure 6 in chronological order.

Figure 6 illustrates the parcel, land use, land-use objects, and temporal cell complex. To simplify the illustration, they are plotted on single-time dimension (database time). However, all three
(DBT, WT, and ST) are implemented. From T1 to T10, various changes trigger the birth and/or death of new objects or versions (depending on the type of change). C-1’ and Ind’ represent the new state (version) of the parcel C-1 and land-use Ind, respectively.

The first column shows the parcels and their versions. The parcel categories representing the land use of the parcel are R (residential), A (agricultural), P (park or recreational), C (commercial), and I (industrial). These categories indicate the planned or designated land use for each parcel as defined by urban planning agencies. The land-use survey determines the actual land use of these parcels. The second column represents the observed land use corresponding to the parcels in the first column. Any difference between planned and observed or surveyed land use shows that a parcel is either being misused or vacant. In the third column, the land uses of the second column to objects and versions are mapped. The fourth and fifth columns are the spatial or geometric representation of the parcels (i.e., TTC [p]). Using an interval time stamp, all objects are represented as active (TFrom, NULL) or inactive (TFrom, TUntil). In this example, we are dealing with three objects (parcel, land use, and TTC objects). Modeling of parcel and land-use objects is discussed in this article. However, greater emphasis is on modeling land-use changes. The modeling and operations of TTC objects can be found in Raza and Kainz (1999, 2000).

**Parcel Object**
- At time T1, there were two parcels (R-1 and A-1).
- At time T2, parcel A-1 changed to P-1 (park or recreational).
- At time T4, parcel P-1 subdivided into two parts: C-1 and I-1.
- At time T6, parcel C-1 expanded in size, parcel R-1 ceases to exist, and a new parcel I-2 came into existence.
- At time T8, parcels I-2, C-1’, and I-1 merged (amalgamated) to form parcel I-1’.
- At time T10, parcel I-1’ changed (transformed) to R-2.

**Land-Use Object**
The land-use object has a number of properties. The essential property of this object is land use (the core concept). The non-essential properties are parcel, area, perimeter, and so forth. The object land use is the same as long as its land use is unchanged; any other change, such as parcel change, merely creates a new version (Raza et al. 1998). Land uses are described as residential (Res), agricultural (Agr), recreational (Rec), commercial (Com), or industrial (Ind). At time T1, there were two land uses: Res(O1) and Agr(O2); these two land uses were associated with parcel R-1 and A-1. At time T3, Agr(O2) was changed to Rec(O3), and at time T5, Rec(O3) splits into Com(O5) and Ind(O4). At T7, Ind(O4) remained unchanged, Com(O5) expanded in size, and became O'5), and Res(O1) converted into Ind(O6). At T9, all Ind(O5), Com(O'5), and Ind(O6) transformed to Ind(O'4). Finally, at T10, all Ind(O'4) converted to Res(O6).

**Parcel, Land-Use, and TTC Objects**
- At time T1, two parcels (R-1 and A-1) and two corresponding land-use objects (O1 (Res) and O2 (Agr)) were entered into a database. These two parcels were represented by two TTCs: p1 and p2.
- At time T2, parcel A-1 changed to P-1. No other change in land use and geometry is recorded.

*Figure 5: Spatiotemporal Characteristics of a Parcel Object.*
At time T3, a change in land use was observed; O2(Agr) was replaced by O3(Rec). There was no geometric change.

At time T4, two new TTCs, p3 and p4, were spawned as a result of the subdivision of parcel P-1 to C-1 and I-1. At the same time, the TTC p2 became inactive.

At time T5, a change was observed in land use and O3(Rec) was replaced by O4(Ind) and O5(Com).

At time T6, parcel C-1 has changed in size and become C-1', R-1 has disappeared, and I-2 has appeared. As a result of these changes, two new TTCs (p5 and p6) were created and became inactive.

At time T7, O4(Com) expanded in size to become O'(Com'), O1(Res) ceases to exist, and a new object O6(Ind) has appeared.

At time T8, parcels I-2, C-1', and I-1 merged to form parcel I-1'.

At time T9, land-use objects O4(Ind), O'(Com), and O5(Ind) merged to form O'(Ind).

At time T10, parcel I-1' and object O'(Ind) transformed to parcel R-2 and object O7(Res), respectively.

Modeling Parcel Changes
The parcel object and its various versions are shown in Figure 7. The life of parcel object R-1 is from T1 to T4; the life of parcel object I-1 is from T4 to T9. This object has two versions: I-1,1 and I-1,2. The life of these versions ranges from T4 to T7 and from T8 to T9, respectively. Similarly, the life span of each parcel version is indicated in Figure 7.

Each parcel version is defined by a set of TTCs (polygons), that is, R-1,1 = {p1}, A-1,1 = {p2}, P-1,1 = {p2}, C-1,1 = {p3}, I-1,1 = {p4}, I-2,1 = {p5}, C-1,2 = {p6, p3}, I-1,2 = {p3, p4, p5, p6}, and R-2,1 = {p3, p4, p5, p6}. The parcel R-1 is still pointing...
to TTC p1. This approach is different from other approaches. For example, the space-time composite or approach adopted by Worboys (1994). In the space-time composite, parcel R-1 would reference TTCs p5 and p6 and TTC p1 would disappear. Keeping the TTC in the CTSTDM in this fashion preserves the spatiotemporal topology of TTC. This would help in formulating the historical spatiotemporal queries. For example, at time T10, one can ask what the neighbor of parcel R-1,1 at time T2 was.

The approach proposed by Worboys is based on the concept of simplicial complexes, which is one of the fundamental approaches for any generic temporal geographic information system (GIS). Although the simplicial complexes are the simplest forms of spaces and their manipulation is comparatively easy, their adoption results in voluminous data. This may increase the system response time. It is not clear in Worboys’ approach how the changing topology would be stored. None of the commercial GIS software packages provides the data model needed to store spatiotemporal data in a manner (such as temporal cell complex) in which changing topology can be retained (Figure 6 and Figure 7).

Most of the commercial systems are closed systems that cannot be extended or modified (Mioc et al. 1998). Wachowicz (1999) shared the same experience and reported the limitations and difficulties of adopting Smallworld GIS while implementing the spatiotemporal public boundaries of Great Britain. For example, ArcGIS 8 and Smallworld provide the version databases. Version databases are the coarse form of spatiotemporal databases. ArcGIS 8 supports two types of spatial data models: geodatabase and file-based models. The geodatabase model is implemented using standard relational database technology. Only this model supports the versions of the database. The geodatabase model employs the object-relational approach and provides a good graphical interface to define the properties of objects. The file-based model includes a
coverage and shapefile. Only coverage data models support the topology, which is based on the notion of planar topology. This model provides the basis to implement the space-time composite model. The coverage approach has been implemented by Raza et al. (1998) for modeling general land-use change. Many researchers have reported the limitations of the space-time composite model, which is based on the coverage model. The major limitation is that it loses all spatial historical data.

The parcel-parent relationship is indicated by parcel/parent (e.g., P-1/A-1 represents that the parent of parcel P-1 is A-1). The details of parcel-parent, parcel-version, and version-parent relationships are demonstrated in Figure 8. Each parcel object has a single parent (e.g., the parent of parcel I-2 is R-1, and the parent of C-1 and I-1 is P-1 [Figure 8a]). However, a parcel object can have multiple parents. Each parcel object may have one or many versions; for example, parcel R-1 (R-1,1) has one version and parcels C-1 (C-1,1 and C-1,2) and I-1 (I-1,1 and I-1,2) have two versions (Figure 8b).

The finer decomposition can be achieved by establishing the parcel version-parent relationship (Figure 8c). Each parcel version may have one or many parents (e.g., the parent of parcel version I-2,1 is R-1,1 [single parent], but the parents of parcel version C-1,2 are C-1,1 and R-1,1 [multiple parents]). To simplify the model, a multiple relationship is not incorporated; only a single-parent relationship of object and version is considered. In the case where a parcel object or version has multiple parents, the oldest or senior parent becomes the parent of the parcel object or version. The same concept is used for all objects and versions in CTSTDM.

Modeling Land-Use Changes

During time T1 to T10, seven land-use objects (O1, O2, ..., O7) have been spawned. For example, at T3, object O3 is generated from O2 because the land use is changed, while at T7, version O5,2 came into existence due to the change in parcel C-1,1 to C-1,2. The land-use object has versions, where the spatial extent of the version is described by a parcel version. The land-use object O1 has two versions: O1,1 and O1,2 (Figure 9). The O1,1 version is defined by the parcel version I-1,1 and the O1,2 version by the parcel version I-1,1,2. Similarly, other land-use objects are defined by parcel objects or versions, and parcel objects or versions are defined by TTCs (see Figure 7). Each land-use object and version (cube) represents the time, land use, and parcel object (Figure 9).

The land-use object O1(Res) is defined by a single parcel R-1, while land-use object O4(Ind) is defined by two parcels (I-1 and I-1'). The conceptual schema presented in Figure 1 is a generic model for CTSTDM. This can be extended to a parcel-level (detailed) land-use change by incorporating the parcel class and the land-use class (Figure 10). The AttributeClass is a metaclass of LanduseClass and EvidenceClass. The EvidenceTemporalClass is the aggregation of EvidenceClass and TemporalClass (WorldTime and DataBaseTime). The EvidenceTemporalClass has two subclasses: BuildingPermitClass and FieldSurveyClass. In this article, FieldSurveyClass is considered evidence for the land-use change. The SpatioTemporalAttributeClass is the metaclass of ParcelClass and ParcelLanduseClass. Each parcel is defined by a set of TTCs, while a TTC may have zero or many parcels. Each parcel has one or many parcel versions. A parcel parent may have one or many children. The ParcelLandUseClass is the aggregation of LandUseClass, FieldSurveyClass, and ParcelClass. The data members of each class are shown in Figure 10.

Let T_From be the lower bound and T_Until be the upper bound of 1-T. The temporal consistency constraints pertaining to the ParcelClass and ParcelLanduseClass can be
defined as follows:

- \( T_{\text{From}} \) of any object (ParcelLanduse or parcel) must be less than or equal to \( T_{\text{Until}} \).
- \( T_{\text{From}} \) of a ParcelLanduse object must be greater than or equal to \( T_{\text{From}} \) of parcel object.

**Logical Model**

The logical schema for the conceptual schema presented in Figure 1 is provided in Raza and Kainz (1999). The object-relational approach was utilized to achieve normalized relations by employing the dependency-check technique. The same approach is used in this article to model the parcel and land-use changes by incorporating the AttributeClass, its subclasses, and associated classes. Therefore, details for deriving the normalized relations are not included here. Dependency statements associated with LandUseClass, FieldSurveyClass (a subclass of EvidenceClass), ParcelClass, and ParcelLandUseClass are defined, followed by normalized relations and a relational diagram.

**Dependency statements:**

1. The object of LanduseClass is denoted by LanduseID. ClassLevel, Description (land use), and Remarks define the data members of this class.
2. The object of FieldSurveyClass is represented by

---

**Figure 9:** Decomposition of Land-Use Objects into Versions and Parcels.
Figure 10: Conceptual Schema for Parcel-Level Land-Use Change.
Figure 11: Relational Structure for the Cell Tuple-Based Spatiotemporal Data Model for Detailed Land-Use Change.

Figure 12: Residential in 1990.

Figure 13: Residential in 1995.
FieldSurveyID. Each FieldSurvey consists of SheetNumber, ConductedBy, CheckedBy, SurveyDate1-T, and DBT1-T.
3. The object of ParcelClass is represented by ParcelID and ParcelVersionID. Each Parcel object consists of a set of TTC, DBT1-T, WT1-T, and ParentID.
4. The object of ParcelLanduseClass is represented by ParcelLUID. Each ParcelLUID consists of LanduseID, ParcelID, BuildingPermitID, DBT1-T, VersionID, and ParentID.

Due to normalization, these four classes emerged as six relations (tables) in the relational database.

**Relations:**

R1: Landuse (LanduseID, Description, Classlevel, Remarks).
R2: FieldSurvey (FieldSurveyID, SheetNo, NoOfStories, ConductedBy, CheckedBy, SurveyDateFrom, SurveyDateUntil, DBT_From, DBT_Until, Remarks).
R3: ParcelVersion (ParcelID, ParcelVersionID, BlockNo, SchemeNo, DigitizedBy, CheckBy, Parent, WT_From, WT_Until, DBT_From, DBT_Until).
R4: ParcelLanduseFS (ParcelLUID, LanduseID, WT_From, WT_Until, DBT_From, DBT_Until, Parent).
R4.1: ParcelLanduseVerFS (ParcelLUID, ParcelLUVerID, FieldSurveyID, ParcelID, VersionID, WT_From, WT_Until, DBT_From, DBT_Until, PLUParent, PLUVersion).

The single underline is the primary key and the bold underline is the foreign key. The above relations are mapped into the relational diagram (Figure 11). The left side (six tables) shows the above relations, while the right side (seven tables) is the generic part of the model (Figure 11).
Scanning Land-Use History

Karachi is the largest city in Pakistan and has an annual population growth rate of about 5%. The latest population Census shows a rise in the population of Karachi from 5.4 million to 9.2 million in 1998 (Dawn 1998). The City of Karachi consists of various housing schemes. Approximately 500,000 parcels have been planned by the Karachi Development Authority in these schemes (KDP 1991). Each housing scheme has a number of blocks, and each block has a number of parcels. For urban planning and design purpose, each housing scheme is divided into either Analysis Zones (ANZs) or Master Planning Zones (MPZs). A total of 58 ANZs evolved from the 241 MPZs. One block of housing scheme number 16 is selected to demonstrate the applicability of the model. The time series land use of 1972 (assumed vacant), 1987, 1993, and 1998 has been used for prototyping.

Land-use records from 1970 to 1998 have been collected, digitized, and stored in the relational form. Land-use data of 1987, 1993, and 1998 were available in AutoCAD format. This was imported to ARC/INFO to finally store it into Oracle. Oracle (8.01) has been used to store the data, and the OO programming language Visual C++ (6.0) has been used for implementation of operators. Like any other relational database management

<table>
<thead>
<tr>
<th>Table 1. History of parcel D-139.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARCELID</td>
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<tr>
<td>D-139</td>
</tr>
<tr>
<td>D-139</td>
</tr>
<tr>
<td>D-139</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2. List of parcel D-139 with spatial information.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARCELID</td>
</tr>
<tr>
<td>D-139</td>
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<td>D-139</td>
</tr>
<tr>
<td>D-139</td>
</tr>
</tbody>
</table>
system (RDBMS), Oracle lacks recursive functions, and certain consistency checks could not be performed. Therefore, these consistency checks are implemented in Visual C++.

As discussed earlier, Langran (1992) described four types of queries. Apart from these four types of queries, a temporal GIS should be able to scan the history of any object, such as how the object has evolved. The knowledge of such a type of evolution can be captured through the object-parent relationship; for example, how an object has evolved or what the parent of the object was. Following are examples of this type of query followed by simple temporal and temporal range queries. The SQL statement of each query is presented in the Appendix. Each of the following queries needs different logical steps to retrieve the data from the data model. Only Query 2 explains these steps; the rest of the queries are explained without these logical steps.

**Scanning History**

**Query 1: How has parcel D-139 evolved? Or show the history of parcel D-139.**

In this case, only the parcelversion table is needed to retrieve all of the versions of parcel D-139. No time or version filter is required. The data show that parcel D-139 has three versions (Table 1). Version 1 was valid from January 1, 1972 to April 2, 1989, version 2 from April 2, 1989 to November 12, 1994, and version 3 from November 12, 1994 to the present. Furthermore, the data indicate the ParcelParent and ParcelVersionParent.

To display this parcel and its version, spatial information (point, ZTC, OTC, and TTC) is also needed. This can be achieved by modifying the SQL statement as shown in Query 1.1. The data in tabular form of parcel D-139 and its versions are shown in Table 2. In this case, all tables (including twocell, twonetcell, onecell, onepointcell, and point) are used to retrieve information that defines the TTC associated with parcel D-139. To simplify the SQL statements, in the rest of the query examples, the SQL statement to retrieve spatial information is omitted because it is the same in all cases.

**Query 2: In 1993, what was the previous land use of parcel C-38?**

Logically, this involves the following steps to retrieve data from the data model. This query needs only two tables, parcellufs (parcel-land-use object) and parcelluverfs (parcel-land-use version), and three filters for parcel object, time, and parent. First, the parent land-use category (say, X land-use object) of parcel C-38 is pulled from the parcelluverfs table. The land-use category (17) of this land-use-parcel object (80 in this case) is retrieved with a time filter (i.e., Wt_From up to 1993 and Wt_Until after 1993 or Wt_Until is NULL). In 1993, the previous land use of parcel C-38 was 17 (i.e., utilities) (Table 3).

**Query 3: At present, what is the land-use history of parcel ST-0?**

In 1998, the land use of parcel ST-0 was 13 (government office); in 1993, it was 17 (utilities); and in 1972, it was 26 (i.e., vacant) (Table 4).

**Simple Temporal Query**

**Query 4: What was the state of residential land use in 1990?**

This query will retrieve all the objects valid at time \( t \). This \( t \) could be any point between time interval \( 1-T [t_{0},t_{n}] \).
Query 5: What was the state of residential land use in 1995?
The output of Query 4 is shown in Table 5 (Figure 12) and the output of Query 5 is shown in Table 6 (Figure 13). The land use in 1998 is shown in Table 7 (Figure 14).

Query 6: Show land uses that turned to residential in 1998.
This type of query will retrieve all the objects, where \( t_i \) is equal to the lower bound of 1-T. Queries 4 and 5 provide the state of residential land use in 1990 and 1995, respectively, while Query 6 (Figure 16) renders the changes that occurred in 1998.

Graphic display is one of the fundamental requirements of any GIS. The three-dimensional phenomenon (space, time, and attribute) is depicted in two dimensions, where time is collapsed to zero (Figure 12 to Figure 15). More work is needed to display these results in three dimensions. However, these displays still provide the impression of how residential land use has grown from 1990 to 1998 (Figure 12 to Figure 14) and where the change in residential land use has occurred (Figure 15). This display would facilitate the urban planners to assess the direction of growth, timely intervention, to encourage or discourage the growth, validate the growth according to plans, and so forth.

Temporal Range Query
Various queries could be formulated based on four types of relations (as mentioned earlier); for example, to understand all land uses from 1972 to 1980, get all land uses from 1975 to 1985, get all land uses from 1985 to 1987, or get all land uses during period 1972 to 1987.

Outputs of this query are shown in Table 8 and Figure 16.

Query 8: Shows residential land uses valid from 1994 until present.
The output is shown in Table 9 and Figure 17.

The CTSTDM is a generic model. The queries noted above are just a few examples of parcel and land-use change applications. Many additional queries could be formulated (e.g., to check the neighbors or history of neighbors of any land-use or parcel object). In this type of query, the cell-tuple structure could be used to retrieve the spatiotemporal topology. This query is not demonstrated in this article. It is demonstrated that one can formulate simple temporal and temporal range queries (e.g., land use in 1995 [Figure 14] or land use from 1990 to 1992 [Figure 17]).

Conclusions
A novel approach is presented to model land-use and parcel changes. This approach is based on OO concepts and can be

### Table 6. Residential land use in 1995.

<table>
<thead>
<tr>
<th>PARCELLUID</th>
<th>LANDUSEID</th>
<th>PARCELUVERID</th>
<th>PARCELID</th>
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<td>1</td>
<td>D-12/1</td>
<td>01-JUN-93</td>
<td></td>
</tr>
</tbody>
</table>

180 rows selected.

### Table 7. Change to residential land use in 1998.

<table>
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<tr>
<th>PARCELLUID</th>
<th>LANDUSEID</th>
<th>ParLUVer</th>
<th>PARCELID</th>
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<th>WT_UNTIL</th>
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<td>78</td>
<td>1</td>
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<td>C-1</td>
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<td>1</td>
<td>7</td>
<td>C-9</td>
<td>01-JUN-93</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>96</td>
<td>1</td>
<td>7</td>
<td>C-28</td>
<td>01-JUN-8</td>
<td>14</td>
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<td>238</td>
<td>1</td>
<td>3</td>
<td>D-99/3</td>
<td>01-OCT-98</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>239</td>
<td>1</td>
<td>1</td>
<td>F-39</td>
<td>01-OCT-98</td>
<td>49</td>
<td></td>
</tr>
<tr>
<td>239</td>
<td>1</td>
<td>2</td>
<td>F-39/1</td>
<td>01-OCT-98</td>
<td>49</td>
<td></td>
</tr>
<tr>
<td>241</td>
<td>1</td>
<td>1</td>
<td>F-49</td>
<td>01-OCT-98</td>
<td>51</td>
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<td>1</td>
<td>2</td>
<td>F-49/1</td>
<td>01-OCT-98</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td>241</td>
<td>1</td>
<td>3</td>
<td>F-49/2</td>
<td>01-OCT-98</td>
<td>51</td>
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<tr>
<td>241</td>
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<td>4</td>
<td>F-49/3</td>
<td>01-OCT-98</td>
<td>51</td>
<td></td>
</tr>
</tbody>
</table>

94 rows selected.
extended to applications similar to these applications, Census tracts, cadastral/land registration, building permits, land cover, and so forth. It is shown that, at any time, not only can the state of an object be determined, but the change can also be discerned. However, in the absence of temporal SQL, careful formulation of SQL statements is suggested. At the logical level, the CTSTDM is realized in a relational fashion, where object-relational technique is employed. OO databases do not support a standard query language such as SQL. Most of the OO databases employ an ad hoc query approach. This drawback made the OO databases a weak candidate for implementation of CTSTDM. The advantage of the object-relational technique is threefold. First, any commercial RDBMS can be utilized. Second, the powerful functionality of RDBMS, such as unified data management, data recovery (rollback), data backup, consistency constraints, multiuser access, and so forth, can be advantageous. Third, the power of SQL can be exploited to retrieve the spatiotemporal data. However, the SQL implemented in commercial RDBMSs does not include spatial and temporal operators. Further, SQL is not a complete language. The format of spatiotemporal data stored in relational form does not conform to the format needed for graphic display. It is difficult in SQL to achieve the desired format. Therefore, some interface is needed to make the data available for graphic display. The approach applied here is useful for designing integrated urban information systems because parcels and land uses are a fundamental requirement for many urban applications.

Authors

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Acknowledgments

The authors wish to thank Professor Lew Hopkins and Professor Harlan Onsrud for the critical comments and suggestions they provided to improve this article. The authors would also like to thank Mr. Scott Grams for advice to enhance the graphics.

References


Appendix

SQL Statements

Query 1:
Select parcelversion.parcelid, parcelversion.versionid, parcelversion.WT_From, parcelversion.WT_Until, parcelversion.parcelparent, parcelversion.versionparent
From parcelversion
Where parcelversion.parcelid = 'D-139'
Order by parcelversion.parcelid

Query 1.1:
Select parcelversion.parcelid, parcelversion.versionid, parcelversion.WT_From, parcelversion.WT_Until, parcelversion.parcelparent, parcelversion.versionparent
From parcelversion
Where parcelversion.parcelid = 'D-139'
Order by parcelversion.parcelid

Query 2:
Select Parcellufs.parcelluid, Parcellufs.landuseid, parcelluverfs.parcelluverid, parcelluverfs.parcelid, Parcellufs.wt_from, Parcellufs.parent
From Parcellufs, parcelluverfs
Where parcelluverfs.parcelid = 'C-38' and Parcellufs.wt_from <= to_date('1993', 'yyyy') and (Parcellufs.wt_until >= to_date('1993', 'yyyy') or Parcellufs.wt_until is null) and parcelluverfs.pluparent = parcellufs.parcelluid
Order by Parcellufs.parcelluid, Parcellufs.wt_from

Query 3:
Select Parcellufs.parcelluid, Parcellufs.landuseid, Parcellufs.wt_from, Parcellufs.wt_until, Parcellufs.parent
From Parcellufs
Where Parcellufs.landuseid = '1' and Parcellufs.wt_from <= to_date('1990', 'yyyy') and (Parcellufs.wt_until >= to_date('1990', 'yyyy') or Parcellufs.wt_until is null) and parcellufs.parcelluid = parcelluverfs.parcelluid
Order by Parcellufs.parcelluid, Parcellufs.wt_from

Query 4:
Select Parcellufs.parcelluid, Parcellufs.landuseid, parcelluverfs.parcelluverid, parcelluverfs.parcelid, Parcellufs.wt_from, Parcellufs.wt_until
From Parcellufs, parcelluverfs
Where Parcellufs.landuseid = '1' and Parcellufs.wt_from <= to_date('1995', 'yyyy') and (Parcellufs.wt_until >= to_date('1995', 'yyyy') or Parcellufs.wt_until is null) and parcellufs.parcelluid = parcelluverfs.parcelluid
Order by Parcellufs.parcelluid, Parcellufs.wt_from

Query 5:
Select Parcellufs.parcelluid, Parcellufs.landuseid, parcelluverfs.parcelluverid, parcelluverfs.parcelid, Parcellufs.wt_from, Parcellufs.wt_until
From Parcellufs, parcelluverfs
Where Parcellufs.landuseid = '1' and Parcellufs.wt_from <= to_date('1995', 'yyyy') and (Parcellufs.wt_until >= to_date('1995', 'yyyy') or Parcellufs.wt_until is null) and parcellufs.parcelluid = parcelluverfs.parcelluid
Order by Parcellufs.parcelluid, Parcellufs.wt_from
Query 6:
Select Parcellufs.parcelluid, Parcellufs.landuseid, parcelluverfs.parcelluverid, parcelluverfs.parcelid, Parcellufs.wt_from, Parcellufs.wt_until, Parcellufs.parent
From Parcellufs, parcelluverfs
Where parcellufs.landuseid = '1' and round(Parcelluverfs.wt_from, 'Year') = to_date('01-01-1999', 'dd-mm-yyyy') and parcellufs.parcelluid = parcelluverfs.parcelluid
Order by Parcellufs.parcelluid, Parcellufs.wt_from

Query 7:
Select Parcellufs.parcelluid, Parcellufs.landuseid, parcelluverfs.parcelluverid, parcelluverfs.parcelid, Parcelluverfs.wt_from, Parcelluverfs.wt_until
From Parcellufs, parcelluverfs
Where Parcellufs.landuseid = '1' and to_date('1990', 'yyyy') >= Parcelluverfs.wt_from and Parcelluverfs.wt_from >= to_date('1987', 'yyyy') and (to_date('1992', 'yyyy') <= Parcelluverfs.wt_until or Parcelluverfs.wt_until is null) and (trunc(Parcelluverfs.wt_until, 'year') <= to_date('1994', 'yyyy') or Parcelluverfs.wt_until is null) and parcellufs.parcelluid = parcelluverfs.parcelluid
Order by Parcellufs.parcelluid, Parcelluverfs.wt_from

Query 8:
Select Parcellufs.parcelluid, Parcellufs.landuseid, parcelluverfs.parcelluverid, parcelluverfs.parcelid, Parcelluverfs.wt_from, Parcelluverfs.wt_until
From Parcellufs, parcelluverfs
Where Parcellufs.landuseid = '1' and to_date('1993', 'yyyy') <= parcelluverfs.wt_from and to_date('1998', 'yyyy') >= parcelluverfs.wt_from and parcelluverfs.wt_until is null and parcellufs.parcelluid = parcelluverfs.parcelluid
Order by Parcellufs.parcelluid, Parcelluverfs.wt_from
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Descriptive and Comparative Studies of 1990 Urban Extent Data for the New York Metropolitan Region

Ann-Margaret Esnard and Yizhao Yang

Abstract: Regional planners and decision makers are teaming up with data providers and urban growth modelers in the ongoing effort to map historic extents of urbanization, forecast future extents, and predict impacts on the local environment. Spatial data layers that are nationally consistent across space and time are valuable input variables for some predictive models, but can be of limited use because of varying definitions of urban land and methods of data capture. This article reports on a descriptive and comparative study of two national data sets for mapping the extent of 1990 urbanization for the New York-New Jersey-Connecticut metropolitan region: 1) urban land classes based on Multi Resolution Land Characteristics data, and 2) block group urbanized area data from the United States Census Bureau. As multiple data sets from the earth, natural and social sciences proliferate and are injected into models, it is imperative that researchers and practitioners conduct and share findings of such comparative studies as part of the emergent metadata culture.

Background

Two generations of decentralized growth have dramatically expanded the urban portion of the New York-New Jersey-Connecticut tri-state region. In the last 30 years, the amount of urban land has increased by more than 60% despite only a 13% increase in population. (Regional Plan Association, 1998)

The disparity between population growth and land consumption, spatially and temporally, has made research on urban sprawl an issue of increased notoriety. Furthermore, the direct impacts on the physical, ecological, natural, and cultural resources are compounded by the fiscal costs associated with building new infrastructure and public services in remote developments. Since 1999, a multidisciplinary team from the United States Geological Survey, the Regional Plan Association, and Cornell University's Department of City and Regional Planning have collaborated to create digital views ranging from the 1930s to 1990s for the tri-state metropolitan region. This collaborative project is part of the United States Geological Survey's Urban Dynamics Research Program and builds on other similar efforts throughout the U.S.

The study region includes five counties in Connecticut, nine counties in New York State, the five boroughs comprising New York City, and 14 counties in New Jersey (Table 1).

Urban Growth Modeling for the NY-NJ-CT Metropolitan Region

In general, urban dynamics research intends to evaluate, utilize and enhance predictive models that at a minimum would allow urban planners, local government officials and the general public to visualize future urbanization growth patterns and potential impacts on the local environment. One such model, the SLEUTH model, also called the Clarke Cellular Automata Urban Growth Model and the Clarke Urban Growth Model, has six data inputs: slope, land use, exclusion, urban, transportation, and hill shading (Clarke et al. 1997, U.S. Environmental Protection Agency 2000). An underlying assumption is that historic growth trends will continue and that the future can be projected based on these trends.

In the SLEUTH model, urban land is defined as residential, commercial, mixed use, and industrial land uses (U.S. Environmental Protection Agency 2000) and for the 1930s to 1990s was generally compiled using aggregated, multiple source scanned graphics and digital vector and image data from historic maps, satellite imagery, aerial photos, Census statistics, and commerce records (Acevedo et al. 1996). At least four urban time periods are required, with one defined as the "seed" or start year from which to predict urban expansion. In the case of the study region, the seed year is 1990 and the main sources of data have been the U.S. Geological Survey, the Regional Planning Association, the New York Public Library, and the U.S. Census Bureau.

<table>
<thead>
<tr>
<th>Table 1 Counties and boroughs in study region</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Connecticut</strong></td>
</tr>
<tr>
<td>Fairfield, Hartford, Litchfield, Middlesex, New Haven</td>
</tr>
</tbody>
</table>
Descriptive and Comparative Data Studies as an Important First Step

In setting out to create the 1990 urban extent snapshot for the study region, a choice had to be made between two national data sets: 1) urban/developed land classes based on Multi Resolution Land Characterization (MRLC) data captured and classified by remote sensing and spectral procedures, and 2) Census block group urbanized area data based on a population density threshold.

Concerns that spectral classifications do not adequately identify urban extent, particularly in heterogeneous urban fringes (Vogelmann et al. 1998, Zhu et al. 2000), and that Census-defined urbanized areas and the proxy measure of population density do “not measure the structures on land and does not account for the commercial, industrial or transportation components of urban land use” (Hitt 1994, p. 14) are well founded.

The choice was made based on these and other reported differences between land cover and land use and the common practice of employing land cover to study physical processes and land use to study cultural and economic processes (Dobson 1993). The dilemma is that urbanization and sprawl, like many other phenomena, have physical, social, economic, and cultural dimensions.

The literature provides limited information on: 1) the correlation between the two data sets, particularly land-use intensities in MRLC data and population density in Census data, 2) whether combining them resolves some of the known limitations, and 3) the appropriateness of both data sets for multi-state regional analyses and urban growth modeling efforts.

This article attempts to partially fill this information gap by reporting on the results of a descriptive and comparative study of the two national data sets previously mentioned. The impetus for these pre-modeling studies is perhaps best captured by a statement by Briassoulis:

Given all the constraints surrounding the proper use of theories and models, the elite who possess the requisite education and skills has an ethical obligation to guide the users of theories and models, i.e. the actual decision makers, to making wise use of them. It rests, therefore, with those individuals who “control” the available information to assure sensible and appropriate use (Briassoulis 2000, section 5.14 on website).

Urban Land in Multi Resolution Land

Characteristics Data

MRLC is a generalized land cover (30-meter spatial resolution) data set created using a multiple-layer land-characteristics approach with Landsat thematic mapper as the main data source. Vogelmann et al. (1998) provide details of compilation procedures for U.S. Federal Region III, which includes the states of Pennsylvania, Virginia, Maryland, Delaware, and West Virginia. Similar procedures were used for Federal Region II, which includes the study region.

The MRLC data are broken down into 15 classes; however, for the purposes of this study, land cover Classes 21 (low-intensity residential), 22 (high-intensity residential) and 23 (high-intensity commercial/industrial/transportation) were selected to represent the extent of urban land (Figure 1). In general, these areas are characterized by a higher percentage of construction materials (e.g., asphalt, concrete, and buildings). Undeveloped land that is completely surrounded by developed areas (e.g., cemeteries, golf courses, and urban parks) is not differentiated within these developed lands (http://landcover.usgs.gov, accessed May 2002).

Class 21: low-intensity residential – includes areas with a mixture of constructed materials and vegetation or other cover. Constructed materials account for 30-80% of the total area.

Class 22: high-intensity residential – includes heavily built-up urban centers where people reside. Constructed materials account for 80-100% of the total area.

Class 23: high-intensity commercial/industrial/transportation – includes all highly developed lands not classified as high-intensity residential.

According to Vogelmann et al. (1998, p. 51), “ancillary data was used to aid in the class labeling procedure and to split clusters into discrete land cover classes.” The ancillary data include digital elevation data, population Census information, defense meteorological satellite program city lights data, soil, prior land-use and land-cover data, leaf on/leaf off normalized-difference vegetative index, digital line graph data, and national wetlands inventory. According to Sohl (2000), the population Census data were primarily used to split urban forests (residential areas with heavy
tree cover) and real forest (forest land) that have similar vegetative signatures, and to differentiate Class 23 from Classes 21 and 22.

**Urbanized Areas In Block Groups**

Population density based on Census statistics is commonly used to present snapshots of the extent of urbanization and suburbanization. The Census Bureau defines urbanized areas as continuously built up areas with a population of 50,000 or more. Population density of at least 1000 people per square mile is one of the definitional criteria, the threshold value having remained the same since it was adopted for the 1960 Census (U.S. Bureau of Census Geographic Areas Reference Manual).

Block groups (BGs) were used to encode population density since they were the smallest Census summary level consistently available from multiple data providers and for the entire study region. Urbanized block groups were selected using the population density threshold of greater than 1000 people per square mile. The spatial extent of Census-defined urbanized areas is shown in Figure 2.

**Observations and Interpretation**

The overall match and correlation between land-use intensities and population densities were examined by summarizing aerial coverage and population data for: 1) urbanized BGs, 2) MRLC developed land, 3) developed land in urbanized BGs, and 4) the spatial combination of urbanized BGs and MRLC developed land (see figure 3). The findings are presented in Tables 2 and 3.

**Overall Match Between the Two Data Sets: A Focus on Aerial Coverage of Urbanized Block Groups and MRLC-Developed Land Classes**

Class 23: MRLC captures more “high-intensity commercial/transportation/industrial” land (371 square miles) when compared to the aerial coverage of urbanized BGs (74 square miles) in this category (see Table 2). Two explanations are that urbanized BGs do not capture these non-residential land uses, and/or MRLC is overestimating urban land as part of this developed land class. For example, a closer examination of the two data sets revealed that transportation routes spread into remote areas and industrial sites are picked up by MRLC.

It may be acceptable to identify such areas as “developed” in the sense that they are “man-made” as opposed to “natural;” however, such physical transformation may not be a sufficient qualification in some urban growth models for defining urbanized areas. Given the ambiguity in defining urbanization, it is necessary to review model assumptions and simulation rules. For example, in the case of the SLEUTH model, road-influenced growth is one of four types of growth being simulated (U.S. Environmental Protection Agency, 2000). Therefore, it is important to

<table>
<thead>
<tr>
<th>Table 2. Aerial coverage (square miles) by land use intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 21</td>
</tr>
<tr>
<td>Low Intensity</td>
</tr>
<tr>
<td>Residential(sq. miles)</td>
</tr>
<tr>
<td>Area of Urbanized BGs *1</td>
</tr>
<tr>
<td>Area of MRLC *2</td>
</tr>
<tr>
<td>Total developed land area in urbanized BGs *3</td>
</tr>
<tr>
<td>Area of MRLC and urbanized BGs spatially combined</td>
</tr>
</tbody>
</table>

*1 – An entire urbanized BG was classified as one type of developed land class (i.e. 21, 22 or 23) based on the majority developed land class in that urbanized BG.

*2 – Area of the MRLC developed land class (21, 22 or 23) in the entire study region.

*3 – Actual developed area (21, 22 and 23) in the urbanized BG.
include data sets that capture transportation networks.

Class 22: Urbanized BGs capture less high-intensity residential land area. One explanation is that the averaging of population densities across entire BGs fails to specifically identify some high-intensity residential hot spots compared to the MRLC spectral classification.

Class 21: MRLC captures less low-intensity residential land area. Two explanations are the inability of MRLC to capture urban fringes due to the spatial resolution limit and/or the inclusion of the entire area of urbanized BGs despite the fact that development only took place in a small fraction of the BG.

### Overall Correlation between the Two Data Sets: A Focus on Developed Land Area within Urbanized BGs

**Class 21:** There is a discrepancy in the aerial coverage of urbanized BGs in their entirety (2697 square miles) and the “developed land” in BGs (1883 square miles) – that is, only 70% of the land in all urbanized BGs in the study region identified by the population density criterion was captured in MRLC as developed. A covering percentage metric (the ratio of MRLC urban land area to the urbanized area of the block group) was used to examine this discrepancy more closely.

Results showed that there is a large variation between the extreme covering percentage values in each land-cover class, with minimum values as low as 1.27%, maximum values reaching 100%, and average values in the 73-85% range. More than 10% of the urbanized BGs had a covering percentage below 50% and only 2.5% were totally built up (i.e., 100% covering percentage) by 1990.

### Urbanization Extent in Relation to Population Distributions among Land-Use Intensities: A Focus on Regional Variations

For all urbanized BGs in the study region in 1990, 62% of the total population were found in low-intensity residential BGs, but 87% of the total developed land was consumed for this intensity...
of land use. This can be compared to the population distribution and land consumption in high-intensity residential BGs — 36% of the population consumed about 10% of the total developed land. This disproportional population distribution in relation to land consumption prompted a closer look at the intra-regional conformance or variation from this pattern.

In Table 3, the summary statistics for the New York counties and boroughs and the New Jersey counties in the study region show two contrasting patterns of urbanization:

- In New York, a much lower proportion of the population resided on land developed as low-intensity residential, compared to New Jersey.
- Comparing values of “percent of population” and “percent of total developed land,” land consumption is more directly proportional to population distribution among different classes of land-use intensity, in the New Jersey counties. In the case of New York, there are distinct differences in values among the low and high-intensity residential land uses. This contrast can be explained by taking a closer look at average population density, which shows lower and similar values across the land-use intensities in New Jersey, compared to that for New York.

These observations highlight the obvious limitations of trying to generalize theories, trends, and patterns of urbanization patterns at the regional level and the hidden details in broadly categorized urban and non-urban land uses. There is also a need for other metrics such as employment densities, building types, and floor area ratio to explain some of the anomalies and discrepancies between population density, construction intensity, and covering percentage. For example, BGs with similar population densities and construction intensities could have different covering percentage of developed land due to differences in floor area ratio. A higher floor area ratio (such as high rises) can potentially reduce the horizontal urban extent.

**Conclusions and Implications**

This study confirmed the limitations of the two data sets that can be used to map the 1990 extent of urbanization for metropolitan regions. Overall, the advantage of combining the two data sets lies in the findings that MRLC can compensate for commercial/industrial and transportation mixed uses, while urbanized BGs can compensate for low-intensity residential land use. However, it is also important to understand model assumptions and simulation rules in deciding between individual or combined data sets.

One of the important messages/reminders was the need to understand regional data sets and inter-regional variations in concert with model results, given the differing concepts of urban land and different patterns of urbanization. Such “data studies” and the questions that they prompt provide requisite knowledge for model-output interpretation and signs of faulty output.

Beyond this specific case study, prevailing practices make these types of “data studies” relevant to geographic information system professionals, data providers, database designers, model developers, and policy makers. First, multiple data sets from the physical, earth, natural, and social sciences will continue to proliferate and be injected into models that have applicability to socio-economic-natural-demographic phenomena such as urbanization and intra-regional variation. Second, model users from multidisciplinary groups will continue to interpret commonly used terms such as “user-defined data sets” and to choose data based on levels of familiarity or widespread use in their fields of expertise.

It is imperative that researchers and practitioners conduct and share findings of descriptive and comparative studies on data sets as part of the emergent metadata culture. At the very least, it is a basic ethical obligation.

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Acknowledgments

The study in this article is one part of a collaborative project on Temporal Mapping in the NY-NJ-CT metropolitan region between the U.S. Geological Survey, the Regional Plan Association, and Cornell University. We wish to acknowledge the input of collaborators Robert Pirani of the Regional Planning Association and Dan Sechrist, Janet Tilley and Roger Barlow of the U.S. Geological Survey. Thanks also to Terry Sohl (affiliated with Raytheon ITSS Corp. at the time of this study) for providing detailed clarifications on questions related to the creation of MRLC data, and to the reviewers and editors for their helpful comments and guidance. The views expressed in the article do not necessarily reflect that of our collaborators.

References


Sohl, T., 2000, Email Exchange with A.M. Esnard, June 27.


Endnotes

1 The Urban Dynamics Research Program web site is http://landcover.usgs.gov/urban/intro.html, accessed May 2002

2 Urban land is used in some contexts to mean built-up or developed land. In the land classification scheme described by Kaiser et al. (1995), developed land classes are characterized by lands currently developed for urban purposes with urban service available.

3 The U.S. Census Bureau defines a block group as a combination of Census blocks that is a subdivision of a Census tract or a Block Numbering Area (BNA). For the 1990 Census, enumeration guidelines specified an ideal size for a block group of 400 housing units, with a minimum of 250 and a maximum of 550 housing units and an average population of 1000 people. The guidelines further required that block group boundaries follow clearly visible features such as roads, rivers, and railroads.

4 In research by Hitt (1994), there was a further breakdown by housing density (e.g., low, medium, intermediate, high and very high density residential, and rural development) to facilitate the study of the impacts of point and non-point source pollution on water quality.

5 We also looked at TIGER files and Census attribute tables available from the U.S. Census Bureau’s web site and from Cornell University Geographic Information Repository (http://cugir.mannlib.cornell.edu/).

6 A block group was designated as the same type of developed land to which the majority of Multi Resolution Land Characteristics grid cells in that block group belong.
Dirty Hands in the Commons: Technology and the Future of Federalism

A Review of The Radical Center: the Future of American Politics

by Ted Halsted and Michael Lind
(Doubleday, 2001, 264 pp.)

Hmm...you don't much like oxymorons, huh? No doubt, the notion of “radical center” qualifies as one of the better ones, right up there with “military intelligence,” “greater Cleveland,” and “Geographic Information.” While “radical center” is a real stretch, it becomes, by book’s end, a viable concept. More importantly, it may function as a platform for the stovepiped GI communities who are, at present, “united” only by their mutual fascination with the technology of spatial toys, the desire for more data, and an aversion to departing the ivory towers of GI, be they in government or academy.

Halsted and Lind’s construct of the “radical center” proceeds from their analysis of voters’ growing rejection of the cant that passes for platform planks in both the Republican and Democratic parties, as evidenced by the growing numbers who have declined to vote in elections, national and otherwise. The authors' studies and analyses of political, demographic and social trends are grounded in an abiding faith in the individual, and suggest that the very failure of the policies of both major parties is attributable, in large, to a latent, but still virulent, paternalistic attitude about voters.

“America’s increasingly competent citizens are capable of flourishing in a system that permits far more individual choices and responsibilities. Unfortunately, the sophistication of our citizens has surpassed that of our dominant institutions, as well as the ideologies that maintain them. Our basic social contract, our political parties, our governmental programs and our educational and even charitable institutions are designed on the premise that highly educated experts should be in charge of relatively passive, ignorant, and incompetent people. A century ago this paternalistic approach may have promoted progress. Today it retards progress.” (P.19)

While the authors admit the possibility, albeit remote, of either party redefining itself to capture what they so alliteratively term the “disengaged and dealigned” citizens, they see instead a continuance and enlarging of the trend toward voters designating themselves as “Independent.” Such a trend is consistent with society-wide trends toward enlarging the choices available to us, in all arenas, not just the political. Perhaps the most visible of these trends is the emergence of the “free agent” or “contingent worker” who is an independent contractor, moving from job to job and, indeed, career to career- -a model 180 degrees opposite the once-dominant, single employer for life, gold-watch-on-retirement model.

Yeah...that’s nice, you say....but what does it have to do with me and GI?

GI specialists’ love with technology and its toys is well within the tradition of technology’s close ties to periodic renewal/redefinition of our nation’s social contract. I recall being astounded the first time I heard that “GIS will lead to world peace.” Halsted and Lind are quick to disabuse tekkies of such infatuations, by insisting that those who believe such have cause and effect inverted.

“No more than in the past will the successful renovation of America be the automatic result of technologically driven change....
in the economy and society. Those technological determinists who believe that the new technologies of the Information Age will inevitably produce more democracy, equality, and prosperity have their history backward. Technology is the result of freedom, not its cause.” (P.57)

Given the fact that most GI professionals fall within the ambit of the “highly educated experts,” it will be useful for them to peruse Halsted and Lind’s arguments— if only to learn how to move away from adding the label of “paternalistic” to extant monikers of “tekkie” and “elitist.” In spite of all the talk of “moving GIS out of the back shop,” making the technology and accompanying tools “transparent,” and developing “enterprise” GIS packages, its practitioners remain resolutely behind the curtain, content to produce the latest version of the “map of the day” to solve management’s crise du jour and bask in the acclaim of grateful users.

Halsted and Lind’s respect for and reverence of the individual as the keystone of our democracy is not to be equated with a libertarian outlook, which elevates the individual and individual choice to that keystone position. Rather, the Radical Center concept seeks to maximize individual choice in a system featuring our “...core commitment to a division of social authority among three distinct realms of society: the market, the state, and community...interdependent, complementary, and mutually supporting. For our nation to flourish, all three must be in relative balance with one another, so that each may perform its unique functions, and provide its unique form of freedom.”

In order for that happy condition to come about, the GI communities, either separately or cohesively, must step out from behind the screen and the back rooms, go to the commons, and dirty their hands with the other citizens by teaching the gentle GI skills. Because our future federalism will be an intensely interdependent one, so must its citizens be interdependently skilled. And the citizens of the commons will prove surprisingly adept at, and intensely interested in, the offerings of the all-too-reclusive GI folk. Were this scenario to occur, we would all triumph over what Halsted and Lind so accurately term “...the segmenting effects of new technology and new media [which] make it ever more difficult for Americans to feel that they share a common frame of reference.”

World peace? Doubtful- -sounds more like another oxymoron. But the commons are calling. And they will be heard, even by the most hardened GI provider. Come to the commons and help build Halsted and Lind’s Radical Center, ye GI faithful!

Reviewed by:

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