Seattle City Light’s Electrical Usage
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Cover: The illustration is a 3-D display of 1993 electrical usage for the 131 square-mile Seattle City Light service area in Seattle, Washington. Magnitudes are in average (hourly) megawatts consumed by quarter-section (¼-square mile) units. Using GIS technology, the utility is analyzing power consumption as part of emergency response planning, long-range load forecasting, transmission and distribution planning, and other resource management activities. For more on the city of Seattle's use of GIS technology, see the Feature Map and accompanying text on p. 69.

Cover map display produced by Seattle City Light Information Technology Division. Map authors: Fred Podesta and Susan Bevacqua.
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MANUSCRIPT SUBMISSIONS: URISA Journal is dedicated to sharing knowledge about information systems among managers, users, developers and educators, so that improved systems can be developed and used more effectively and equitably at all levels of government. Manuscripts, correspondence or questions on editorial matters should be addressed to the following section editors: Refereed: Ken Dueker, Portland State University, P.O. Box 751, Portland, OR 97207; (503) 464-4042. Features: Lyna Wiggins, Rutgers University Center for Urban Policy Research, Livingston Campus Bldg. 4161, New Brunswick, NJ 08855; (908) 932-3423. Reviews: Rebecca Somers, Somers-St. Claire, 3157 Babashaw Ct., Fairfax, VA 22031; (703) 204-0033. Maps: Ted Koch, Wisconsin State Cartographer, 160 Science Hall, 550 N. Park St. Madison WI 53706; (608) 262-6852.
In this issue . . .

Robert Simons and Mark Salling apply GIS to the public real estate problem of how to select residential housing sites for redevelopment in an inner-city neighborhood. They use an older, environmentally contaminated, inner-city neighborhood in Cleveland as their study area.

GIS is increasingly capable of working with data that extend above the land surface, such as buildings and above-ground infrastructure. Ian Bishop, John Spring and Rohan Potter look at how one urban center made additional use of its spatial data for visual appraisal of development projects.

Zhongren Peng and Kenneth Dueker assert that transit demand modeling requires the integration of transit ridership, transit service and socioeconomic data. Their paper addresses the issue of data requirements, data structure and data integration for transit demand modeling. The accuracy of different methods to allocate demographic and socioeconomic data from census areas to the service areas for transit routes are compared.

Last, Horwood Critique Prize winners Cynthia Brown and Floyd Staynor discuss the methodology for the selection of potential wetland migration sites, using GIS to automate the evaluation process.

Editorial Intent

The refereed section of URISA Journal strives to share new knowledge in the technical, social, economic, and institutional subject areas that support information systems technology. It is the intent that this section of the Journal contain papers that are representative of URISA’s membership and the broader information systems community. We encourage the participation of system designers, implementors and users as well as the educational and research community.

We hope that the refereed section will provide reliable information and new insights resulting from experience, research and scholarship. We also hope that this section will link academia, industry and the user community through the sharing of critical investigations and organized knowledge. To this end, we are seeking three forms of work: (1) Reports of current research and development pertinent to the overall information systems community; (2) systematic literature reviews of research for the research and development community; and (3) systematic reviews of applications which explain successful systems and procedures to the overall information systems community.

The refereed process consists of a “blind review.” After receiving a manuscript from an author, we send it out for review to three or more persons who have been identified as being knowledgeable in the topical area. The name and affiliation of the author are removed from the paper so the reviewers can give it an impartial review; likewise, the names of the reviewers are not revealed to the author. We ask the reviewers to respond to the following: (1) Is the thesis or purpose stated early and clearly; (2) is the significance of the paper stated explicitly; (3) is the thesis argued persuasively; (4) is the writing clear, concise, straightforward, interesting, and in the active voice, where possible; (5) is the paper tied in appropriate ways to relevant literature; (6) is the paper illustrated appropriately; (7) are the methods sound and appropriate to the paper; (8) are the methods explained clearly; and (9) is the paper interesting to many different types of URISA Journal readers?

If the manuscript is accepted and does not need revising, it is sent to the managing editor for comments and final editing. If the manuscript needs revision, assistance is provided by the editors. If the manuscript is not accepted, it is returned with an explanation by the editors. (For complete guidelines regarding the preparation of manuscripts and illustrations, see pp. 91–92.)

Kenneth J. Dueker
Using GIS to Make Parcel-Based Real Estate Decisions for Local Government: A Financial and Environmental Analysis of Residential Lot Redevelopment in a Cleveland Neighborhood

Robert Simons and Mark Salling

Abstract: This study applies geographic information systems (GIS) to a public real estate problem: how to select residential housing sites for redevelopment in an inner city neighborhood. The objective is to identify the least expensive combination of parcels which could be assembled by the city for redevelopment. The study area is an older, environmentally contaminated (brownfield), inner-city neighborhood in Cleveland that has experienced substantial tax delinquency. We use GIS by creating a polygon base map, and merging it with local assessor and other data. SQL capabilities of the software system are used to develop the analysis and provide results to the city. Our study demonstrates that GIS can be helpful as decision support for local government in real estate redevelopment.

The purpose of this paper is to present a methodology and case study using geographic information system (GIS) technology as a decision-support tool in planning and facilitating the redevelopment of residential lots in an inner city neighborhood.

The client-driven study is conducted from the perspective of the Department of Community Development of the city of Cleveland, which owns numerous vacant lots and wishes to return these lots to productive use by making residential lots available to developers. Its objectives are to make available the largest number of buildable residential lots as cheaply as possible by providing inexpensive, clustered and clean sites, while retaining each area's unique character. Because of prior land use, environmental problems and associated clean-up costs are commonplace in the city.

As importantly, information and analysis tools are needed to assist the city make efficient and rational decisions about redevelopment possibilities and costs. This paper discusses how GIS technology was used to assist the Department of Community Development in this process. In this application a GIS is used for spatial and attribute database queries and spatial analysis and display. A base map of land ownership parcels was created and merged with attribute data used for tax assessment by the Cuyahoga County Auditor (in which the city of Cleveland is located). A series of layers, including ownership, physical characteristics, financial and tax payment factors, and prior land uses (related to potential environmental contamination) were prepared and merged, and SQL was employed to analyze data and assist in the presentation of key information.

A cost-minimizing approach was used to identify those parcels that could be most readily and least expensively redeveloped. The method emphasizes developing accurate cost factors (acquisition, site preparation, and environmental remediation costs) conducting structured queries on various layers of information, and producing information-rich but easily interpretable tables and maps of redevelopable lots for possible use in a development prospectus. The cost-minimizing approach was valuable in suggesting actions that would promote the most efficient use of government resources.

This paper therefore presents the results of the study as well as the GIS methodology. We begin by briefly presenting literature on related applications, followed by a discussion of the client's problem and the study area. The client's objectives drove the need for and selection of data and specified the type of map output. We then recount the methodology used in constructing the data set and maps, layer by layer. We present the final redevelopment map and recommendations to the client, and conclude with observations concerning the use of GIS as decision support for real estate applications for local government.

Robert Simons is an assistant professor in the Levin College of Urban Affairs at Cleveland State University.

Mark Salling is director of the Northern Ohio Data and Information Service at Cleveland State University.
Literature on Related Applications

The use of GIS in a number of related analysis and application areas is growing rapidly. In real estate analysis and management its use has been recently espoused by researchers and practitioners alike. Thrall and Marks (1993) describe the ability of the tool to study the spatial impact of real estate decisions. Marks, Stanley and Thrall (1994) provide guidelines for evaluating GIS software for real estate analysis. Castle (1993a) argues that the real estate industry, including brokers, home buyers and developers, can use GIS to improve residential brokerage by merging it with Multiple Listing Service records. Castle (1993b) also describes how GIS is being used in property valuation. Landscape architecture has been using computer-aided drafting for the past decade, but the added database management and analysis tools of GIS are being explored more recently (see for example, Johnson 1994).

We characterize our Cleveland neighborhood analysis as an example of the use of GIS as a decision-support tool for a public agency, using parcel level analysis assembled at a neighborhood level. Our process combines physical, historical and financial characteristics of each property. Individual lots are aggregated to small “strategic parcels,” defined as those that could be readily combined to form clusters of redevelopable lots for private housing development. Our overall approach is similar to research conducted by Armstrong, Llonis and Honey (1993) who used GIS as a decision-support tool for a local school district. Their data analysis included merging parcel level records with neighborhood level requirements. Tomaselli (1991) used GIS to conduct fiscal analysis on behalf of local government. Her use of fiscal cost factors on a small area basis is similar to our application of environmental redevelopment cost factors.

Our approach to creating a GIS database is consistent with at least two other applications. Juhl (1994) assisted a Florida county to analyze growth management by helping them prepare a parcel-level real estate database combining physical and financial characteristics. Part of the work involved translating image files to named polygons capable of presenting underlying data. Hintz and Onsrud (1990) discussed preparation of a parcel level database using land ownership, and physical characteristics, using a layered approach to building the database.

Our application for city community development planning is a step toward making the GIS technology available to community development planners, as set forth by Van Demark (1992) who called for a GIS database to be a desktop resource for city planners.

Our analysis demonstrates the viability of using GIS as a decision tool in stimulating economic development in declining neighborhoods. Indeed, there are numerous case studies of how GIS and related information technologies are used to manage growth in developing communities (for example, Juhl 1994), but there is little treatment of applications of the technology to assist in the management and improvement of communities experiencing economic, social, and physical decline. There are examples of GIS use in redevelopment. Coffeen (1994), for example, describes use of GIS to support what he calls “reverse urbanization”, which involves the environmental restoration and redevelopment of land. The application he describes is the use of the Presidio Army Base in San Francisco. But that land would be redeveloped with or without government direction because of the high demand for such land in cities such as San Francisco.

Stimulating land redevelopment in Cleveland and some other “rust belt” cities of the Midwest, however, is a different and more challenging problem. But it is also perhaps even more important in such communities, and there is no apparent reason why GIS has not been applied to a greater extent in these settings, except perhaps for the costs incurred in developing and maintaining this capacity.

The Client’s Problem

The city of Cleveland Department of Community Development is charged with redeveloping the 38 neighborhoods in the city. Community Development administers expenditures of Community Development Block Grant funds, which in 1993 approximated $25 million. Part of Community Development includes the Land Bank, which currently contains over 5,300 vacant tax parcels obtained through the property-tax foreclosure process. Parcel intake since 1990 has averaged 1,200 per year. Nearly all Land Bank parcels contained prior land uses, and most contain rubble from prior buildings on site. Thus, environmental problems and associated clean-up costs are commonplace. The city wishes to return these lots to productive use by making residential lots available to developers. Its objectives are to make available the largest number of buildable residential lots as cheaply as possible. Community Development also wishes to retain the urban fabric of the neighborhood, and avoid demolition of functional structures if at all possible.

Through various financial inducements and an innovative and progressive Land Bank program, the city has managed to induce a small but growing amount of redevelopment at substantial per-unit subsidy cost. However, the next generation of redevelopment is likely to require more difficult decisions, be more costly, and will require a more systematic approach to land assembly.
Hence, providing inexpensive, clustered and clean buildable sites is a high priority. Several moderately declining neighborhoods, selected on the basis of market acceptance, location and political factors, have been targeted by the city for a systematic allocation of redevelopment funds.

The authors and the Urban Center at the Levin College of Urban Affairs at Cleveland State University (CSU) were asked to provide assistance to the city in April 1993. CSU performed the work under contract, over a two-month performance period. This included assembling the database, performing the analysis, generating a report, making presentations to city administration directors and staff, and turning over the database to the city. The study was completed over the summer of 1993. The project, directed by the first author, was assisted by GIS and data management specialists and graduate students in the Urban Center. The project required about 300 hours of staff time.

The Study Area

The study area for this project is the Bluffs section of Cleveland’s Tremont neighborhood (see Figure 1).
This area includes parts of 15 city blocks, and currently contains approximately 410 residential and 80 commercial lots. About half the lots are vacant, with the city Land Bank owning approximately 70 parcels.

Tremont was first developed in the 1880s, primarily as a working-class residential neighborhood, due to its close proximity to the industrial jobs along the Cuyahoga River. The Bluffs portion of Tremont directly overlooks the industrial valley below, and has excellent views of downtown Cleveland, which is less than five minutes away by car.

Tremont has retained its high-density character, and is filled with small, single-family detached bungalows on small lots. For example, Tremont lots are typically 25-foot frontage and 2,500 square feet, compared with 40-foot fronts and 4,800 square feet in other parts of Cleveland. Many of the lots back onto alleys, which are part of the "urban fabric" of the neighborhood. Demographics of the area can be characterized as blue collar, and low-to-moderate income. While Cleveland's population peaked in 1950, population has declined in Tremont since 1920, when it was 36,686 persons. Most of this loss occurred prior to 1980. In 1980, the area's population had declined to 10,304; and by 1990 it had declined to 8,875 persons. This decline in the 1980s decade was -13.9 percent, more than the -11.9 percent experienced by the city as a whole (1980 and 1990 U.S. Census of Population and Housing). However, due to its excellent location and relatively sound housing stock, there is some potential for gentrification.

Setting Objectives for the Study

The goal was to generate the maximum number of redevelopable lots within the study area at a minimum cost. Identification of the cheapest and most feasible parcel clusters (referred to as strategic parcels) was required, building on properties already owned by the city. Strategic parcels were identified based on the following objectives and criteria:

- Retain the urban fabric. Parcels with occupied structures and paying property taxes were excluded from the list of potential lots for redevelopment investment.
- Avoid costs associated with severe environmental contamination. Parcels which were found to have "severe" environmental contamination were excluded from consideration. Severe and non-severe contamination were operationally defined as lots having underground petroleum and waste storage tanks, past complex commercial land uses, or potentially multiple environmental problems.
- Retain parcels that have both frontage on a street and direct back alley access. Placing a premium on retaining the high-density character of the neighborhood, we assumed that single lots with both street frontage and direct access to an alley would be generally marketable.

- Enable assemblage of scattered-site, lower-density areas for redevelopment. Parcels not meeting criteria contained in objectives 1 and 3 above were further screened so that smaller, spatially isolated parcels that would be contiguous to other similar parcels would be included as strategic parcels.

Methodology

The next step after identifying objectives and development criteria was to build a spatial database for the study area. Our general approach is consistent with both Juhl's (1994) Florida growth management project and with Hintz and Onsrud (1990), both of which employed a parcel-level real estate database combining physical and financial characteristics. Like these studies, we used a layered approach to building the database. Conceptually, three "layers" of data were required: 1) a parcel base map capable of accessing underlying attributes; 2) land use, ownership, and property tax status; and 3) environmental factors. Information about buildings, land use, ownership, tax status, and environment are actually attribute variables for a parcel-based graphic file. But conceptually they constitute layers in the sense that a sequence of maps, viewed methodologically as layers, was produced to help screen parcels and identify target parcels for redevelopment. While our approach was to utilize GIS to the greatest extent possible, many, but not all, parts of our analysis are mechanical. Human judgment was required at nearly all junctures in our study, especially between steps (e.g., assuring that maps were properly integrated).

Table 1 shows an example of the data for selected parcels. Data included a unique lot number, owner name and address, a land use code, lot frontage and square footage, number of buildings and market value, and tax delinquency status. These data are readily available from the computerized records maintained by the Cuyahoga county auditor for tax assessment purposes.

After the initial attribute database was compiled, we had to build a base map with the appropriate layers and conduct a series of structured queries to determine if the parcels had the potential to be strategic. A relational spatial and attribute database was required.

Constructing the Base Map

The county auditor and engineer jointly maintain computerized parcel maps, but not as a continuous, seamless map. Cor are the map files integrated with the tax assessment data. Therefore, we imported the auditor's parcel map files, in a dxf format, into our relational GIS software package. Merger of five dxf format maps was required. Topological structure was added to the imported dxf files by creating a uniquely named polygon
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TABLE 1. Strategic Parcel Database
for each of the 490 lots in the study area. Street names were also added. Figure 2 shows the base map (for the northern portion of the Bluffs area) after the five dxf files were merged but before topology was enhanced.

Enhancing topology was not a trivial task. Problems included:

• Merging “hooked” parcels. Historically, as adjacent parcels are combined the original lot lines are kept on the tax maps and their merger noted by a “Z” hook crossing the common lot line. Tax assessment and other parcel-based attribute data are identified by current parcel definition.

• Eliminating extraneous information. Hooks, circles, ellipses, parcel identification codes, arrows, and other graphic information on the dxf files constitute information noise and were unnecessary for the project.

• Forcing parcel boundary lines to meet, creating a continuous polygon boundary. The auditor’s graphic file does not define parcels as polygons. Our real estate GIS required that parcels be associated with attribute data and that the attribute data could be used to create thematic parcel maps.

Because of the problems noted above, parcel boundary polygons had to be created by “tracing” (on-screen digitizing) the boundary lines. Our graduate students were able to digitize about 30 parcels per hour.

**FIGURE 2. Merged DXF Map Before Clean Up**

### Linking Tax Assessment Data to the Base Map

The next task was to merge the Auditor’s tax assessment data with the cleaned and computerized base map, merging on permanent parcel number (ppn). Two types of tax records, one for the land and building characteristics (last updated in 1988) and another on property tax status (vintage 1992), had to be added to the system. Unfortunately this task, too, was not as straightforward as hoped. The automated match between both data sets and map polygons based on ppn was largely successful (96 percent). The lack of match can be attributed to the use of “reference parcels” on the property tax records, where a “lead” parcel contained all the attribute data and adjacent parcels under the same ownership were not on the database. However, the accuracy of building attribute data from the 1988 tape was worse (e.g., the number of buildings on the property) because of demolitions and other changes that had occurred during the intervening years. Thus, the data set contained some internal inconsistencies which had to be resolved, usually by individual attention.

### Land Use, Ownership and Property Tax Delinquency Attributes

Our first layer on top of the base map included selected tax assessment variables about buildings on site, lot frontage and square footage. We also considered payment of property tax payment status, because tax delinquent properties could be obtained through the Land Bank. We then queried parcels to exclude those with buildings that were current on their property taxes. These were considered to be part of the urban fabric (hence, non-strategic). All other parcels, e.g., vacant or tax delinquent or those already owned by the city, were revealed by visual inspection of the map.

### Environmental Factors

Additional data were included on environmental factors. We were looking to avoid environmental “surprises” which earlier redevelopment projects had encountered in the city. Based on the history of the neighborhood, we expected to find a few underground storage tanks, indications of past commercial activity (both heavy, such as chrome plating, or light, such as retail), presence of automobile garages, and demolition debris from tenement apartment houses. To incorporate environmental factors, we conducted a systematic analysis of original Sanborn insurance maps for 1887, 1912 and 1952. We also included updated Sanborn and Hopkins maps for the 1930-1950 and 1960-1970 periods, and a Titus, Simmons and Titus map for 1857. These
maps were key in identifying prior land uses with possible environmental problems. A comprehensive list of registered environmental sites from a private firm was also obtained and findings incorporated onto an environmental hazards map, shown in Figure 3. 7 The environmental factors map helped to identify residential “brownfields” (e.g., properties that because of prior use, require significant environmental clean-up in order to be redeveloped). 8 Our GIS application of environmental redevelopment cost factors is similar to Tomaselli’s (1991) use of fiscal cost factors on a small area basis.

Field Verification
We next sought to field verify all the data. Some changes were expected, due to vintage of the data, elapsed time between data collection and the current period, and dynamic aspects of redevelopment (e.g., fires and building demolition). Field verification involved marking up a hard-copy map while in the field so that corrections and additions could be made to the computerized database back at the office. 9 Figure 4 shows a portion of this map. It included preliminary strategic parcels.

Finalizing Strategic Parcels
At this point we exercised our decision criteria noted above and finalized identification of the boundaries of strategic parcels in our study area. Having already eliminated parcels with occupied structures current on property taxes, we further excluded lots with potential environmental problems, such as underground storage tanks, past high-intensity commercial land uses involving industrial processes, or parcels with multiple potential for environmental problems.

The remaining lots were included in strategic groups, often clustered around Land Bank lots. The number of buildable new lots was determined by applying design criteria appropriate for the neighborhood, while still requiring off-street parking.

There were 176 existing parcels that met the criteria. These parcels were combined into 38 strategic,
developable parcel groups containing 138 new marketable developable lots. One hundred-one lots met the higher-density criteria, usually in multiple lot clusters. Thirty-seven new lower-density buildable lots were available, each combined from at least two old parcels. We generated a working map of these strategic parcels very similar to the final product, only with different strategic number identifiers.

Conducting the Cost-Minimizing Analysis

Once potentially developable lots were identified, we shifted the analysis to estimating redevelopment costs for all lots identified as part of a strategic lot assembly group. Costs were broadly defined to include all additional expenses to complete the process of bringing lots to market. Costs were calculated for individual items such as demolition, legal/other, site preparation, property maintenance, re-platting, alley infrastructure and property acquisition. Environmental factors included residential and commercial debris digging, hauling and burial and soil remediation. We developed expected cost factors based on past experience of other community development projects. The cost estimates assume enforcement of recent regulations on disposal and handling of friable asbestos. A summary of redevelopment cost factors is shown in Table 2.

Study Results and Recommendations

To the City

Results

Strategic parcels were ranked from low to high, based on least-expensive average redevelopment cost per lot. Table 3 contains the results. Total and average redevelopment costs for each group and line item are shown. The range of average lot redevelopment costs in Tremont is estimated to be between $3,300 and $19,000. The least expensive 30 lots (the cheapest to redevelop and therefore the "most" strategic parcels) would average about $4,300, the next 30 lots would be $7,000 per lot, with $8,200 for the third group of 30 lots, and an average redevelopment cost of $9,400 for the fourth group. The costs also exclude all past expenses incurred by government agencies such as demolition, maintenance, and opportunity cost of foregoing back property taxes. The total cumulative redevelopment cost for all 138 new lots would be $1.1 million. Figure 5 provides a schedule of the number of lots and total redevelopment cost.

For the entire group of strategic parcels in the Tremont study area, the dominant cost components include property acquisition (27 percent), environmental factors (debris haul, burial and soil remediation—38 percent combined), and alley infrastructure (20 percent). These and other less expensive costs are shown in

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**TABLE 2. Lot Redevelopment Cost Factors Used in Tremont Study**

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<th>Cost Per Lot</th>
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<td>Soil remediation-auto garage</td>
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<td>Alley Infrastructure-per linear foot of &quot;backage&quot;</td>
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* Simple commercial includes building alley, upholstery, etc. where contamination is likely to be light. Costs here include an environmental phase 1 study with a few soil borings, assumed to be negative. Complex commercial includes machine shops, paint storage, and businesses with a production process. Here the assumption was for multiple soil borings and some light soil remediation expense. These are subjective probabilities.

MV: lot's current market value according to the latest County Auditor data.

MD: lot's outstanding property tax delinquency, according to the latest County Auditor data.
The final, comprehensive redevelopment map is shown in Figure 7 (in black and white; the original map is in color). The map is compact, containing over 20 variables. It can be used as a base map for marketing clusters of lots to developers.

**Recommendations**

Recommendations from this study include using the results of this analysis for budgeting purposes by the Community Development Department. Also, the department should replicate this redevelopment plan approach (subject to improvements noted in footnote 4) in other neighborhoods of the city. But even more importantly, the city should be monitoring and managing its land resources, in combination with its public works infrastructure, using GIS technology. These tools are proving their worth in the challenging atmosphere of growth management; communities faced with "shrinkage" management could also benefit from the same GIS technology.
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Conclusions

There are several conclusions regarding use of real estate GIS applications as decision support for local government.

General Advantages of Using GIS

There are several major advantages to using GIS in the manner described above. First, the planning analyst has access to an on-line database which combines graphic, text, and statistical information about each parcel in the study area. This saves time in data access, and compilation, and facilitates ad-hoc queries.

Second, the SQL process can be extremely fast, and allows numerous attempts to access and visually present (on screen) different combinations of crucial spatial and attribute data about the study area. This provides the analyst the ability to explore various aspects of the problem, potentially providing a better final product.

Third, the database can be effectively and efficiently maintained and updated. This advantage would be maximized if the original map and attribute data were maintained in a true GIS format, as opposed to strict use of hard-copy maps and data. The city of Cleveland and other communities are already taking steps toward this end. GIS maps are generally attractive, detailed and compact, and can be readily reproduced in different sizes and scales to facilitate customized data access, data sharing, and marketing of lands for redevelopment and other applications.

Real Estate GIS and Decision Support for Local Government

The advantages noted above speak to the general attributes of GIS for most if not all application areas. While use of GIS in urban communities has largely focused on public works and infrastructure management, planning and community development departments frequently use the technology to map and analyze demographic patterns (for example, see Bossard and Zhang 1994). Counties experiencing growth and development can justify use of GIS to monitor and manage growth because infrastructure and service expansions require reliable information systems for planning, management, and operations functions. Further, growth generates revenue which helps pay for improving information management.

In other communities, however, those whose economic and resource bases are not expanding but may be declining, it is more difficult to allocate scarce resources to information management systems at the expense of basic service delivery. While cost reduction for map maintenance and other operational activities may be valid reasons to automate, it is our contention that better information management and analysis tools also help these communities to maximize their land redevelopment possibilities, particularly because they are competing with those communities that are using these advanced tools.

Finally, our application of GIS to residential redevelopment strategies confirms the assertions of Thrall and Marks (1993) that:

Geographic information systems can improve the accuracy of and decrease the time required to perform real estate research and analysis. . . . GIS allows the mapping of real estate data that, in turn, enables the researcher and analyst to visualize the spatial interplay between phenomena on the landscape. . . . GIS also permits the evaluation of real estate data through the geographer’s matrix overlay techniques. All these features of a GIS translate into an important paradigm shift for real estate research and analysis. (pp. 59–60)

Our case study supports by example the efficacy of Van Demark’s (1992) call for desktop GIS for planners, and shows its usefulness as a decision-support tool. In a broader context, our work is consistent with the conclusions of Armstrong, Lolonis and Honey (1993) which illustrate the potential of a greater role for GIS in decision support for local government. Thus, the value of a real estate GIS in a decision-support capacity for planners and other local government agencies is emerging.

Notes

1. We would like to thank the City of Cleveland Department of Community Development for financial support of this project.

2. It has been pointed out most recently by van Hekken (1994) that many planning organizations under-utilize GIS technology and data because of the high cost of database development and maintenance, but that reliance on multi-agency consortia sharing data and applications can significantly increase use of the technology in such agencies.

3. This may seem counter-intuitive to current trends in urban development to exclude alleys from new projects because they may be associated with higher maintenance costs, difficulty in accessing emergency equipment, and perceived resident security issues. However, in this case, alleys are considered one of the keys to maintaining the urban fabric of the area and allow adequate off-street parking access, keeping distance between houses small. Thus, they are featured in the study.

4. Several other potentially important variables were not included in the GIS, including slope, soils, and drainage. Properties on the northern end of the neighborhood are particularly affected by slope and subsequent database construction should include these factors where appropriate.

5. “Digital exchange format” (DXF) is a commonly used spatial data format and is therefore a de facto transfer standard for graphic and spatial data. It was developed by AutoCAD (TM).
6. One redevelopment property turned up with approximately $250,000 in unexpected lot clean up costs for four lots in a twenty lot project.

7. The source for this customized data run, and for all Sanborn maps was ERIS, located in Alexandria, Virginia. The data run included registered environmentally sensitive sites on 11 publicly available lists and a computer map of listed locations within a 1/2 mile radius of the study area.

8. A developer may be faced with a choice of developing a virgin lot ("greenfield") in an outer suburb or bearing the additional costs and uncertainty of developing an inner-city, brownfield parcel. Such choices may significantly limit inner-city redevelopment potential.

9. Hand-held systems make possible such changes more directly, though this technology was not used in this study.


References


Extending the Geographic Information Base into the Third Dimension for Use in the Urban Environment

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Abstract: Geographic information systems are increasingly capable of working with data that extend above the land surface. This paper describes how one urban center has made additional use of its spatial data for visual appraisal of development projects. Elevation data have not been confined to a digital terrain model but have been extended through photogrammetry to include the roof planes of all buildings within 2 km of the major commercial and civic center. These data have been used, in conjunction with terrain models, aerial photographs and facade textures, to generate visual simulations and animations from both ground level and elevated view points. Additional attribute information—such as property values, height limit envelopes or date of construction—can be shown simultaneously with minor abstraction of the simulations. It is argued that GIS users will increasingly opt to extend their data sets to include buildings and other above-ground infrastructure as three-dimensional elements.

Geographic information systems have long been defined as computer software for the collection, storage, retrieval, transformation and display of spatial data (Burrough 1986). Although no dimensional restrictions are explicitly stated in such a definition, it is generally understood that a GIS works with the type of data that have historically been encoded as maps. That is, data about the state of the earth’s surface. Specialized software have been developed for working with below-surface data, e.g., seismic records, groundwater modeling. Computer-aided design (CAD) software has been widely used for modeling objects built above the surface. Fractals, L-systems and other procedural techniques have been applied to modeling of vegetation and other natural phenomena. Now, users who work with digital map data also frequently have concern for underground or above-ground activity. Packages that integrate GIS capability with the capacity to model and visualize in the third and fourth dimensions are in increasing demand.

This paper describes how data from the third dimension have been used in the urban environment to review development proposals and to present data from a different perspective. The data have been drawn from a combination of GIS and engineering CAD sources and used in commercial animation software. Pioneering work that combines GIS, CAD, rendering and animation technologies on a single platform has been undertaken by Danahy and Wright (1988). Lange (1994) has used these developments in an environmental planning context. Nevertheless, at this time, such work is frequently dependent on data translators and the use of multiple packages or platforms.

Camberwell Junction

Camberwell Junction, at a junction of three major roads 10 km east of Melbourne, is a “district center” offering many shops and stores along the major north/south arterial road. It is a strip shopping center that primarily serves the municipalities of Camberwell and Hawthorn. Forty-thousand commuter cars pass through the junction every day. Two tram lines, one train line and several bus routes serve the Camberwell Junction center.

In the late 1950s, the Camberwell Council started purchasing land at the rear of the center to provide off-street parking. Parts of these extensive purchases were
financed and acquired through the “Planning Permit” conditions for redevelopment in the center. High car-parking to retail floor-space ratios required either extensive on-site car parking facilities or cash-in-lieu-of car-parking payments. The success of this strategy from 1950 to 1970 helped the Junction shopping center become a leading retail center with rental rates rivaling the central business district and other major shopping malls. However, by the late 1980s the Camberwell Junction customer base declined as regional shopping centers improved and expanded. The last large retail store in the Junction was developed in the 1970s; since then parking has increasingly fallen behind that offered at other regional centers.

To help with planning decisions for the changing Camberwell Junction, the Camberwell and Hawthorn Councils carried out several joint studies from 1973 to 1992. Despite spending over $375,000 on independent consultants in 1990, no great progress was made towards a “Junction Strategy” that could be incorporated into legislation as planning-scheme amendments. With its existing holdings, the Camberwell Council has 28 percent of the non-residential land in this highly desirable and affluent part of the municipality. The council is now working through a procedure for defining not only economic and planning goals, but also actual site-specific development parameters.

**Phase 1: Data for Structure Planning**

To underpin the analysis of development options, council officers proposed a pilot geographic land information system employing existing Hewlett-Packard Apollo workstations and a 3-D surface modeling interactive graphics system (SMIGS). Objectives for the pilot project included site-specific floor area limitations and overall statements of strategic direction on development sites, public transport, heritage and urban development guidelines.

The Camberwell Council, with help from consultants, developed map data sets for the Junction. The mapped area is 1.7 km by 2.1 km and contains about 4500 buildings. It was important that they use a process that could be used directly for any planning scheme amendment while storing data for future use and reference was necessary. This had not been achieved by the previous studies. They also envisioned that the process would provide for more visible and graphic illustration of the future structure of development in the junction and hence be more readily understood so discussion could concentrate on the ‘real’ issues and not extraneous detail.

Digital cadastral data were purchased initially. These had been digitized from old 1:2500 maps and were found to be inaccurate, especially for the large number of properties that were not generating rates. They supplemented the data with photogrammetric interpretations of 1988 stereo photography. The photography had been flown at 670 meters providing an acceptable 1:4500 scale reproduction with on-ground accuracy of plus or minus 0.2m. Physical boundaries, basic contours and all existing building footprints were digitized as 3-D coordinate strings. Specifically the data set contained:

- Outline of all buildings in the study area taken at parapet or eave location for X, Y and Z coordinates. A series of simple rules was used in digitizing the buildings which concentrated on the footprint and squared the roof at the eave or parapet. Each building was classified as either residential, commercial or public/institutional.
- All existing fences and visible boundaries with one of three “confidence” attributes:
  1. excellent definition and location, or
  2. partly obscured but reasonable confidence, or
  3. difficult identification, questionable or obscure.
- Indicative contours at 5-meter intervals.

A base data set for the area was thus generated from existing internal compiled maps and other sub-division and building permit data plus two external data sources. The project was commissioned in November 1991 and had a deadline for public advertising of a “structure plan” in April/May 1992. The pilot GIS work was on time and cost-effective. Over 4000 properties were included in the data area. The total cost of data acquisition and preparation was $82,000 (Australian).

A series of 12 A0 sized plots was produced mapping the recommendations for proposed planning scheme amendments and control of development in the Junction. From this first phase, site-specific details would be developed with actual building control envelopes and other urban design guidelines.

**Phase 2: Data for Urban Design Guidelines**

The next stage was more complicated in requiring actual urban design alternatives to be developed, assessed and tested financially. The normal role of the council as simply a “statutory authority” has shifted dramatically with Camberwell’s large ownership of the commercial center. More than just “statutory” functions must be assessed; a wrong development decision would have direct economic and physical repercussions.

Visual simulation was proposed as a component of this evaluation so that councilors, officers and the public could feel more confident about the physical extremities of proposed buildings and works in the real environment. The simulation models could also be used to test major planning guidelines associated with building lin-
itation envelopes, height restrictions, maintenance of views and building bulk.

After some initial simulations using the Phase 1 data sets, it became clear that additional contour data along with street verandas and roof detail were necessary to make the simulation models recognizable and believable. While landscape simulations do not necessarily need high-accuracy data to achieve their "effect," the city of Camberwell specified high-accuracy requirements because of the potential savings in answering planning and building development questions directly from simulations. This is especially the case where height limitations or relative building bulk control is important.

New aerial photography was taken on a non-business day and at a time with appropriate shadow angles. This was to provide as much on-the-ground and building detail as possible. Additional survey control was also specified to enable the final digital results to be surveyed on the ground for accuracy. Eventually 50mm accuracy was achieved in the "central core" retail area.

Additional contours at 0.5-meter intervals plus spot heights were provided along with roof planes and verandas and other major roof equipment. Break line features, involving embankments and retaining walls, were given special attention so that the digital terrain model (DTM) was as accurate and recognizable as possible. The quantity of information in the core (non-residential area on the Camberwell side of the junction only) was enormous. It was greatly underestimated because of the traditional methods of quoting "aerial digitization" on the basis of numbers of properties rather than numbers of roof planes.

The specification for 2-D and 3-D snapping of complex roof shapes and features in X and Y plus X, Y and Z coordinates was a challenge: especially as this was done on-line at the time of data capture (Figure 1). Buildings such as churches with polygon dome roof and turret become quite expensive to digitize; in some cases three times the traditional rectangular building digitizing costs. The final data file in Intergraph '.dgn' format held five times the data volume of the Phase 1 files for the same buildings and area.

The Simulation Process

The local photogrammetrically derived data sets were combined with wider area terrain data and an existing CBD model to form an overall simulation model, which can be thought of as three concentric areas of decreasing precision around the civic core.

The new, very precise data of Phase 2 replaced the Phase 1 data in the inner zone, which included all the civic and commercial area of Camberwell adjacent to the junction. The terrain model in this zone was based on 0.5meter contours. This area covered roughly 1200m by 300m with an elevation change of up to 30 meters. The next zone included the adjacent commercial areas in Hawthorn and residential areas in both municipalities and a DTM based on 2-meter contours. This gave an area modeled from photogrammetric data of approximately 1.7km by 2.1km.

The contours in these two zones were converted to a triangular irregular network (TIN) model using Intergraph's terrain modeller (MSM). The TIN model and the roof planes were converted from '.dgn' to the '.obj' format used by Wavefront Technologies' Advanced Visualizer using in-house software. To create the buildings, the roof planes were extruded downward to intersect the ground plane. No obvious problems arose from using this procedure, even with the domed church, but it would be more problematic for complex curved buildings such as the Sydney Opera House.

FIGURE 1. An illustration of the roof, parapet and veranda digitization process. Two- and three-dimensional snapping was done during data capture to ensure that gaps and overlaps did not develop.

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* 2D and 3D indicate where the closed planes should be snapped in either two or three dimensions.
An aerial photograph of the Camberwell area was scanned in Photoshop and rectified using Intergraph's image analysis module using control points drawn from the digital model. The image was converted to a 2048-by-2048-resolution texture map in the Advanced Visualizer environment and draped over the terrain model. This technique has been described in Bishop (1994), while the use of Advanced Visualizer software in environmental visualization is reviewed in Bishop (1994).

In order to expand the area of coverage and to avoid the visual contradictions induced by a very obvious hard edge to the data set, we added to the Camberwell data sets a third outer zone. This included a terrain model based on 20m contours for the surrounding area—from the Melbourne CBD to the Dandenong ranges at the edge of the metropolitan area—and a CAD model of the Melbourne CBD. Although the CBD model was not current, it was sufficient to show the relation of the junction area to the CDB and to establish the relationship between proposed development and views to the city. The full data set gave effective simulations from both oblique aerial (Figure 2) and ground-level viewpoints.

To further enhance the ground-level views, photographs of building facades taken from street level were texture mapped onto the corresponding building walls. Street furniture and other details have been designed using CAD software and added to the data set to generate realistic images of the current environment and the effects of development proposals (Figure 3).

Additional attribute information—such as property values, height-limit envelopes or date of construction—can be shown simultaneously with minor abstraction of the simulations. An example is the 11-meter height limitation proposed for alterations and additions to the existing (Burke Road) shopping strip buildings. This was supposedly to protect the view of the Melbourne skyline. The simulation (Figure 4) proved that this 11-meter

FIGURE 2. Oblique aerial view which shows the character of the data set. In the background is the outer data zone including the central business district (CBD) of Melbourne and the edge of Port Phillip Bay. In the right foreground and middle distance are the buildings of the second zone with flat roofs (single Z values). In the center of the image the detailed modeling of the inner zone derived from full roof plane acquisition and extrusion is clear.
FIGURE 3. Ground level view showing texture mapped shop facades, street furniture and traffic.

FIGURE 4. A prominent location within the area currently enjoys a spectacular view back toward the CBD over the low-rise local shops. The image shows that a proposed height envelope for redevelopment of those shops would cut into the CDB view. Other proposed building masses are also shown.
height restriction would not protect this view; consequently this limitation is under review.

The simulations have proved a very effective means of presenting block building forms as a planning-limitations envelope. Levels and site lines to the CBD skyline have been easily judged using the simulation along with proposed planning scheme height-limitation controls. Because of these simulation “experiences,” a number of alternatives have been discarded or redeveloped to take account of factors which have only become obvious through the simulation.

Conclusion

The project has employed a number of graphical and landscape simulation techniques unique in local government. The idea of collecting highly accurate data with the aim of modeling the existing environment realistically, plus the ability to quickly introduce development proposals for testing public reactions, has been a demanding exercise. A substantial amount of effort has been placed on acquiring photogrammetry data of buildings and land levels to enable site lines and view presentations to be accurate, understandable and believable. Presentations using dual projection with the simulation and actual complementary slides have been very successful in illustrating the urban design alternative guidelines now being developed for council and public consultation.

Aerial photography and photogrammetry have proved to be a cost/time-effective technique in the Camberwell Junction GIS Pilot Study and Landscape Simulation Project and will continue to be used for the remainder of the council’s GIS implementation.

For the city of Camberwell, extension of their data sets to include buildings and other above-ground infrastructure as three-dimensional elements has had clear advantages. It is hard to envision councils and other urban-oriented agencies adopting GIS without also discovering the urge to undertake 3-D modeling of their building information. This probability should enter into their deliberations as they choose hardware and a GIS.

Note

Since this paper was prepared, the cities of Camberwell and Hawthorn have merged with the city of Kew to form a single municipality—the city of Boroondara.

References


Spatial Data Integration in Route-Level Transit Demand Modeling

Zhongren Peng and Kenneth J. Dueker

Abstract: This study addresses the issue of data requirements, data structure and data integration for transit demand modeling. Transit demand modeling requires the integration of transit ridership, transit service and socioeconomic and demographic data. These data are not stored in consistent geographic units that are required for transit demand modeling. Two data integration issues are addressed: the spatial and attribute data allocation, and the inter-route relationship. The accuracy of different methods to allocate demographic and socioeconomic data from census areas to the service areas for transit routes are compared, using data from Portland, Oregon metropolitan area. Spatial data integration is also used to analyze transit inter-route relationships, the extent to which routes are independent, complementary or competitive. Inter-route relationship analysis facilitates route-level ridership modeling to estimate the ridership impacts of service changes not only on the route with the service change, but also on other related routes.

Several efforts to address the issue of common digital map databases for a variety of applications for public transportation systems are underway. The Advanced Public Transportation (APTS) Map and Spatial Database User Requirements Working Group (MSDWG) is addressing the issue of standardization of spatial data entities for transit service (Okunieff 1994). The MSDWG efforts focus on a broad range of potential applications, such as demand-responsive systems, fixed-route operations and service planning, customer information systems, and transit decision-support systems. A common database requirement provides a basis for defining and describing transit data elements in a consistent and transferable form, so users can integrate different data with common definitions and common relationships among data sets.

This paper addresses the spatial data requirements and integration for transit demand modeling based on work for the Tri-County Metropolitan Transportation District of Oregon (Tri-Met), the regional transit agency in the Portland, Oregon metropolitan area. Transit demand modeling is data driven. Valid and accurate data are needed for model specification, a key factor to generate an unbiased estimation. Invalid or inaccurate data will result in biased and inefficient model estimation. Geographic information systems (GIS) have an important contribution to organize and integrate transit location, ridership, service, and socioeconomic and demographic data for transit demand modeling.

Database Requirements of Transit Demand Modeling

Different types of models have been developed to estimate route-level transit ridership. They belong to two basic approaches. One is a traditional urban transportation planning system (UTPS) approach, which treats transit routes as a network system, and uses a four-step modeling process (trip generation, trip distribution, mode choice, and trip assignment) to derive and assign ridership to individual transit routes. The other approach is direct demand modeling. It uses regression models, regressing ridership at the individual route, route segment, or bus stop level against the determining factors of transit ridership within the transit-route service areas. These two approaches serve different purposes and have different data requirements.

The UTPS-type model is a large-scale and long-range transportation planning tool. It is capable of estimating modal split at the zone-to-zone level or the household level.
level and assigning transit trips to individual routes, especially the recent development of the disaggregate choice model and multipath assignment algorithm. However, it is incapable of providing sufficiently accurate estimates to guide short-term operational improvements like transit frequency changes (Papacostas 1987), nor is it very sensitive to transit service changes. The UTPS-type approach focuses on travel origins and destinations, traffic flows and equilibrium assignments to the network. It requires data on traffic flows, trip origins and destinations, as well as socioeconomic and demographic data at the traffic zone level. These data are usually travel behavior survey data that have travel origins and destinations. It does not require transit ridership data at the individual route level, but it does require zone-to-zone travel time for modal splits and a transit network for assigning transit rides to individual routes. Disaggregate choice model variants require more detailed household-level travel and demographic data.

In contrast to the UTPS-network approach, the direct demand model is more sensitive to transit service changes and therefore suitable for short-run what-if scenario analyses. The direct demand models focus on transit ridership and service on a specific route, or part of route. They utilize the observed transit ridership and regress it against transit service variables, and socioeconomic and demographic characteristics in the transit-route service area. They require very detailed data on transit ridership, service, and socioeconomic and demographic data at the route, route segment, or transit stop level. Thus, data on transit routes and stops consist of both location and attribute components related to specific transit routes. Because of these data requirements, a GIS is a useful tool for integrating spatial and attribute data.

This paper will not address the data requirements and database design for UTPS-type modeling and discrete choice modeling. Rather, it addresses the database requirements, design and integration issues for the direct-demand modeling approach.

There are three major categories of models that use the direct-demand approach: cross-sectional, time-series, and the combination of the cross-sectional and time-series model. Each of these models requires different data.

Cross-sectional models mainly deal with the spatial data. They relate transit usage, transit service and socioeconomic variables over space for a given point in time. Time is not considered explicitly and independently in the modeling process. Different models are developed for different time periods, such as models for the peak, midday and night period using different data set in different time period.

Time-series models are used to deal with long-range temporal change. They are developed to estimate transit demand changes on a spatial unit, usually for a whole city or metropolitan region, as service and other variables change over time. To treat spatial variations, individual models are developed for each spatial unit. Time-series models primarily require longitudinal data.

Cross-sectional models capture variations of transit ridership across different routes in space, and time-series models capture variations of ridership over time. A combination of cross-sectional models and time-series models is used to capture variations of transit ridership in time as well as in space. Therefore, it requires both spatial and longitudinal data (Kyte et al. 1988).

In addition to the spatial and temporal components in the data requirements for transit demand modeling, there is also a directional component. For example, in the morning peak period, there is a large difference of ridership between inbound and outbound direction. To serve the purpose of route-level service planning, the database design must address these spatial, temporal and directional variations to satisfy the needs of transit demand modeling.

Spatial and Temporal Transit Database Design

Typical regression modeling requires at least three kinds of data—ridership, transit service variables, and socioeconomic and demographic data.

Ridership data usually refer to boarding rides at a spatial unit such as a bus stop, a route segment or a whole route. Transit service data include service quantity variables such as bus frequency, hours of service, and route length of service; and quality variables such as on-time performance. Transit service variables also include the location, usage and capacity of park-and-ride lots provided by transit agencies.

Demographic and socioeconomic characteristics at the place of residence are used to estimate the potential transit users at trip origins, which include population and age structure, household income, and auto ownership. The demographic and socioeconomic variables at the destination are used to represent the characteristics of destinations of the transit trips, which include such data as employment and high school enrollment.

Data from different sources may relate to different spatial units. Some are related to transit stops like boarding and alighting, some are related to transit routes such as service frequency, and some are related to areas such as population and employment. A regression model requires these variables to be measured in the same geographic unit. In other words, all variables have to be consistent in space and in time. To achieve this
data consistency, these data have to be spatially related and integrated.

To relate data spatially, each variable has to be related to a common unit of observation. Geographic units of observation are usually areal, such as traffic analysis zone, census tracts, blocks or parcels. However, they may be linear, such as street segments, routes, or rivers. Or they can be points, such as accidents, bus stops.

A point is a basic unit of location. It can be represented by an (x,y) coordinate, or a milepost along a line. It has zero dimension. From the modeling point of view, the transit stop, the starting and ending point of a transit route, an intersection point of two transit lines, a transit transfer center, and the centroid of a high school or a park-and-ride lot can be treated as spatial points.

A link is a line between two points. It has one dimension. The line between two bus stops is a spatial link. A line between a bus stop and a rider’s home is another example of a link.

In our model, a route segment is the piece of a transit route, or a set of several links within a fare zone. And, a route is a set of segments beginning from a starting point (from-node) to the ending point (to-node) of a transit line.

A polygon is an enclosed area bounded by three or more links, such as a census block, block group, census tract, fare zone or transit service area of transit stops or routes.

Every spatial feature has associated attribute data. For example, a bus stop is associated with the number of boarding, alighting and transfers. A route segment has associated characteristics such as transit fare structure. A transit route is associated with route typology such as a radial, crosstown, feeder or express route. A polygon has associated areal data such as aggregated employment and population. A detailed list of spatial features and associated transit attribute data is shown in Table 1.

The relationship among spatial features can be established by analysis of several types: point-on-line, point-in-polygon, line-in-polygon, and polygon overlay. Several are in preparing data for analysis, such as buffering route segment to generate transit areas of service, and using point-in-polygon algorithms to allocate population to route buffers. Similarly, polygon overlay was used to allocate income data by block group to route segment buffers.

To facilitate making relationships among bus stops, bus stops to routes, and among transit routes, bus stops and routes were related to TIGER lines and nodes. This facilitates identification of transfer points between routes. Similarly, it serves to identify bus stops that serve several routes. Relating point and linear transit data to the TIGER network enables integration and avoids redundant geographic representation. This eliminates the need to redigitize portions of each route that might traverse a relocated street.

There is a temporal component at every spatial unit. For each bus stop, for instance, there could be ridership data for time of a day, season and year. The temporal component can be for a time point and time period. The time point is the basic unit of time, like 2:00 pm. Time-point data are not necessary in most modeling applications, unless used in a real-time application. Time period is a time unit that is longer than a time point. It could be a subdivision of a day or a week, such as the morning peak period, midday period, or the weekend. It could also be for a longer duration, such as a season or a year.

There is also a directional component of spatial data. The directional component can be treated in two ways. The first method is for a symmetric system, i.e., the data

<table>
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Source: Adapted from AFTS Map Database User Requirements (Okunieff 1994).
are the same for both directions in a linear system. For example, if two bus stops in inbound and outbound are on the same two-way street, and are oppositely located across the road, these two bus stops can be considered as one in a linear network system like a street centerline file. Ridership data in either direction can be related by the same bus stop but with different directions.

The second method is for a nonsymmetric system, i.e., data points for two directions are not the same. The directional data are related to different geographic locations. For example, on a one-way street, the bus stop for inbound and outbound direction will have different locations, and must be treated as independent points.

The systematic GIS database design can aid transit service planners to query and display transit ridership, service and socio-economic characteristics in the service area by stops, route segments or the whole routes. By displaying and linking these spatial data, it facilitates the spatial analysis of transit service supply to determine places that have the most or least service. It can also be used to target certain population groups, such as low-income, disability or elderly groups, to determine if these target groups get enough transit service. More importantly, the systematic-designed GIS database provides a basis for efficient data analysis and transit demand modeling.

**Data Integration**

For the purpose of transit demand modeling, separate data must be related to common geographic units and the modeler must select the level of detail—the bus stop, a route segment, or the whole bus route. If the unit of observation is at the bus stop level, all linear and polygon data representing route service and population locations must be related to the point data that represent individual bus stops. That is, at each bus stop, there must be a data set that describes the transit ridership, transit service, population and employment within walking distance of that stop. Similarly, if the basic observation is the bus route segment or a whole route level, the point and polygon data have to be related to the route segment or route level.

The overlay operation in GIS is often used to integrate polygon data and point or linear data. Caution must be exercised to determine whether the topological and geometric relations represent the real relationship among the polygon, point and linear data. In other words, even though the population in a census tract can be associated with a bus stop or a route segment by an overlay and allocation operation in GIS, it is necessary to determine whether that population contributes to the transit ridership in that transit stop, or whether the transit service in that segment serves all or part of the population in that census tract. The question remains as to specifying or allocating population and the kind of population to specific transit stops, route segments, or the whole routes.

To allocate polygon and point data to transit stops, route segments, or the whole routes, the transit service area has to be defined. Previous studies have shown that walking distance is the most important determinant of the transit service area (Ilorowitz and Metzger 1985; Lam and Morrall 1982). Most people will not walk more than a quarter-mile, or approximately five minutes, to use public transit. Therefore, the transit service area is usually defined as a one-quarter mile around the transit lines, or more precisely, around transit stops. Some previous studies have used this service area concept in transit demand modeling (Hunt et al. 1986).

Prior to using GIS for route-level modeling, this issue of data consistency was not dealt with well. For example, Kyte et al. (1988) relied on the county-level population and employment to estimate their route-level models. If two routes run through the same counties, the same population and employment will be used to estimate the ridership on both routes. The more typical relationship used by modelers was to assign census tract population to all routes that intersected the tracts (Stoopher 1992). This leads to double counting if more than one route serves a tract. For a route-level transit ridership estimation model, in which the population and employment are major determinants of transit demand, this lack of consistency is the major source of inaccuracy in estimating route-level demand models (Multisystems, Inc. 1982).

The service area for each transit stop or route can be delineated by either a geometric distance buffer or a topological neighborhood search (Dueker and Vranic 1991). For a geographic buffering approach, bus stops are buffered by a quarter-mile distance, because it is the bus stops that determine the real walking distance. The area inside the buffer is the service area for that particular transit stop. Because the distance between bus stops is usually less than a quarter-mile, there is overlap among bus stop buffers. Objects such as population in those overlapped areas are allocated to the nearest bus stop.

If the model is developed at the route segment or route level, however, buffering bus stops and allocating objects to bus stops may not be necessary. Bus routes, rather than bus stops can be buffered for urban routes, wherein the bus stops are less than a quarter-mile apart. This can achieve sufficient accuracy and reduce the redundancy of buffering individual bus stops on bus routes.

The topological approach delineates the service areas of a transit stop by searching for a quarter-mile distance in the street network. This approach considers the actual walk distance in the street network, so it is more accu-
rate to define a transit service area. However, in the urban areas where the network is very dense, the geometric and topological approaches produce similar results.

In developing a transit demand model at the route-segment level, we used the geometric buffering approach to buffer a quarter-mile distance around a transit route segment to define the transit service areas, and allocated the demographic and socioeconomic data to the buffers. The demographic and socioeconomic data are mainly from the 1990 U.S. population and housing census, available at the geographic unit of census tract, block group and census block. Since the boundaries of these geographic units are not consistent with the boundaries of the bus route buffers (Figure 1), data in those different geographic units (census tracts, block groups and blocks) have to be allocated to the route service areas.

Count and attribute data are allocated differently. Count data, including the number of population, employment, high school enrollment, and park-and-ride facilities, are counts of spatially distributed subjects and can be allocated to different geographic units by overlay functions in GIS, i.e., spatial allocation. Attribute data representing the characteristics of those count data, like income, auto-ownership rate, population age structure, cannot be allocated by the overlay functions in GIS, unless these data are at the individual person or household level. They have to be allocated differently as discussed later.

**Count Data Allocation**

Count data in an areal unit are the aggregate number of thematic features. There are four basic methods of count data allocation (Peng and Ducker 1993). They are:

- all or nothing allocation,
- allocation based on the uniform density assumption,
- allocation based on land use types, and
- allocation based on block centroids.

These four allocation methods are by no means exhaustive, but they are the most commonly used in spatial data allocation.

All-or-nothing allocation allocates spatial count data like population and employment of the whole census tracts or block groups to the bus-route service area if the transit line buffer overlaps in part or whole with the census tract or block group. The whole census tract or block group is considered as being served by the bus route as long as there is some common area between a bus route buffer and the census tract or block group, regardless of how large or how small the common area is. If a census tract or block group is very large and a transit route runs on a major arterial, which is often the

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**FIGURE 1. An Illustration of Spatial Data Allocation**

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boundary of census tracts, the real walking distance for some people living in the census tract is far more than a quarter-mile (see Figure 1). Assuming that they all are served by the transit route is unreasonable. Including them in the route-level transit patronage model as determinants of transit ridership introduces measurement errors.

The uniform density allocation assumes that the population and employment in a census tract are uniformly distributed, and the allocation of population and employment is based solely on the proportion of the area of a census tract that is within the bus line buffer area. This method will result in errors in tracts where population is not uniformly distributed. It is especially inappropriate for employment data, because employment is often clustered together rather than evenly distributed.

Allocation based on the type of land use relates population to residential land uses and relates employment to non-residential land use. Population and employment can be allocated uniformly to residential and non-residential land areas, or building floor areas. This is a better alternative than the uniform density allocation method. Still, it can introduce errors if population and employment are concentrated and mixed, such as a mix of single-family and multi-family housing, and a mix of different commercial and industrial land uses.

Allocation based on census block centroids assumes all the population in the census block is located at a single point (block centroid). The whole block's population is allocated to the transit service area if the block centroid is located inside the transit route buffer area.

In urban areas, a census block is the smallest geographic unit wherein census data are available. It is small enough to be considered as a spatial point. This study used 1990 census block data to allocate population to the transit service areas. The point coverage of census block centroid was first overlaid with the transit route or stop buffers, the routine-specific population within the service areas was aggregated by summing population of block centroids inside the buffer. Although this study does not prove that the population allocated by the block centroid is the ground truth, it can be reasonably argued that this method generates the least error in urban high-density areas. This assumption, however, cannot be applied to low-density suburban and exurban areas.

To compare the accuracy of different data allocation methods, the uniform density, all-or-nothing and the land-use allocation methods were used to allocate population to a transit-route buffer, using data in the Portland metropolitan area. The allocated results were compared to that using the census block centroid method.

The allocation methods are compared by the percentage differences of allocated population using that of block centroid method \(\text{BLOCK}_{\text{z}}\) as the basis. These differences are calculated both at the block group and census tract level, by the following formulas:

\[
\text{Average Percentage Difference of AON}_z = \frac{\sum (AON_{ij} - \text{BLOCK}_{ij})}{\sum \text{BLOCK}_{ij}} \times 100
\]

\[
\text{Average Percentage Difference of UD}_z = \frac{\sum (UD_{ij} - \text{BLOCK}_{ij})}{\sum \text{BLOCK}_{ij}} \times 100
\]

\[
\text{Average Percentage Difference of LU}_z = \frac{\sum (LU_{ij} - \text{BLOCK}_{ij})}{\sum \text{BLOCK}_{ij}} \times 100
\]

AON, UD and LU indicate all-or-nothing, uniform density and land-use based method. The geographic area, \(j\), on which the population allocation is based, could be either the census tract (CT) or the block group (BG) number. The allocated population are compared at the route segment (fare zone) level, \(z\), \(\sum \text{BLOCK}_{ij}\) is the allocated population at the fare zone \(z\) based on the population in the block centroid.

The difference of these three methods is shown in Table 2. It shows the results of different methods of population allocation to the bus route buffer aggregated at the route segment level. There are four segments segmented by fare zones in this study area, zone 0, 1, 2 and 3, concentric with the downtown Portland central business district (CBD).

Table 2 shows that, compared with the block centroid method, the all-or-nothing method generates larger difference than the uniform density method, both at the block group level and the census tract level. Because

| TABLE 2. Comparisons of Population Allocation Aggregated to the Transit Route Segments: Percentage Difference from Allocation of Block Data. |
|-----------------|-----------------|-----------------|-----------------|
| **Allocation Method** | **Uniform Density** | **All-or-Nothing** | **Land Use** |
| Geographic Unit | Block Group | Census Tract | Block Group | Census Tract | Census Tract |
| Median difference | 7.4% | 13.0% | 202.0% | 327.9% | 11.5% |
| Mean difference | 44.6% | 35.6 | 1057.9% | 2762.4% | 28.9% |

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land use is not available at the block group level, population was allocated based on land use at the census tract level only. Land-use allocation produced better results than uniform density and all-or-nothing allocation at the census tract level (Table 2). In terms of allocation errors of the area type, allocation based on the block group produces a better result than that based on the census tract. There is a big difference between the mean and the median, because the mean error includes larger outliers.

The differences in Table 2 are aggregates at the route segment level. Aggregation tends to reduce the variance and errors. If the allocation difference of different methods is compared at the census tract level, the difference is much larger. Peng and Dueker (1993) have a more detailed analysis that shows the allocation to route segment buffers introduces less error than does allocation to smaller geographic units like census tracts. It is interesting to note that the mean difference of uniform density allocation using census tracts is less than that using block groups at the route segment level. This may be due to the balance of the over-allocation (positive difference) and under-allocation (negative difference) in the process of aggregation; it does not necessarily indicate the population allocation based on the proportion of census tract areas is better than that based on the block group areas.

Unlike population data, employment data are simply not available at the census block level. The block centroid allocation method used for population allocation cannot be used to allocate employment data.

Employment data are only available at the census tract level by industry in the Portland metropolitan area. Metro, the regional planning organization for the Portland metropolitan area, geocodes state employment data to census tracts. We have allocated these employment data to route-specific service areas based on land use types, from Metro's parcel-level Regional Land Information System (RLIS). RLIS is used because it identifies land use type at the individual parcel level. Every land parcel in the RLIS database has a specific land use type, i.e., residential single-family, residential multi-family, industrial, commercial, and farm lands.

Employment data at the census tract level are available by industry: manufacturing, commercial, government, transportation, real estate, and agricultural. These industrial categories are not consistent with the land use categories. In order to relate employment data to land use types, this study relates manufacturing employment to industrial land use, agricultural employment to farm lands, and all other employment to commercial land uses. The employment allocation process is described as follows:

First, each land parcel in the RLIS was converted to a centroid point. Then the RLIS parcel point coverage was overlaid with the census tract polygon coverage. Parcel-level floor area and land use area by different land use types allocated to census tracts were aggregated, and employment density (employment per unit of floor areas or land use areas) by employment type was calculated using Equation (4). For example, if census tract 1 has 500 manufacturing employees and 250 acres of industrial land, its manufactural employment density is two employees per acre.

\[
\text{Employment Density}_{pk} = \frac{\text{Employment}_{pk}}{\text{Land or Floor Area}_{pk}}
\]

Where the subscript p is employment typology: commercial, industrial, and agricultural; k is the census tract number. For commercial employment allocation, floor area rather than the land area is a better measurement of employment density.

Next, the transit buffer was intersected with the land use point coverage from RLIS and the census tract polygon coverage. If the centroid of a land parcel is located inside the buffer, that parcel is counted as being served by the transit route. Land and floor areas inside the route buffer in each census tract by land use types were aggregated, and were used to calculate the proportion of these land and floor areas that are within the buffer by land use typology.

Lastly, the specific employment in transit buffer areas is the product of the employment density of an employment type and the proportion of the land area or floor area inside the buffer as illustrated by Equation (5). The employment in a census tract served by the transit is the summation of employment of all employment types in the census tract (Equation (6)). The total employment served by a transit route segment is the summation of employment served in all census tracts that the route segment buffer goes through (Equation (7)).

\[
\text{Employment}_{zik} = \text{Employment Density}_{pk} \times \frac{\text{Land or Floor Area}_{zik}}{\text{Land or Floor Area}_{pk}}
\]

\[
\text{Employment}_{ik} = \sum_p \text{Employment}_{zik}
\]

\[
\text{Employment}_{iz} = \sum_k \text{Employment}_{ik}
\]

Where the subscript i, z is the route buffer area of the transit route i at fare zone z; the subscript p and k are defined as in Equation (4).

Caution is needed to allocate employment data based on the uniform-density land uses, especially for industrial and agricultural land. It can only be used as a proxy of the ground truth. It is nevertheless still an improve-
ment of the uniform-density assumption without considering land use types.

The allocation of high-school enrollment and park-and-ride facilities are relatively simple. The locations of high schools and park-and-ride lots are represented by a point coverage. The point coverage can be easily overlaid with the transit route buffers. High schools and park-and-ride lots are allocated to the buffer when they are within the bus service areas. One high school or park-and-ride lot may be allocated to more than one bus line if there is more than one bus line within walking distance, indicating there is more than one bus service available for that school or park-and-ride lot.

An important implication of this finding is that different allocation methods generate different results. But even a simple allocation method based solely on the uniform density assumption is an improvement over traditional no-allocation (or all-or-nothing allocation) at all. GIS provides an efficient tool to reduce measurement errors and increase accuracy, validity and consistency of spatial data in transit demand modeling.

However, there are limitations in these spatial data allocation procedures. First, although blocks are small enough to be considered spatial points, they may be large in suburban and rural areas. Where blocks are large, they should be treated as polygons rather than as points.

The second limitation lies on allocating employment according to land area. Using land area to allocate commercial employment is crude. The uniform density assumption within the same land use type is also questionable, because employment density varies for different commercial land uses. The employment density of a car lot may not be the same as that of a retail store.

The third limitation is the errors associated with GIS operations, especially for spatial overlays (Blakemore 1984; Flowerdew 1991; Pullar and Beard 1990). The commonly mentioned problem in spatial overlay operation is the creation of a host of "sliver polygons" and "dangling chains" (Flowerdew 1991), and the mismatch of a point on a polygon or line. Error arises when the land parcel is out of the census tract when it should be in, and vice versa.

**Attribute Data Allocation**

Different people have different taste and demand for transit service. The characteristics of persons and households such as age, income, car ownership and other attribute variables are very important factors that determine transit ridership.

At the individual level, every person has associated characteristics; there is no need for allocation. At the aggregate level, data allocation is necessary if attribute data are only available at the higher level of aggregation. Such is the case for population count data at the levels of census block, block group and tract. However, detailed attribute data pertinent to ridership like income and car ownership are only available at either the block group or the tract level. Since this study used population of 1990 at the block level to allocate population to the bus route buffer, income and auto ownership data at the block group level have to be allocated to the buffer areas. Three methods can be used to allocate attribute data like income and car ownership.

The first method is to assume each block is like its parent block group. For example, the proportion of zero auto households of a block group is used to calculate the zero auto households that are within a transit route buffer for the same block group. That is, to estimate the number of household without automobile for the part of the block group g that is inside the route i buffer area, the formula (8) can be used:

\[
\text{Zero auto households}_g = \frac{\text{Zero auto households}_b}{\text{Households}_g} \times \text{Households}_g
\]

Similarly, income can be allocated to transit service from block groups by income group. For example, the number of households with income of $20,000 to $30,000 can be expressed as in Equation (9):

\[
\frac{\text{Households with income of 20-30K}_b}{\text{Total households}_g} \times \text{Households}_g
\]

The second method is simply to apply a median value such as median income of a block group to all blocks of that block group, as illustrated in Equation (10). This method cannot be used to allocate auto ownership data, unless the average auto ownership is calculated for the block groups.

\[
\text{Median income}_b = \text{Median income}_g
\]

Where b represents block, and g represents block group.

These two methods are based on an assumption that the population and households are homogeneous inside a block group. This assumption may not be valid because even inside a block group there can be considerable variation.

The third method is to use a regression model to estimate population attributes. Even though the census data do not provide income data at the block level, it does, however, provide block level surrogates of income such as housing values, rents, population age structure and housing size. If a relationship can be found between income and these surrogates at the block group level,
the income of the households at a census block can be derived.

Lycan (1993) formed a relationship of income and its related variables using a regression model at the block group level. The estimated coefficients can be applied to the variables at the block level. Equation (11) illustrates the regression equation at the block level:

\[
\text{INCOME}_{g} = \alpha + \beta_1 \text{HOUSVAL}_{g} + \beta_2 \text{RENT}_{g} + \beta_3 \text{PCT650}_{g} + \\
\beta_4 \text{PCT18U}_{g} + \beta_5 \text{SIZE}_{g} + \beta_6 \text{PER/ROOM}_{g} + \epsilon \tag{11}
\]

Where, the subscript g means all variables are at the block group level, INCOME is the median income; HOUSVAL and RENT are the median housing value and rents; PCT650 and PCT18U are percentage of population with age of 65 and over, and with age of 18 and under, respectively; SIZE is the housing size measured by square footage, and PER/ROOM is the average persons per room; \( \epsilon \) is an error term.

These estimated coefficients (\( \alpha, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6 \)) are then applied to the independent block data. At the block level, these estimated coefficients and their corresponding variables are used to estimate income for each individual block as shown in Equation (12).

\[
\text{INCOME}_{b} = \alpha + \beta_1 \text{HOUSVAL}_{b} + \beta_2 \text{RENT}_{b} + \beta_3 \text{PCT650}_{b} + \\
\beta_4 \text{PCT18U}_{b} + \beta_5 \text{SIZE}_{b} + \beta_6 \text{PER/ROOM}_{b} + \epsilon \tag{12}
\]

Where, the subscript b indicates all variables are at the block level.

One problem with this approach is that there are many missing data for some variables at the block level such as housing values and rents. Income cannot be estimated if any of the variables are missing from the block, especially the important variables of housing value and rent.

This means additional models are needed at the block group level with the selected variable(s) excluded. Then, estimates can be made for blocks with missing values for rent, if there are no rental housing units in that block. This block group level model should exclude the rent variable, using those block groups that are mostly owner-occupied (such as 90 percent) to estimate the coefficients. Similarly, another model at the block group level could exclude the housing value variable, using those block groups that are mostly renter-occupied to estimate coefficients to apply to blocks having no owner-occupied housing units.

There are several problems associated with these alternative models. The first problem is that there may not be enough block groups without housing values to estimate a model, because not many block groups are purely renter-occupied. The second problem is that if the model excludes the housing value variable, and some block groups have owner-occupied housing, the model will not be fully specified. An incorrectly specified model will result in a biased estimation.

The third problem is that if all variables are expressed in terms of median or mean values, extremes are excluded, and the resulting model tends to under-estimate the low end and over-estimate the high end.

Because the ground truth of income at the block level is not available, it makes the comparison of these three allocation methods difficult. This study used the first method, assumed income and car ownership distribution in each block is like its parent block group, to allocate income and auto ownership data at the block group level to the transit service areas. Because income and auto ownership data need to be aggregated to the route segment level, the number of households within an income range is easier to aggregate, while the use of average income at the block or block group is more difficult to aggregate.

**Inter-Route Relationships**

A transit system is not a set of independent routes. A change of service and ridership in one route may have impacts on related routes. The inter-route relationship is therefore an important factor in estimating transit ridership at the route level.

From the planning point of view, an inter-route relationship is a physical relationship among two or more routes. For the purpose of modeling, an inter-route relationship is the service and ridership influence of one route upon the other. The same physical relationship may have different possible ridership impacts, for example, a service increase in one of the two routes that serve the same service areas may draw rides from the other route. It may also attract more riders from the service areas because of the total level of service increases in that area. The net effect of the service increase in one route may be a simple redistribution of current riders with little or no increase of total transit ridership. It is therefore necessary to differentiate between the inter-route physical relationship and ridership impact. The former is defined as inter-route linkages while the latter as inter-route effects in this study.

The physical relationship between two transit routes can be identified by analyzing the relationship of transit routes by their overlapping service areas (Figure 2). The inter-route linkage can be identified by analyzing the overlap areas. There are three kinds of inter-route physical linkages: independent, complementary and competing.

If two route buffers have no overlap at any part of the routes, i.e., they are at least half a mile apart, these two
routes are independent, like route 71 (RT71) and route 75 (RT75) in Figure 2. Transferring and competition between them is unlikely because there is no overlapping area within walking distance of both. These independent routes can be treated as independent from each other in the route-level modeling. A service change in one route presumably has no impact on another.

If two route buffers overlap, they are linked. The relationship between them can be identified by the configuration of the routes and topographic constraints. Two inter-route linkages can be identified: complementary and competing.

If two route buffers overlap only at one end of transit routes, such as at a transit transfer center, and the other ends are in different directions, wherein the beginning node of one route is the ending node of the other route, the relationship between these two routes is considered complementary. Riders from one route may transfer to the other, and the two routes do not compete for the same riders. A service change in one route will have a direct impact on the other. A typical example is the relationship between a radial bus and a feeder bus.

If two route buffers intersect at one point other than the ends of routes, and the two routes have different origins and destinations, such as radial bus and crosstown bus, these two transit routes are also considered as complementary. For example, route 71 and 75 are complementary routes of routes 19 (RT19) and 20 (RT20) in Figure 2, and vice versa. Potential riders may transfer from one route to the other at the intersection point.

The common characteristics of these two types of complementary routes are that they are connected with each other at one point; at least one end of the routes is different from each other, and there are potential riders who may transfer from one route to the other.

If two route buffers overlap linearly with each other, and have at least one common end, they are considered as competing routes. Routes 19 and 20 in Figure 2 are examples of competing routes. Competing routes share some common service areas with each other, i.e., they run either on the same road or nearby parallel roads. One route will compete for riders with the other from the common service area. A service change on one route will affect the ridership on the other. For example, for two competing routes 19 and 20, a service increase in route 19 will attract some riders from the route 20. Some potential riders in the overlap areas have the choice of going to either route 19 or 20, because both routes are within their walking distances and both routes have at least one common end.

The competing effects of two competing routes are determined by how close the two competing routes are to each other. If two route buffers overlap only for a small portion, the competing effect will be small. If two
routes run very closely or even on the same road, a service change on one route will have a greater impact on the other. The area of overlap, or, more precisely, the population in the overlap area, between the two competing routes determines the inter-route effects. The population in the overlap area of two competing routes can be conveniently estimated using the overlay function in GIS. It is defined as:

\[
\text{OVLAY}_{ij} = \frac{\text{POP}_{ij}}{\text{POP}_{ij}}
\]  

(13)

Where, OVLAY% is the proportion of population in the overlap areas to the population in the competing route buffer, the subscript of i refers to the route of interest, j refers to the competing route of i. The subscript of z refers to the route segment fare zone number.

The inter-route relationship discussed above assumes a homogeneous and barrier-free surface, these inter-route relationships have to be checked against geographical barriers, such as freeways, rivers and steep slopes. Two routes may be in parallel and their buffers overlap, but if there is a freeway or a river between them, they cannot compete for riders with each other. Potential riders cannot cross the freeway or the river to ride the bus on the other side. All bus routes have to be checked against these geographic barriers in the identification of inter-route linkages.

The inter-route relationship can be estimated by a simultaneous equation model. Ridership on the route of interest is modeled as a function of total ridership on the competing routes and complementary routes, as well as the service and demographic variables on the route of interest. The ridership of the complementary and competing routes is modeled as a function of ridership and service on the route of interest, the service and demographic data in the complementary and competing routes.

The simultaneous equation model results (Pong 1994) indicate that there exists a strong relationship among related transit routes. The ridership on one route depends on the ridership and service of the competing and complementary routes, and vice versa. A service improvement on the subject road will draw away some rides from its competing routes. The boarding rides on the subject route but will decrease on the competing routes, so the net effects of the service improvement is smaller than the boarding ride increase on the subject route. The magnitude of the net effects depends on the strength of the relationship with competing routes. The more the two routes overlap, the more competing effects and the less of the net effects of service changes.

Conclusions

GIS is a powerful and efficient tool in spatial data integration and inter-route relationship analysis. It has an important role in route-level transit demand modeling. The spatial data allocation in GIS is essential to integrate different spatial data sets to support transit demand modeling. It is a capable tool to achieve data consistency and to analyze inter-route relationships. Important GIS database design issues have been developed to maintain spatial and temporal data for transit demand modeling.

GIS database design and spatial data integration are used to increase the accuracy and validity of relating transit ridership and service data to demographic and employment data. The results of data integration show that various allocation methods would result in different allocation accuracy. But even a simple allocation based solely on the area percentage coverage would be an improvement over no allocation at all. An appropriate data allocation could significant reduce measurement error, and increase the validity, accuracy and consistency of spatial and attribute data in route-level modeling. The comparison of different data allocation methods provides a framework for analysis of spatial and attribute data allocation. Hopefully, it will promote a more systematic choice of allocation methods used in GIS analysis.

This paper also provides an approach to inter-route relationship analysis. By overlaying transit route buffers, the physical relationship— independent, competing and complementary—among transit routes can be easily identified. This physical relationship can be further clarified by considering other geographic barriers. The strength of inter-route relationships was measured by analyzing the overlap area of transit route buffers. The inter-route analysis provides a basis for a simultaneous modeling analysis of the relationships among complementary and competing routes. This also provides a useful tool for transit planning.

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References


Abstract: This paper describes a decision-support methodology developed by the South Carolina Water Resources Commission for the selection of potential wetland mitigation sites, utilizing a GIS and 1:24,000 scale information sources to automate the mitigation site-evaluation process. The described methodology combines the capabilities of GIS technology with current scientific theory and narrows the choices for mitigation site selection based on landscape-scale indicators of wetland functions such as size, shape, contiguity and hydrologic position. This systematic approach thoroughly inventories the wetlands occurring within a watershed and identifies large complexes of potential mitigation sites. It offers obvious advantages over current piecemeal approaches to mitigation site selection which often contradict the goal of "no net loss" of wetland function due to the selection of sites which are fragmented or unconnected and not defensible in the long run. By explicitly stating ecological assumptions that should be considered when selecting sites for wetland mitigation, the proposed methodology can help streamline the decision-making process through an initial identification of potential mitigation sites requiring further site-specific evaluation by wetland specialists. As described in the paper, the model should be applied for advanced planning in establishing mitigation banks and for more specific analysis of proposed mitigation plans considering the long-term value of wetland functions actually enhanced by mitigation activities. It should be expanded and tested with better data as such information resources become available. It can provide needed guidance to our data collection and classification agenda. This model provides a foundation for working towards the goal of no net loss of wetland functions as we attempt to balance inevitable land use modifications with the watershed-level goals established by the Clean Water Act and related legislation.

Permitted land use, development pressures, and illegal fill activity continue to threaten the viability of our nation's wetlands. Although regulatory safeguards have been established to avoid or minimize the impacts resulting from such activities, compensatory mitigation is sometimes required to replace the ecological loss resulting from wetland destruction or fragmentation. In this study, potential mitigation sites on the South Carolina Coastal Plain are identified using a GIS and 1:24,000 scale information sources.

When designing strategies for mitigation, it is often assumed that area-for-area replacement of the same type of wetland (i.e., "in-kind"), at the same location as the filled wetland (i.e., "on-site"), will assure that any lost ecological function is offset. However, in-kind mitigation projects are often not available on-site. As a result, mitigation is pursued on-site/out-of-kind, off-site/in-kind or finally off-site/out-of-kind. Also, many projects, both on-site and off-site, are fragmented or unconnected and not defensible in the long run. Thus, conventional approaches to mitigation have the potential to counter the desired goal of "no net loss" of wetland acreage. Too often, the ability of a replacement wetland to mimic the ecological function of the filled wetland is questionable. The goal of "no net loss" of wetland function can also be contradicted.

To adequately address the issue of functional replacement, the potential mitigation site must first be considered as an integrated component of the landscape, hydrologically linked to all other land uses/land covers within the watershed (Lee and Gosselink 1988). Thus, sound mitigation strategies require identifying sites that have not only a high physical potential for successful mitigation (i.e., appropriate soils, hydrology, and vegetation), but also contribute to the
In 1985, URISA established the Horwood Critique Prize in memory of Dr. Edgar Horwood of the University of Washington, who founded URISA in 1966. The objective of the prize is to challenge information systems professionals to more critically interpret developments in the field. The prize is given annually to the author(s) of a paper published in the previous annual URISA Proceedings representing the best critical analysis of an urban, federal, regional or local system design, implementation or application; technology policy or issue; or contextual environment.

Papers are judged on their candor, critical insights, and conclusions and methods employed in the critique. All papers appearing in the Proceedings are judged in the competition. In this issue of the URISA Journal, we are featuring the 1995 Horwood winner, "Toward No Net Loss: A Methodology for Identifying Potential Wetland Mitigation Sites Using a GIS," by Cynthia R. Brown and Floyd O. Stayner. In keeping with the critical intent of these papers, we welcome your comments.

Data Development

The data used in this study were developed by the South Carolina Water Resources Commission (SCWRC) as part of the Natural Resources Decision Support System (NRDSS) project that began in 1988 (Hale et al. 1991). One of the objectives of the project was to develop a GIS to provide products and services to support natural resource management decisions. Table 1 describes available data coverages used in this study.

Each data layer used in this study adheres to accepted national data classification systems and mapping standards as established by various federal programs. These include the U.S. Geological Survey’s (USGS) National Mapping Division’s Digital Line Graph (DLG) program, U.S. Fish and Wildlife Service’s National Wetlands Inventory (NWI) program, and the Natural Resource and Conservation Service’s (NRCS) county soils mapping program. All data are based on the 1:24,000 scale USGS topographic map series. The digital data are registered to common geographic registration coordinates, insuring comparability of various data layers in scientific analyses.

The layers of primary importance to this study are wetlands, land use, soils, roads, hydrography, and significant natural areas. The wetlands data are derived from 1:40,000 color infrared National Aerial Photography Program (NAPP) photography captured in 1989. Wetlands delineations are classified according to the Cowardin classification system developed by the NWI (Cowardin et al. 1979). For the purposes of this study, the wetland classification are simplified to four categories of community types:

- savannas/wet meadows/freshwater marsh;
- wet flatwoods/pine savannas;
- bottomland hardwoods/wooded swamp/deciduous shrub swamp; and
- bayforest/evergreen shrub bog.

The land use data are photointerpreted in conjunction with the wetlands data. Land use is mapped for all upland areas, or those areas not classified as wetlands. These data are classified to Level II of the Anderson classification system (Anderson 1976). The land use cat-

overall ecological integrity of the entire watershed. In many instances, off-site wetlands located within the same watershed best meet these criteria. In identifying these potential mitigation sites, it is necessary to recognize similar characteristics between the filled and replacement wetland sites.

Our understanding of how wetland characteristics relate to wetland function has greatly increased in the last several years. Certain large-scale, physical characteristics of wetlands, including the size, shape, and position of a wetland site on the landscape, generally support wetland function (Brisson 1988; Preston and Bedford 1988; O’Neil et al. 1991; Whigham et al. 1988; Kuenzler 1989; Taylor et al. 1990; Harris and Gosselink 1990). GIS is a tool that can be used by regulators and managers to help identify and evaluate these landscape-scale characteristics. The GIS methodology proposed in this study provides an initial screening tool for identifying complexes of wetlands within a hydrologic unit that are physically amenable to restoration, enhancement or protection. Sites determined to be physically suitable for wetland mitigation are segregated into community type and further evaluated to determine their potential to provide “opportunity,” or social/ecological benefits, and to assess threats that may influence the utility of the site. While wetlands are responsible for providing a broad spectrum of ecological and social benefits, those considered in this study include a site’s potential to contribute to wildlife habitat (based on contiguity, fragmentation, size, and extent of interior habitat) and water quality and floodwater storage (based on geomorphological setting, stream order and stream proximity). In addition, known locations of endangered/threatened/rare species habitat and significant natural areas, as well as cultural resources, are considered. Threats are identified in this study as potential toxic, nutrient, or sediment sources and include mines, hazardous waste sites, and industrial and domestic waste landfills. The Four Hole Swamp subbasin in South Carolina is used as a case study for the application of this model.
### TABLE 1. Data Used in Analyses

<table>
<thead>
<tr>
<th>Coverage</th>
<th>Source</th>
<th>Data Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining and reclamation</td>
<td>South Carolina Land Resources Conservation Commission</td>
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<tr>
<td>Hazardous wastes treatment, storage and disposal</td>
<td>South Carolina Department of Health and Environmental Control</td>
<td>point</td>
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<tr>
<td>All landfills</td>
<td>South Carolina Department of Health and Environmental Control</td>
<td>polygon</td>
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<td>Archaeology</td>
<td>South Carolina Institute of Archaeology and Anthropology</td>
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<td>National Register of Historic Places</td>
<td>South Carolina Department of Archives &amp; History, U.S. Department of the Interior</td>
<td>polygon/point</td>
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<td>Protected areas (government parks, forests, refuges)</td>
<td>U.S. Geological Survey topographic quadrangle maps</td>
<td>polygon</td>
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<tr>
<td>Sensitive species and communities of concern</td>
<td>South Carolina Wildlife and Marine Resources Department</td>
<td>point</td>
</tr>
<tr>
<td>Digital line graphs (separate coverages for roads, hydrography)</td>
<td>U.S. Geological Survey topographic quadrangle maps</td>
<td>line</td>
</tr>
<tr>
<td>Soils</td>
<td>Natural Resource and Conservation Service topographic quadrangle maps</td>
<td>polygon</td>
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<tr>
<td>Land use</td>
<td>1989 NAPP 1:40000 photography, 10-acre resolution, South Carolina Water Resources Commission</td>
<td>polygon</td>
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<tr>
<td>Wetlands</td>
<td>1989 NAPP 1:40000 photography, 1-acre resolution, National Wetlands Inventory, U.S. Fish and Wildlife Service</td>
<td>polygon</td>
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<tr>
<td>Natural Areas Inventory</td>
<td>1989 NAPP 1:40000 photography, South Carolina Water Resources Commission</td>
<td>polygon</td>
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</table>

The soils data are derived from standard NRCS county soils maps. A hydric attribute was added to label those soils that have hydric characteristics as defined for each county by SCS. The hydric soils category used in this study was reduced substantially to include only those with no agricultural productivity potential as determined by state soil scientists.

The roads and hydrography are standard USGS 1:24,000 scale (DLG) products. Several attributes were added to the DLG data by SCWRC, including drainage order, which is pertinent to this study. All streams in the hydrography data layer were ordered by using the Strahler method of stream ordering (Strahler 1952). The SCWRC employs several quality-control procedures on the data to correct various problems with the original digital data. These procedures include edge-matching and attribute correction where possible. One problem with the DLG data that could not be corrected was the currency problems inherent with 1:24,000 quad maps that are the source for DLG data. These maps range in date from 1960 to 1989 in the study area. Funding and source material were not available to update any of the older data.

The significant natural-areas data layer was developed as a result of the Natural Areas Inventory, a study sponsored by the National Oceanic and Atmospheric Administration and conducted by the South Carolina Water Resources Commission and The Nature Conservancy (White 1993). In this study, natural areas of particular ecological significance were delineated by using NAPP photography and field-verified by overflights and ground surveys. The final sites were then digitized by the SCWRC. The purpose of this systematic survey was to identify sites in the study area with relatively undisturbed, high-quality natural communities.

Other data themes available for this study include domestic waste permits, industrial waste permits, hazardous waste sites, archaeology sites, historic sites, sensitive species and communities of concern sites, and mining and reclamation sites. These data were obtained from the agencies responsible for the particular permitting activities.

### Model Components

When identifying sites suitable for mitigation, a wide spectrum of factors must be considered. These include the potential for successful mitigation posed by physical characteristics and the potential public or natural resource benefits provided by mitigation. Logistical considerations, such as availability for acquisition and
number of landowners, are also valid considerations but were beyond the scope of this study. However, these could be considered if more detailed spatial data themes covering these elements were available (e.g., parcel maps, real estate data). The sequence of analytical steps used to address the model components is as follows:

- Identify wetlands (by community type and watershed) that are physically amenable to mitigation; then
- Evaluate the opportunity potential of these sites to provide public benefits through either improved wildlife habitat, water-quality enhancement or floodwater storage; and finally
- Further assess the opportunity a site provides (or potential limitations it poses) by identifying unique cultural or public benefits (e.g., endangered species, historic/archaeologic sites) and assess the threats (e.g., nearby mines, landfills) that may diminish a site’s long-term mitigation potential.

**Physical Suitability Analysis—defining mitigation classes**

In conducting the physical suitability analysis, three types of potential mitigation classes are identified: restoration and enhancement sites, which possess potential for wetland reestablishment; and protection sites, which represent viable, functioning wetlands important to the ecological landscape (Table 2).

Mitigation efforts in the Southeast sometimes involve restoration of marginal agriculture lands to bottomland hardwood wetlands (personal communication, Dr. Russell Lea, Hardwood Research Cooperative, North Carolina State University). These lands typically occur on the margins of flood plains where the hydrologic regime is unpredictable. Frequent flooding makes these areas effectively unproductive for agriculture. Farmers are often willing to allow their property to be restored to an original bottomland hardwood community, for example, and have future use restricted by perpetual conservation easements or other transfers of development rights. In this study, potential restoration sites are identified by first identifying hydric soils, as defined for each county by the SCS. These include those soils for which the entire mapped area is identified as hydric. These areas are further analyzed to determine mitigation potential on the basis of soil productivity as derived from the SCS Land Capability Classes. Only those soils with low reported crop yields are given consideration in this study. State soil scientists have further reduced the list of potential soil types to those that have extremely limited or no agricultural productivity. Next, agricultural areas are identified in the Anderson level II land use data layer and overlaid with the hydric soils data to find corresponding areas. The agricultural areas that are identified as hydric are assumed, in this methodology, to represent wetlands that have been converted to crop-land. All such areas are termed prior converted (PC) wetlands in this study.

In order to identify sites suitable for enhancement, the 1989 NWI data are analyzed to identify areas that have been altered to some extent by dikes, impoundments, excavations, drains or ditches. Only those areas that support hydropytic vegetation (i.e., palustrine emergent, palustrine scrub shrub, palustrine forested) are included in this analysis. Interpretation of the alphanumeric NWI code can often lend insight into community type or land use at the time of image capture. For example, excavated areas likely represent abandoned gravel pits, large ditches or the occasional sewage treatment pond. Impounded areas are often wetlands associated with dams or stock ponds. Drained areas exist where the water level has been lowered but where hydrophytes have survived. It should be noted that wetland vegetation may remain intact for decades after drainage. Thus, even though hydrologically altered wetlands support hydropytic vegetation, changes in hydroperiod imply changes in wetland function (Brinson 1988). Although these systems are characterized as wetlands, restoring their hydrology could prevent the inevitable conversion to a system characteristic of drier soils. In general, it has been suggested that most ditched/partially drained sites likely represent silviculture areas or abandoned agriculture fields. In some instances, the surrounding floodplain of a channelized stream might also have mitigation potential (personal communication, Charlie Storrs, U.S. Fish and Wildlife Service).

Protection sites include all NWI wetlands that theoretically have not been modified as described above. For purposes of this analysis it is assumed that these wetlands are fully functional wetlands that are crucial in providing habitat, maintaining water quality and sustaining proper hydrologic function. Ecologically, these sites are extremely important. It can be argued that preservation of these viable areas is a desirable component of a mitigation plan, as they provide some current level of ecological function. These areas can also increase the likelihood of successful mitigation of nearby

<table>
<thead>
<tr>
<th>TABLE 2. Definition of Mitigation Classes</th>
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<tr>
<td><strong>Summary Of Mitigation Classes</strong></td>
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<tr>
<td>• Restoration—agricultural fields with hydric, marginally productive or unproductive soils, which represent prior converted wetlands</td>
</tr>
<tr>
<td>• Enhancement—all modified NWI wetlands (ditched/partially drained, excavated, or diked/impounded)</td>
</tr>
<tr>
<td>• Protection—all NWI wetlands that have not been modified</td>
</tr>
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</table>

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degraded sites due to intact hydrology and the presence of a seed source. This methodology requires that connected mitigation sites be identified according to the status and position of currently existing, functional wetlands. It is necessary to identify these unmodified wetlands in order to perform proximal analyses.

**Opportunity Analyses: determining the benefits**

Opportunity analyses are performed in order to evaluate the potential that an identified potential mitigation site might have in providing public, natural, or cultural benefits on the basis of watershed characteristics. The opportunities, or benefits, considered for these analyses are wildlife habitat, water quality, and floodwater storage.

**Wildlife Habitat**

Many native species populations are in decline in South Carolina, as in other parts of the country. While population decline is attributable to a variety of causes, habitat loss and fragmentation are perhaps the most significant. Reduction in biological diversity and species quantity is directly related to the reduction in total area available for wildlife habitat. This is especially true for far-ranging species requiring extensive tracts of land with adequate interior habitat. Fragmentation results in a landscape well-suited for edge species such as deer. Thus, mitigation strategies should consider habitat needs for those species less adaptable to human-induced perturbations on the landscape and should place priority on large intact sites with a large proportion of interior habitat. Also, since many species utilize a range of habitats during their life cycle or seasonally, it is important that upland/wetland complexes be identified. The criteria used to identify mitigation sites in this analysis prioritize mitigation sites based on their contiguity with upland habitats, their degree of fragmentation, the presence of interior habitat and total habitat area.

Mitigation sites that are optimal for wildlife habitat are identified by first defining core habitat sites and then identifying contiguous enhancement and restoration sites. Core habitat sites are defined in this study as all unmodified wetland sites (protection sites), as well as all impact upland forests (excluding pine plantations), protected areas (i.e., wildlife refuges, state parks, national forests) and significant natural areas as identified by the Natural Areas Inventory.

Contiguous enhancement and restoration sites that, if mitigated, would extend the acreage of these core habitat sites are then identified. This association of core habitat sites and contiguous mitigation sites is termed “habitat complex.” Identified habitat complexes as well as contiguous mitigation sites (without associated core habitat sites) are further analyzed to determine optimal wildlife habitat on the basis of three criteria: fragmentation, extent of interior habitat, and size.

All habitat complexes and potential mitigation sites are evaluated for fragmentation by considering the existence of paved roads. Large multi-lane or divided highways pose significant barriers to wildlife movement. These highways are overlaid on the selected habitat sites to further divide the sites and determine true habitat boundaries.

Edge habitat is common across the landscape; it can therefore be argued that habitat needs for edge species are already met by the existing landscape conditions. Thus, the habitat complexes meeting the above criteria are further analyzed to determine conditions supporting good interior habitat. In this analysis, the complex boundaries are reduced by 328 feet (100 meters) to determine interior habitat (Temple 1986; from O’Neill et al. 1991). It is theorized that this distance effectively represents edge habitat. If any of the complex remains after reduction, it can be assumed that the complex provides some interior habitat function. The habitat sites remaining after reduction are expanded back to their original boundaries.

Finally, only habitat complexes of at least 40 acres in size are considered for the rest of the habitat analysis (Adams 1987). Also considered are all enhancement and restoration sites that are not part of a habitat complex but that are at least 40 acres in size. Figure 1 provides a summary of steps used in the wildlife habitat analyses.

**Water Quality and Floodwater Storage**

Because wetland systems are extremely variable in structural characteristics, it is difficult to identify unifying concepts that would allow a convenient breakdown of wetland types on the basis of water quality or hydrologic function. However, it is recognized that watershed-level characteristics do influence a site’s potential to serve these functions.

Wetland location within a watershed is an important determinant of its contribution to water quality. Brinson (1988) contended that riverine wetlands, because of their extensive association with upland systems and the nature of their soils, have both high capacity and opportunity to positively impact water quality and to store floodflow. Because of this, and because of their abundance in the study area, these wetland sites are given sole consideration in the water quality and floodwater storage analyses. A wetland’s position along a drainage network also influences its opportunity to contribute to water quality and store floodflow (Kuenzler 1989; Brinson 1988; Whigham et al. 1988). Riparian transport, or overland water runoff, from agriculture, urban and silviculture areas first encounters wetlands associated with small order streams. It is here that a majority of the
FIGURE 1. Steps in Wildlife Habitat Analyses.

Upland forests, excluding pine plantations

Significant Natural Areas

Core habitat sites

Determine fragmentation of habitat complex by overlaying multi-land and divided roads

Reestablish original extent of remaining complexes by buffering 328 feet (100 meters)

Optimal Wildlife Habitat sites

All protected areas

Protection mitigation sites (unmodified NWI wetlands)

Identify contiguous modified NWI and PC wetland sites and define habitat complex

Buffer inward 328 feet (100 meters) to determine extent of interior habitat

Eliminate all habitat complexes less than 40 acres

nutrients and sediments resulting from these land uses settle out and are recycled. Thus, with some exceptions, low-order wetlands have a greater opportunity to enhance water quality than do higher order wetlands (Whigham et al. 1988; Kuenzler 1989). Also, runoff is attenuated in these wetlands, helping to alleviate downstream flooding. Those wetlands immediately adjacent to a stream have an even greater opportunity to remove pollutants before they are introduced into the water column. In higher order wetlands, overbank flow dominates. In general, these downstream wetland systems, especially if immediately adjacent to a stream, have greater opportunity to store excess streamflow during peak events (Taylor et al. 1990; Harris and Gosselink 1990). It is also recognized that a pollutant removal function will subsequently result from water storage.

In this analysis, all riverine wetland mitigation sites immediately adjacent to a stream, as delineated on the DLGs, are identified. To determine wetland adjacency, streams are buffered 98.4 feet (30 meters) on both sides, and wetlands falling within the resulting polygon are identified. These areas, because of their adjacency, are considered primary wetlands for hydrology and water-quality function. Each is assigned a wetland order according to the order of its associated stream. Lower-order wetlands represent those that, theoretically, have the greatest potential impact on water quality while attenuating runoff. Higher-order wetlands represent those that might have the greatest opportunity to store floodflow while effectively removing pollutants from floodwaters.

Hydrologic connectivity of all other riverine wetland sites is then determined by identifying sites that are adjacent to the sites adjacent to a stream (as defined in above paragraph). All connected sites are classified according to their associated wetland and termed secondary wetlands. The sequence of steps taken in these analyses is presented in Figure 2.

Unique Opportunities/Barriers and Potential Threats—locating endangered species, cultural resources, and potential contaminant sources

Endangered species habitat and cultural resource sites (archaeologic/historic sites) represent important public resources and benefit from some protection provided by state and federal programs. Sites containing these resources may or may not be optimal for mitigation. The impact, either negative or positive, of a mitigation project on these resources should be determined on a site-specific basis. These sites are identified and overlaid on the final composite, created by overlaying the results of the habitat and water quality/floodwater storage analyses.

In many instances, cultural and endangered species inventories have been done primarily in areas where development has occurred. While occurrence information exists for those sites, geographically extensive spatial data coverages that are “complete” for these themes do not exist. It should be noted that this methodology will, in most cases, direct initial selections for priority mitigation sites to areas that are fairly remote and are least likely to have thorough pre-established rare/endangered species habitat and cultural inventories. Synoptic assessment of these impacts are deemed appropriate for this methodology only with subsequent site-specific inventory work.

As previously mentioned, a Natural Areas Inventory of the study area was performed in 1992 in order to identify natural areas of significance. The result of that
inventory indicate that natural habitat acreage—especially upland habitat—has dramatically decreased in the study area. In fact, for the most part, river corridors serve as the last refuge for natural plant communities. These identified communities as well as any upland significant natural areas are overlaid on the composite to graphically display priority wetland mitigation sites in relation to these features.

Finally, it is recognized that surrounding land uses and management practices may pose a threat to the continued viability of a mitigation site. Conversely, the negative impacts of these activities could be ameliorated by a restored or enhanced wetland. In this study, potential sources of threat are defined as nutrient, sediment, and toxicant sources and include domestic and industrial landfills, mines, and hazardous-waste sites. The proximity of these potential sources to mitigation sites is graphically represented on the final composite. Figure 2 provides a complete overview of the summary of steps used in identifying potential mitigation sites.

Results
The physical suitability analyses were successful in thoroughly inventorying the landscape for potential protection and enhancement sites according to their respective definitions, although wetlands other than those delineated by NWI were not identified. Field verification revealed that abandoned farmed wetlands and prior converted wetlands were common throughout the study area although not always selected by this methodology as potential restoration sites. This is partially attributable to the rather conservative selection of hydric soils used in the overlay operation. If the entire list of hydric soils had been used for each county rather than the few identified in this study as extremely hydric, it is probable that this methodology would have identified a greater number of the abandoned farmed wetland and prior converted sites existing in Four Hole Swamp sub-basin. However, the factors contributing to the wholesale abandonment of farming operations in the Coastal Plain and in other places are largely a function of complex economic conditions and only partially related to the physical characteristics of the soil. Data on farmland abandonment are available in hard copy from SCS. It is feasible that these data, in digital form or otherwise, could be used to supplement the results obtained from these GIS analyses in identifying PC wetlands.

Results from this field verification of study results also indicate that although the model was successful in identifying enhancement sites—many of which are currently being effectively drained—there are actually a greater number of potential enhancement sites in the field than determined by this methodology. This is due
FIGURE 3. Summary of Steps for Identifying Potential Mitigation Sites.

Define protection sites (intact NWI wetlands) by community type

Define enhancement sites (all modified NWI wetlands) by community type

Define restoration sites (PC wetlands)

Natural Areas Inventory sites

Upland forests (excluding pine plantations)

Core wildlife habitat sites

Protected sites (State Parks, National Forests)

Identify core/mitigation complexes based on:
1) fragmentation
2) interior habitat
3) size

Identify all riverine potential mitigation sites based on:
1) stream order
2) hydrologic connectivity

Optimal Wildlife Habitat Mitigation Sites
(large unfragmented complexes with adequate interior habitat)

Optimal Water Quality Mitigation Sites
(primary and secondary low-order wetland sites)

Optimal Flood Storage Mitigation Sites
(primary and secondary high-order wetland sites)

Determine endangered species, significant natural areas, cultural resource site occurrence

Determine sources of potential threat

Optimal Potential Mitigation Sites Based On:
- Physical suitability
- Wildlife habitat benefit
- Water quality/floodflow storage contribution
- Consideration of endangered species, natural areas, cultural resources site occurrence
- Consideration of potential sources of threat

Unique Opportunities, Barriers and Potential Threats Analyses

Optimal Potential Mitigation Sites
to the fact that a large number of sites identified as protection sites in the NWI data have actually been modified in some way. While the data used for application of this methodology were fairly current, it is recognized that cross-referencing the final sites selected through this methodology with NAPP or other aerial photography, prior to field verification, would expedite the site-selection process. Interpretation of current aerial photography can detect recent changes in land use or land cover as well as verify the alphanumeric code provided by the NWI data.

Execution of the wildlife habitat component resulted in successful identification of potential mitigation sites that might serve as optimal habitat according to model definitions. Many of the restoration sites fell out of the model; however, large complexes of the three mitigation classes, all which possess adequate interior habitat, were found. Execution of the water quality/floodwater storage analyses was not completely successful in identifying distinct low- and high-order wetland sites. While high-order wetlands were consistently identified along the mainstem of the drainage system, low-order wetlands were identified in the headwaters as well as on the mainstem. A different characterization of wetland orders would likely contribute to better definition of these areas. In addition, a clear delineation of primary and secondary sites was not always possible. This component of the methodology could not consider the complex hydrology existing in the Four Hole Swamp drainage system. Elevation data would be required to better characterize hydrologic conditions in the riparian system.

Conclusions

This model provides a basis for identifying potential wetland mitigation sites according to physical factors (soils, hydrology, vegetation) and according to the following characteristics indicative of ecological function:

- Fragmentation.
- Contiguity with other wetland areas and, thus, inclusion in large complexes.
- Optimal wildlife habitat on the basis of existence of interior habitat.
- Juxtaposition to water bodies and, thus, the opportunity to provide floodflow storage and water quality improvement.
- The existence of potential threats to the ecological integrity of a site.
- Unique opportunities to provide habitat for rare, threatened, or endangered species and communities.

Wetland mitigation sites identified by this methodology can be reported by community type, size, watershed location, and potential opportunity contribution. This information can help managers and regulators identify complexes of in-kind mitigation areas within the same watershed as the filled wetland and, with information provided by the opportunity analyses, make an initial judgment about a site’s potential to replace lost wetland functions. Indicated sites might be more thoroughly assessed by descriptive methods of functional evaluation such as the Habitat Evaluation Procedures or the Wetlands Evaluation Technique to better determine opportunity potential. This methodology is especially effective in identifying large complexes of mitigation sites, rather than isolated fragmented areas. Thus, it can be a useful tool for identifying potential sites for mitigation banks.

Because this methodology is a decision-support tool, the resulting information can better direct mitigation decisions made by those in the regulatory arena. It considers landscape level indicators of function and places priority on large, contiguous complexes of potential mitigation sites. By explicitly stating ecological assumptions that should be considered when selecting sites for wetland mitigation, it can help streamline the decision-making process through an initial identification of sites which, upon mitigation, could contribute to the overall ecological function of the watershed.
Acknowledgements

This study was prepared with funding from the United States Environmental Protection Agency Region IV Office of Wetland Planning.

References


In this issue...

We continue an ongoing examination of what goes into building a successful GIS. For an organization, that requires putting thought into designing the very infrastructure that supports the GIS. Here, Rebecca Somers and Tommie Howell offer two views on what—that means from slightly different perspectives.

Included in this issue is an overview of a new program designed to teach students about spatial learning. The program, Spatialists in Information Technology: URISA’s Program for Student Studies (SIT:UPSS), hosted in conjunction with last year’s annual conference, was a first-of-its-kind, two-day workshop. The short course may ultimately be a precursor to a full-blown GIS curriculum designed for the elementary-school classroom of the future.

Speaking of innovation, an article by Kristine Kuhlman and Ben Niemann track the land-record modernization process in Wisconsin and Ohio counties. Tracking what helps, and what hinders, new technologies that are introduced is important when developing strategies to streamline the process.

Last, an article by Richard Annitto and Bradford Patterson looks at the latest in network and wiring technologies that support the various growing information technologies. Each technical issue is discussed in the context of a case study application.

Editorial Intent

The URISA Journal was originally conceived as having several sections. The Refereed portion would be the most intellectually rigorous, suitable for academic submittals. The Feature section would be more journalistic and visual (that is, giving special emphasis to maps, photographs, other graphics). The remaining sections—Feature Map, Reviews, In My Opinion—are, hopefully, unambiguous. Now, with the Journal beginning its fifth year, this conceptual framework appears to be working. We will, accordingly, carry on.

In the Feature section, we welcome material that is: serious or not so serious; visionary or pragmatic; domestic or international; public or private sector; high or low tech; far-fetched or down-to-earth; managerial or technical; vocational or educational; qualitative or quantitative; GIS or non-GIS. In short, we are open to different ways the world can be explored, described, understood.

Norman Cousins has said “No one really knows enough to be a pessimist.” Assuming further that no one can ever know enough to be a pessimist, the pursuit of knowledge must therefore be an optimistic (or, at worst, realistic) endeavor. Torturing the logic a bit further, an optimistic endeavor is joyful and therefore—ah ha!—contributing material to the Features section is pleasurable. So, please do so.

We ask only that you submit material you genuinely believe will interest URISA’s members, and of which you are truly proud.

Lynne Wiggins
Organizing and Staffing a Successful GIS: Organization Strategies

Rebecca Somers

Editor's Note: This is the first of a two-part article on organizing and staffing a GIS. Here, the author discusses the basic organizational principles behind a sound GIS implementation. In the next issue of URISA Journal, the author will discuss staffing in detail.

In the past two decades, GIS implementation within organizations has become commonplace. It is only within the past few years, however, that attention has shifted from the technical aspects of GIS implementation to the organizational ones. Now it is commonly accepted that organization and staffing strategies will determine the ultimate success of a GIS, but guidance on how to develop successful GIS organization and staffing strategies is more difficult to find.

Examining how other organizations plan and implement a GIS can be valuable, however, others' strategies should be evaluated critically in light of your own organization's circumstances and requirements.

The primary objective of organization and staff development is to make GIS a useful tool for users, not a nuisance. The goal of the GIS staff is to make GIS fit as seamlessly as possible into the users' job environment.

GIS Factors

A number of key factors are involved in developing the appropriate organization and staffing for a GIS project or enterprise. These factors include:

- The number of users, applications and participants. These factors will determine the extent of the system, and more specifically, the coordination, communication and support requirements. The numbers alone can compound the problem in geometric proportions. The diversity of the users, applications and participants creates a breadth to the issues of communication and support that can be overwhelming if not handled properly. The key to developing a strategy for handling any multifaceted GIS is to distill commonalities from a thorough analysis. Identification of commonalities and strategies to meet the needs of users who have some similarities in their interests and needs is crucial to leveraging the organizational and staff resources involved in a GIS.

- The size of the system affects the magnitude of the GIS support staff functions. For example, if the GIS involves vast amounts of data, a large number of user seats, extensive networking and large and/or numerous applications programs, the amount of GIS support staff resources required to handle this environment will be proportionately large.

- Characteristics of the applications and uses determine the type of support functions required. For example, if the GIS is a relatively large system, but all the users are involved in the same application activities, then the support requirements would be less than those for a smaller, but highly diverse system.

- Characteristics, volume, types, and uses of the GIS data affect the data input, quality control, production, maintenance and management functions, and thus the staff organizations and functions to support them.

Determining the GIS support requirements dictated by these factors will reveal important aspects of the necessary GIS organization and staffing approach.

The Role of GIS

The intended role of GIS in the organization is the other major determinant of the organization and staffing plans. "Vision" or "mission" are terms commonly applied to this statement of purpose and role. Whatever it is called, a clear articulation of the planned role of GIS in the organization and agreement among all participants regarding this role is crucial to avoid problems "downstream" during implementation.

Key questions to ask include:

- What will be the short-term and long-term roles of GIS?
- Who will be using it?
- What are the various development tasks that must be done?
- What are the long-term operational goals?

Rebecca Somers is president of Somers-St. Claire, GIS Management Consultants in Fairfax, VA. She has been active in GIS for over 18 years, and is co-editor of URISA Journal's Reviews section.
Which functions and systems will GIS integrate with?

The answers to these questions are a starting point for designing an organization’s GIS staffing plans. Answer these questions before asking, “What staff positions are needed?”

Will GIS become a permanent part of your organization, or just provide capabilities that are limited in terms of time and scope? The staffing responses to each situation are different.

Long-term, program, operational and integration needs call for the design of GIS positions and functions that integrate into the workflow of the organization. Achieving the permanent organizational design may be a multi-step process.

GIS projects that are limited in scope or time may require a separate GIS staff that has its own organizational unit. This unit may only comprise a project manager and consulting services. If GIS needs are limited in scope and apply to only one area, it may be preferable to integrate the GIS skills into the existing professional positions. In this situation, GIS may “disappear” into the organization, and become no more significant than spreadsheets or modeling software regularly employed by the professional GIS would simply be part of the professional toolbox. There would be no “GIS staff.”

Another distinction concerns the difference between full-time GIS users, part-time GIS users and support staff. Users are generally not “GIS personnel.” In the worst case, this issue may become confused by poor GIS staff planning. For example, organizations that have designed the GIS staff in isolation, without considering how it fits into the overall organization, find that the GIS personnel and professionals in other departments start to play “musical chairs” in order to obtain pay increases. Disproportionately low-paid GIS staff may apply for planning or engineering jobs (for which they are less qualified professionally) in order to get the higher salary resulting from the addition of GIS skills to an existing planning position.

On the other hand, professionals who use GIS may abandon their professional positions and apply for GIS staff positions if the pay for the latter is disproportionately high. While the potential for mobility within an organization is desirable, unplanned revolving doors cost an organization a great deal in terms of training, recruitment and administrative costs. Avoiding this problem depends on clearly defining the role and character of the GIS initially.

Organizing GIS Participants

Coordination and communication among multiple GIS users is the major goal in developing an organizational plan. There are two key aspects to address:

1) Varied interests and skill levels of participants, and
2) the lateral nature of interdepartmental coordination.

Multiple participants bring varied interests, application needs, data needs, priorities, organizational issues and political interests to a common project—the GIS. The varied interests must be identified and addressed, and the necessary compromises developed.

Lateral communication and coordination between departments within a hierarchical bureaucracy is not a new issue. GIS aside, many organizations have tackled this problem in order to accomplish joint projects among departments. GIS can complicate the issue because the data and the accompanying processes are often complexly interwoven within the organization.

Figure 1 depicts a model for GIS coordination and communication. The model is based on common approaches to organizing a GIS from diverse organizational situations (Somers 1995).

In the model, the Executive Committee provides policy guidance and support to the GIS effort. Typically, this committee consists of the heads of the major departments involved in the GIS. The Technical Committee provides the driving force for the actual design and development of the

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**FIGURE 1.** Lateral Coordination in Hierarchical Organizations.
Where To Place GIS in the Organization

The location of the GIS staff unit within the organization can be an important factor determining the success of the GIS, or at least the ease with which success can be achieved. There are three basic choices for placing GIS management: in a line organization, in a support area, or at the executive level. Each has its advantages and disadvantages.

- Placement in a line organization would involve positioning GIS management and staff within an operating unit such as planning, engineering, assessment, or facility design. GISs have been initiated and operated at all levels of line organizations over the years. The advantages of this placement, and indeed the reason that many GISs start in such a location, include the obvious tying of GIS to an operational need and budget. However, if the GIS is to serve multiple users in other departments, such a location can be a disadvantage when it comes to coordination. Lack of inherent authority, lack of visibility and possibly a weak budget position also can aggravate this placement.

- Placement at the executive level requires the GIS manager to report to a top decision-maker in the organization, such as the CEO, the mayor’s office, or the assistant county executive. Advantages from such placement include high visibility, inherent authority when dealing with coordination and communication matters, top executive support, and perhaps a strong budget position. Disadvantages may include a perception on the users’ part that the GIS management is too far removed from their operational needs. In addition, high visibility may prove to be a weak point in terms of top management support and budget in a highly charged political atmosphere.

In the past, many GIS projects were initiated in line departments. This was because of the inherent advantages of being tied directly to an operational need and a budget line item, as well as the direct support and control of a manager who saw the need for GIS. As such projects expanded to serve other depart-

Take advantage of the strong points of GIS position and recognize and counteract the disadvantages.

- Placement in a support unit of the organization includes such departments as Information Systems or Data Processing, Technology Support or Management Support. This placement strategy puts GIS within an existing support environment. This provides a professional and objective image for the GIS and its personnel. It also can protect the operations and budget for the GIS while in the developmental stages. Disadvantages in-
users that the system was not being developed according to their needs. In many instances, the displeasure and impatience of these users has led them to initiate independent GIS activities. Another danger of placement at the executive level is that GIS will become a department in its own right. This may lead to extensive duplication of effort within the organization, particularly between the GIS department and the Information Systems department.

Often, placement of the GIS is not a matter of choice, but more of history, budget, chance or opportunity. As they evolve and grow, many GIS operations move from one part of the organization to another—most commonly “up.” In any case, the key point is to take advantage of the strong points of the GIS position and to recognize and counteract the disadvantages.

Where a GIS begins is important, but even more important than where it begins is where it is intended to end. In other words, one structure and location may be good for fostering the development and growth of the GIS, while, long-range plans for the organization’s GIS operation may call for a different design of the organization and location of the GIS management and operation.

When to Do the GIS Organizational Plan

Organization and staffing plans are an integral part of the GIS planning and implementation effort. An organization should begin its GIS organization and staffing plans at the same time it begins its GIS concept planning. Waiting too long has been the root of many organizations’ problems.

Next Issue: Staffing a GIS

References


Debbie, a veteran 911 "telecommunicator," was working her shift at the computer-aided dispatch (CAD) console when the emergency call came in. A semi-hysterical out-of-towner exclaimed that she was witnessing a gasoline station hold-up in progress ... and, hadn't a clue of her whereabouts. All she was sure of was that a robber wearing a Big Bird mask had entered the station, and that she feared violence.

Knowing that many 911 callers were likely to be nervous and excitable, Debbie calmly and expertly fielded the most recent of the 1.7 million emergency calls that the Milwaukee Police Department receives each year. Using a skillful line of questioning, she deftly elicited information from the caller—information that could be integrated and analyzed by the CAD. Within minutes she pinpointed the exact location of the crime and confidently dispatched cruisers to the scene.

This simulated enactment of an everyday 911 scenario kicked off the "Spatialists" in Information Technology: URISA's Program for Student Studies (SIT:UPSS) program. This first-of-a-kind, two-day workshop for students in grades 5–12 was held on the weekend prior to the URISA 1994 annual conference. Thirteen students from the United States and Canada participated in a learning experience that used GIS to facilitate the development of spatially oriented problem-solving skills.

Thirty-six hours after seeing Debbie create a logical framework for resolving her spatial dilemma, students were themselves able to apply a retinue of similar skills to investigate case studies in a GIS-supported environment.

To date, there are only a few instances where GIS has been employed as an educational tool in pre-college classrooms. The idea for SIT:UPSS stemmed from a belief that curriculum modules could be designed that would allow students to semi-independently investigate topics with GIS that focus on spatial learning. This past summer's program proved this assumption to be valid.

The initial SIT:UPSS activities employed traditional mapping exercises to illustrate problems and issues related to information obtained from maps. Participants discovered the value of being able to control how various data types can be displayed, the importance of pattern recognition, and why the ability to ask good questions is so critical for solving problems with a spatial component.

The SIT:UPSS curriculum advisory board and chair created GIS-supported case studies that served as the core of the program. Each study included a scenario describing a problem faced by a fictitious community and specific tasks for student "teams" to complete. A customized database sufficient for completing an in-depth analysis of each case study accompanied each scenario.

The "Rapid Response Team" problem required students to develop a risk-assessment strategy to deal with a ruptured gasoline tank that contaminated Mudville's aquifer. In "Away from the Raging Waters of the Ponspons," student consultants created a relocation plan for Wethersbee, an upper-midwest town whose location in a floodplain made it the subject of frequent inundation. The final study...
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“Domino’s Pizza Delivers,” was a fast-food franchise siting and network/routing problem which was explored using streets, population and economic data.

The SIT: UPSS faculty consisted of a professor of urban planning and two high school teachers who currently use GIS in their curricula. During SIT: UPSS, they employed a cognitive apprenticeship approach to assist students in their spatial learning. Despite the lack of direct instruction with GIS, the support of the faculty and “Technological Facilitators” enabled students to rapidly become comfortable with the technology. An authentic project-based, problem-solving atmosphere emerged, and soon students were tossing about terms like open space, wetlands, topography, overlay, and routing.

During each SIT: UPSS learning module, students were provided with opportunities to acquire knowledge and develop skills to better comprehend space and spatial representations. During frequently scheduled periods of team presentation before the larger group of participants in the program, students demonstrated their knowledge of spatial relationships and provided rationale for the concepts, methods and strategies proposed by their team.

What we observed in SIT: UPSS confirms what many educators who rely extensively on technology in their teaching report. In such enhanced settings, traditional classroom roles are radically transformed. Teachers become mentors; students become workers and makers of their own meaning. The power of GIS to answer questions rapidly and to display environmental data in myriad ways gave students a degree of control over their learning that traditional classroom practices cannot provide. Nowhere was this more apparent than in the interaction between the technologi-

FIGURE 1. In assessing the various alternative water supply sources for the fictitious community of Mudville, students use the GIS to explore the environmental pros and cons of building a water treatment center along the bordering river.
FIGURE 2. Students working on the Mudville problem, advance the study by using the GIS to evaluate the costs, benefits and efficiencies of drilling new wells in extraterritorial lands to the southwest of town.

FIGURE 3. Determining appropriate areas to relocate the fictitious community of Weathersbee, and mitigate the effects of flooding from the Ponspons River, students use 2- and 3-D GIS analytical techniques to advance their studies.

URISA extends its sincerest appreciation to the corporate and government contributors who supported SIT:UPSS through donations of funding, technology support, human resources, and supplies. Together these efforts and resources contributed to the success of this unique learning experience for pre-college students.

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in sign language while her fifth-grade partner synchronously demonstrated their team’s findings using the GIS. To find an optimum location for their fast-food franchises, public-water facilities, and community developments, student teams researched factors like population demographics, household income levels, environmental conditions, land use, traffic light impedances and travel times. Most importantly, they all did it well.

What did we learn from SIT:UPSS? Principally, the experience reaffirmed a belief in the potential for GIS to become an important educational technology for spatial problem-solving. GIS is a tool that even young children can use with ease; a tool that helps students ask the kinds of questions that lead to informed decision-making. GIS provides an ideal technological medium for supporting learning that is project-based and focused on problem-solving contexts that approximate the everyday life experiences of students.

At present, three essential precursors for creating effective GIS-supported learning environments are lacking. First, more teachers need training with the technology. Second, a comprehensive GIS-supported curriculum needs to be developed. Finally, a philosophy of learning needs to be clearly articulated that explains why the type of spatial learning to which GIS can contribute has a rightful place in the pre-college curriculum. Sometime in the future these preconditions will be satisfied. When this happens, the lessons of SIT:UPSS suggest that GIS in schools will become as commonplace as today’s word processing programs.

The SIT:UPSS chair, curriculum advisory board, and faculty congratulate the student participants in the 1994 offering of SIT:UPSS, and encourage them to continue to explore the role that GIS and information technology can play in their spatial learn-
Students in grades 5–12, parents and/or teachers who are interested in learning more about SIT:UPSS, or in registering for the 1995 SIT:UPSS program to be convened during the URISA annual conference in San Antonio this July, should contact Bob Lima, SIT:UPSS Program Chair, c/o Boshe Institute, P. O. Box 116, Hyannis, MA 02601, tel: (508) 362-1305, fax: (508) 362-1319, or e-mail: limabob@delphi.com.

Corporations, organizations and individuals who are interested in supporting the next offering of the SIT:UPSS program (with direct funding or contributions of GIS equipment, technical facilitators, data, materials or food supplies) should also contact Mr. Lima.

Selected References


Building an Information Systems Infrastructure: The “ABCs” from an Agency Perspective

Tommie F. Howell

M any GIS professionals are touting the virtues of the up-and-coming information superhighway, including those at state departments of transportation (DOT). But are we heading for a smooth ride down this superhighway? Do we expect to receive all information needed in a timely, accurate and concise format—one that addresses the needs of all personnel at all levels of the agency? Or are we headed for the dreaded “G” word: gridlock? Will we end up spending our time, money and expertise, complicating the decision-making process and our resources, and ultimately jeopardizing our goals and objectives?

Fortunately, we have the power to create and manage our information technology (IT) future, and we can avoid information gridlock. But if the ball is in our court, where do we start? Why not start at the top? The top is where you discover an important and often ignored ingredient: a CEO’s perspective on the agency’s requirements for information. Sounds easy enough, but easier said than done. Why is top management suddenly going to take an interest in you and in those computers hidden far away from them? Probably because the ability to generate efficient, effective, meaningful and timely reports are increasingly important to everyone, especially CEOs. And in the Texas DOT, as well as other DOTs, new mandates—or rather opportunities—have captured the interest of agency CEOs.

For example, the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 mandates that state highway departments provide management reports on pavement, bridges, safety and other transportation areas. These management reports should be considered more than a bureaucratic mandate for management systems. Instead, view them as a “window of opportunity” for establishing a sound information systems infrastructure. In fact, ISTEA can help build the foundation for a valuable information systems reporting mechanism for all functional areas, not just the management systems mandated. It can help streamline the agency’s use of resources, money, people and information. It can be a building block for establishing the “mother lode”—a well-conceived and integrated database.

The Three Ps: Positioning, Planning, Packaging

While ISTEA and other mandates may provide a structure, they don’t provide the “how to.” For a successful information infrastructure, several “P” words are essential: First, positioning takes advantage of the aforementioned windows of opportunity. We in an agency must position ourselves to “strike when the iron is hot.”

Next, planning is critical at all levels of the agency; but sound planning must trickle down from the top. How can any information systems infrastructure have a genesis without knowing where it is and where it is going? There must be well-formulated agency requirements, and these can come only from the top. Then, information systems personnel must be the thread that insures continuity at all planning levels and that the overall scope of the system stays within predetermined boundaries.

A systems mandate normally helps an agency muster resources. But where are they going to come from when “downsizing” is the current popular buzz word? The old phrase “doing more with less” has never been more of a reality, and an effective use of new technologies can make this possible. By using technological advancements and third-party support, “more with less” can assist in traditional DOT tasks such as design, construction and maintenance, not to mention operations, legal issues and the political arena. Where does GIS fit in this trend? It’s the means for building, accessing and distributing the motherlode of information in a well-conceived database structure.

To insure that all assets available to us are used properly, packaging provides the recipe for a successful end product. With bountiful, quality technology flooding the marketplace, packaging has never been more essential. Packaging is not only pulling together technologies
or systems, it is also putting them together in the right sequence to in- sure meeting deadlines and providing the connectivity pursuant to the information systems infrastructure. We may need to partner up during both planning and packaging, depending on our agency’s resource strengths. But be assured, partnerships can result in many hours saved and create a substantially better final system.

We have the power to create and manage our information technology future.

Without lost time, effort and money: No small task! To ensure success, re-visit planning, where packaging the right planning team is certainly critical to this part of the planning process.

Three More Ps: Partnership, Productivity, Patience

The next P to good management may necessarily be introduced during any phase: partnerships. Why reinvent the wheel when quality products, services, and support are available from potential partners? Internal or external, vendors, consultants, whoever can contribute should be considered as potential partners. In fact, during this era of information sharing, partners are frequently mandated. So accept this new way of doing business and turn the arrangement into an asset rather than a liability. One caveat: beware of the “T” word—always a roadblock and never constructive. That’s T as in TURF! A problem with all the Ps, it’s especially upsetting to partnerships.

Two additional Ps will result from a well-thought out approach to the previous Ps: increased productivity, and a need for patience. Biting off too much of the great technological dessert can cause gridlock. If agency professionals can exhibit patience, then positioning and planning for optimal use of resources via partnering and packaging will insure timely completion of tasks and increased productivity, integrity and credibility within your agency.

These are the ABCs for effective use of GIS when building the information systems infrastructure of tomorrow.
Modernizing Land Records: Tracking GIS/LIS Technology in Wisconsin and Beyond


Modernizing land records has caught on like wildfire in Wisconsin. A grass-roots effort by the Wisconsin Land Information Association (WLIA) that led to the creation of the Wisconsin Land Information Program (WLIP) by the Wisconsin Legislature in 1989, has fueled the modernizing movement. Since its inception, WLIP has generated nearly six million dollars annually through an increase in land record filing fees. The $6 fee, collected each time a homestead purchase transaction is recorded, is used to increase the efficiency of managing land records for local governments. Our task here is to shed some light on the factors pushing or pulling the spread of geographic and land information systems (GIS/LIS) technology, and also to explore what six million dollars a year buys Wisconsin's land records professionals.

We are reporting initial results of Wisconsin's state-wide efforts to modernize land records and also collaborative activities with other states to examine the diffusion of GIS/LIS technology. Data gathered in Wisconsin, where a formal program exists to support land records modernization, will be compared to Ohio data, where modernization activities are done on an ad hoc basis.

Currently, two years of data have been collected in Wisconsin; Ohio is collecting the same information that includes data about demands on government, investment in technology, institutional arrangements, use of products and services, and utility of products and services to investigate the diffusion process.

According to a diffusion model reported by E. M. Rogers in his book *Diffusion of Innovations* (1983), new ideas and technologies spread to users via five stages: knowledge, persuasion, decision, implementation, and confirmation. The diffusion process can be broken down into two key components—adoption and implementation. Once the adoption decision has been made, a new technology must be put into use. In Wisconsin, we are examining the extent to which counties have implemented LIS, and factors that may have helped or hindered the process.

Because GIS/LIS adoption is an evolutionary process, it involves changing the status quo. GIS/LIS technology offers a new way of managing land records for many professionals. Measuring the adoption of innovation means we need baseline data so we can track change over time. We decided that a questionnaire administered over many years would be the best way to gather this information.

Tracking Modernization

Wisconsin's Land Information Program is designed to assist counties in their efforts to adopt and implement modern land information systems. Since June of 1989, WLIP has provided administrative and technical assistance to counties to develop state-wide decentralized LIS. Prior to our questionnaires, no means existed to trace how counties are spending WLIP and locally generated dollars and what activities were being supported. By sending out a questionnaire to each county, we now have the means to obtain a uniform report of modernization activities.

Researchers at both the University of Wisconsin and Ohio State University, in conjunction with the National Center for Geographic Information and Analysis (NCGIA) and WLIP staff, will use four questionnaires for the long-range study:

Q1—Investment status (also known as "The Bean Counting")
Q2—Factors promoting modernization
Q3—Evaluation of WLIP (Wisconsin only)
Q4—Benefits associated with modernization

The results of our findings will be aggregated at comparable units of analysis for both states—at the county level. Wisconsin and Ohio will be used for initial comparisons since local governments have similar mandates and comparable jurisdictions, although they have different approaches toward modern-
izing land records. Wisconsin has a statutory program and funding mechanism to facilitate the diffusion of automated land information systems; Ohio modernizes their land records by local initiatives with state encouragement.

Q1: Taking Inventory

Q1 was designed to take inventory of land records modernization activities in each county. These include some basic components of a modern land information system—geographic reference frameworks; parcels, wetlands, soils and zoning map capabilities; institutional arrangements; communication and education; and public access arrangements. Q1 also covers modernization activities such as utilities, hydrography and transportation mapping. Expenditures, data format and standards were among the questions asked for each modernization activity.

With the responses, we developed status reports and formulated indices of modernization to track activities in each county. The indices are similar to a consumer price index where multiple variables are used to explain a complex process. Because modernization is multifaceted, we used separate indices for a multi-purpose land information system (MPLIS) component, information technology, and data automation to measure modernization implementation.

Initial Q1 results indicate that Wisconsin counties are investing primarily in geographic referencing systems (See Figure 1). Re-monumenting, adding coordinates to Public Land Survey System (PLSS) section corners, and using global positioning system (GPS) technology to form a “High Precision Geographic Network” are a few of the county-initiated activities. Half of the counties are using one or more types of GIS software in managing their land records. Even though geographic reference frameworks and parcel automation financially dominate current modernization activities, 46 of Wisconsin’s 72 counties reported communication and training-education activities to reinforce their commitment to diffuse GIS/LIS technology (See Figure 2). These activities include participation in the Wisconsin Land Information Association (WLIA), and attendance at training programs and national meetings like URISA and GIS/LIS.
Evaluating Success

The three remaining questionnaires, now in process, will examine factors that promote modernization and will help highlight exactly what modernization means to county agencies. Q2, for example, will be used to answer questions about technological "push" vs. the societal "pull" on information systems. That is, what specific interpersonal, organizational and institutional variables affect an organization's decisions to acquire, implement, and use GIS? It is also designed to see if legislative mandates, such as those of WLIP, have had an effect on the modernization process.

Q3 is designed specifically to evaluate WLIP and its role in initiating or accelerating the modernization process. First-year results show that the WLIP is viewed as helping to start and to accelerate the diffusion of GIS technology (See Figure 3). Wisconsin land records professionals have the opportunity to comment on the program's structure, grants procedure, the Land Information Board, and the other participating state agencies. Q3 is helping to identify issues and address problem areas; it is beginning to justify the WLIP to elected officials, in showing that WLIP has acted according to the program's bylaws—"carefully, thoughtfully, and with dispatch."

Q4, the Benefits Template, asks "So what?" questions. Currently under development, Q4 asks the most challenging questions, primarily because effectiveness and equity are not as easily measured as those benefits that are tied to a dollar amount. Benefits are often less tangible and may be anecdotal.

To date, here are some documented benefits:

- Two missing tax parcels worth thousands of dollars were discovered in Waukesha County by the Register of Deeds;
- Thanks to a more accurate floodplain map, a homeowner in Winnebago County no longer needs to pay $1,112.50 in FEMA floodplain insurance;
- Two northern counties, Oneida and Vilas, are sharing GPS data along their mutual border.
- Wisconsin Department of Transportation (WisDOT) and National Geodetic Survey have collaborated to create cooperative GPS projects;
- As a result of encouragement from a group of north-central counties, the Chippewa Technical College is now offering a two-year technical degree for GIS technician.
- The Register of Deeds office in Racine County is now paperless and offers distributed access to the public and private sector;
- Between federal, state, and private sources, USGS conducted the National Aerial Photography Program (NAPP) in Wisconsin from which various other federal, state and local agencies are now constructing digital orthophotos.

Multi-State Effort

Comparing modernization efforts between Wisconsin (where a formal means to promote land records modernization exists) and Ohio (where modernization activities are on an ad hoc basis) is another goal of the questionnaires. Q1 and Q2 will be used by both states to obtain an inventory of modernization activities and factors associated with modernization. These initial steps investigating factors pushing or pulling the diffusion of LIS/GIS technology will aid in understanding the modernization process. As a result of our efforts, we may be able to provide guidelines for adoption and new strategies for implementing modern land information systems. This project is slated to expand to a multi-state project with cooperation from Arkansas, Georgia, North Dakota, Virginia, and Washington. We eventually hope to develop a national survey and a national index of modernization activities. If other states are interested in participating, please contact the authors.

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Selected References


A New Paradigm For GIS Data Communications

Richard N. Annitto and Bradford L. Patterson

Editor's Note: This paper was originally presented at URISA '94 in Milwaukee.

As GIS begins to assume its role as the primary computing environment for many organizations, higher network bandwidth is becoming necessary. The trend towards larger file sizes, image integration, sophisticated applications, and desktop access is placing increased demands on the traditional network technologies and wiring currently in place at most GIS installations. In many cases, the network itself is becoming the bottleneck.

The demand for higher bandwidth is not unique to GIS. Industries such as medical imaging, computer-aided design and manufacturing, and publishing (in many ways, GIS cousins) have been demanding high-speed technologies. In response to this demand, communication vendors have developed newer technologies and cabling to implement high-speed networks. A vast array of products and alternatives are now hitting the market that will greatly enhance network performance. An identification and understanding of these alternatives will become necessary for many GIS managers, who may find network performance degrading as GIS becomes an essential piece of their organization's computing environment.

This paper focuses on three major issues related to high-speed networking:

- Premise wiring;
- Networking technologies;
- Internetworking technologies.

Premise wiring is discussed first because it provides the foundation for networks. The discussion of networking technologies will focus on emerging, high-speed solutions. The final discussion, Internetworking Technologies, will focus on newer methods to connect remote sites into an organization's GIS. Each discussion will specifically address how Nassau County has planned for or implemented the necessary components to make high-speed networking a reality.

Premise Wiring

In response to demands for higher bandwidth, communication vendors have developed twisted-pair copper cables and connecting hardware with enhanced transmission characteristics. To assist in this work, the Telecommunications Industry Association / Electronic Industries Association (TIA/EIA) has been developing standards for the planning and installation of commercial building cabling.

Standards already released include Technical Services Bulletin (TSB-36) and Technical Services Bulletin (TSB-40), which contained specifications for Categories 3, 4, and 5 Unshielded Twisted Pair (UTP) cables and connecting hardware. These bulletins are currently being incorporated into the proposed Commercial Building Telecommunications Cabling Standard (TIA/EIA-568-A). This standard establishes performance and technical criteria. It addresses such items as:

- Horizontal wiring;
- Vertical wiring;
- Telecommunications closets;
- Equipment rooms;
- Entrance facilities;
- 100 ohm UTP Cabling systems;
- 150 ohm STP Cabling systems;
- Optical Fiber Cabling systems;
- Hybrid cables.

This standard can be acquired from the TIA/EIA in Washington, D.C. There is a fee for a copy of the standard, but it is well worth the price to any GIS manager involved in data-communication issues.

Nassau County Case Study

Nassau County has been using these specifications to assist in the implementation of the Nassau Unified Telephone Services project. The primary goal of this project is to rewire all county buildings in a consistent, standard format and to provide standard information outlets (SIO) for voice and data communications. This project provides the physical linkage that is necessary for the GIS to expand county-wide.

The Nassau County standard for station wiring is EIA/TIA Category 5 UTP (also Underwriters' Laboratories Level 5 verified). All new

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county wiring installations will be Category 5. Additionally, all connecting hardware, including SIOs and modular jack connectors, are Category 5 compliant.

The county standard for fiber optic is 62.5/125 μm graded index multimode fiber optic cable. The standard fiber optic connectors are straight tip (ST) type. Multimode fiber optic cable is primarily used in shorter distance applications (under 3 km). For applications that require greater distance, single mode fiber optic cable can be installed.

Networking technologies

The majority of GIS installations most likely employ traditional Local Area Network (LAN) technologies, such as Ethernet or Token Ring. These LANs transmit data at a rate of 10Mbps in the case of Ethernet and 16Mbps in the case of Token Ring. These data transmission speeds are becoming too slow for complex GIS environments. There are a variety of technologies that are now becoming available to allow for faster transmission speeds. These include the following:

- Asynchronous Transfer Mode (ATM)
- Fast Ethernet
- 100VG-AnyLAN
- Fiber/Copper Distributed Data Interface (FDDI/CDDI)

The list above is not all inclusive. To adequately discuss all the options available would exceed the scope of this article. The options listed above are recognized by many in the communications industry and may represent the greatest potential for market share. Each of these technologies is discussed in more detail below.

Asynchronous Transfer Mode (ATM)

ATM is a broadband Integrated Services Data Network (ISDN) technology that is being acclaimed as the next generation of local and wide-area networking. It is a fast cell-switched technology based on a fixed-length 53-byte cell. A final standard for ATM is expected some time in 1996. However, proprietary products are already available on the market, from some of the largest communication hardware vendors. Currently, the physical transport of ATM cells is being provided by the Synchronous Optical Network (SONET) standard; specifically, Level 3 Concatenated (STS-3c) at 155Mbps.

Fast Ethernet

Fast Ethernet is an emerging technology that was developed to create an easy-to-use, standards-based upgrade for Ethernet that would allow high-speed transmission using existing copper wire. It retains all of the Ethernet specification, except the 10Mbps speed has been replaced by 100Mbps.

The final draft standard for Fast Ethernet, submitted in November 1994, makes use of the Carrier Sense Multiple Access/Collision Detection (CSMA/CD) layer. There are two different components of the proposed specification: 1) 100Base-TX and 2) 100-Base-T4. 100Base-TX requires two (2) pairs of Category 5 UTP cabling. 100Base-T4 is designed to make use of Categories 3 and 4 cabling and requires four (4) pairs.

100VG-AnyLAN

100VG-AnyLAN is being proposed as an alternative to Fast Ethernet. It is being designated by the Institute of Electrical and Electronics Engineers (IEEE) as 802.12 standard and abandons CSMA/CD in favor of the Demand Access Protocol and supports speeds up to 100Mbps. It maintains the traditional Ethernet frame format but offers additional features such as security, prioritization and ensured packet delivery.

100VG-AnyLAN runs on Category 3 or higher cable and requires four (4) pairs of UTP cabling, like 100Base-T4. There is no proposed two (2) pair solution.

Fiber/Copper Distributed Data Interface (FDDI/CDDI)

FDDI is a high-speed LAN that uses fiber optic cable as its transmission media. FDDI is defined by the American National Standards Institute (ANSI) X3T9.5 standard, which uses the IEEE 802.5 standard (token passing) as its access control. FDDI is typically configured as a ring topology. The maximum data transmission speed of FDDI is 100Mbps.

CDDI, as it is sometimes referred to by some communication vendors, is a version of FDDI that uses Category 5 UTP as the physical medium, instead of fiber optic cabling. It supports a data transmission rate of 100Mbps. Currently, ANSI is writing a standard for FDDI over UTP. The standard will allow FDDI to migrate from a networking backbone to the user desktop. This standard is termed TP-PMD (Twisted Pair - Physical Media Device).

Nassau County Case Study

As part of the county's GIS conceptual design, a test of high-speed technology was deemed necessary. This test had to meet the following criteria:

- The test must take place in a functioning county location (tested to Category 5 compliance).
- The horizontal wiring distances must be as close as possible to the Category 5 specification (100 meters in total).
- The high-speed networking hardware must function using the most common network operating system in the County (Novell NetWare).

On February 11, 1994, the test was conducted at a newly renovated Nassau County Police facility. Northern Telecom provided a high-
speed data communications hub and three high-speed network interface cards. Northern Telecom's high-speed technology is FDDI over UTP (100Mbps) and is termed X-DDI.

The test was a success. Over 20 billion packets were transmitted, with only five errors. Based on the success of the test, the county acquired the X-DDI hardware to be used as a data communications pilot, to further test the feasibility of implementing high-speed networking technologies.

**Internetworking technologies**

If it were a perfect world, all users needing access to a GIS would reside in a single building or campus environment. Unfortunately, as most of us know, it is not a perfect world and GIS users tend to be geographically scattered throughout an organization's area. For example, take Nassau County. The county seat is located in Mineola and one complex houses many County agencies. This complex is connected via fiber optic cable.

However, scattered throughout the county are various agencies, in over 150 buildings, that may require access to the GIS. These include Police Precincts, DPW Water Treatment Plants, HAZMAT agencies, Health Clinics, etc.

To connect remote sites into a wide area network, one typical approach used is dedicated leased lines. In this scenario, an organization leases T-1 (1.544Mbps) or Fractional T-1 (FT-1) circuits from a local carrier. This scenario is typically an expensive solution, both in terms of the cost of the leased lines and the redundant communications hardware that would be necessary.

Another alternative is to use a network technology, such as ATM, to connect the remote sites into a wide area network. However, this approach may be prohibitively expensive because of the fiber optic cable that would be needed to support such a wide area network, or the costs a local carrier would charge for these types of connections, if even available.

A third alternative would be to use a newly emerging class of broadband technologies, sometimes called Fast Packet Services. Specifically, there are two technologies that are being widely discussed: Frame Relay, and Switched Multimegabit Data Services (SMDS). Both Frame Relay and SMDS are being widely implemented because of the cost savings that they offer over the traditional leased-line approach. This is not only true for GIS environments, but for mainframe and other environments as well. Each of these technologies is discussed in more detail below.

**Frame Relay**

Frame relay is a derivative of Integrated Services Data Network (ISDN), which is being used effectively as a replacement for leased lines. Many industries, such as banking, are using Frame Relay to replace the myriad of multidrop analog 9.6Kbps circuits that they formerly leased.

Using Frame Relay, remote sites access a central Frame Relay switch via T-1 or FT-1 local loops. Frame Relay is typically recommended in environments where the following conditions exist:

- More than 5 sites that need to be connected;
- Meshing of sites, so that each can connect directly;
- "Burst" traffic, typical of a LAN.

Frame Relay is also attractive because of its potential to interoperate with ATM for high-speed applications, such as GIS. Frame Relay speeds range from 56Kbps to 1.544Mbps. Frame Relay services are currently offered by many national and regional carriers.

**Switched Multimegabit Data Service (SMDS)**

SMDS is a public-switched connectionless data service. It is designed to operate over the IEEE 802.6 Metropolitan Area Network (MAN) Standard. It is intended to connect LANs on a MAN or Wide Area Network (WAN) basis. Some of the features of SMDS service include:

- High-speed, low-delay connectionless data transport;
- Any to any connectivity, sometimes referred to as "dialtone for data";
- Multicasting;
- Support for key protocols used in networking;
- SNMP-based network management.

Like Frame Relay, SMDS is attractive because of its potential to interoperate with ATM for high-speed applications, such as GIS.

**Nassau County Case Study**

In Nassau County, the need for a standard internetworking technology was viewed as more than a GIS issue. Other areas that needed to be addressed included access to the county mainframe, internetworking of departmental LANs, and the implementation of a computer-aided dispatch system for the county's police department and emergency services.

Based on these services and GIS requirements, it was agreed that a county-wide internetworking technology should be developed. Potential service providers had to meet the county's specification, which included the ability to do the following (as a minimum):

- Deliver cost effective, reliable fast packet services to County facilities.
- Deliver the ability to upgrade technology to ATM in a 2-3 year timeframe.
- Provide around-the-clock management services for the fast packet network.
- Provide disaster recovery methods.
In September 1994, the county released a bid for Phase I Frame Relay Services for 17 county sites, primarily Police facilities. The bid was awarded to NYNEX and the network became operational in December 1994. Phase II Frame Relay sites, which include many GIS sites, will be operational during the third quarter of 1995.

Conclusions

Data communications technology, with its vast array of jargon and acronyms, can appear overwhelming. It is not necessary for a GIS manager to become a professional data communications person. However, it is necessary for a GIS manager to understand the immense changes in technology that are taking place and what the options and consequences are for his/her organization. When dealing with computer technologies, it is always prudent to research and identify standards (or emerging standards) that an organization can use as a guideline for implementation. There are professional data communications groups (e.g., EIA/TIA, the ATM Forum) that can assist GIS managers in making the correct technology decisions for the future of their GIS installations.
In this issue...

As the core of a high-growth urban area, the city of Seattle, Washington is aggressively developing the effective means for managing its natural resources, and transportation and utility infrastructures. To make its management procedures more efficient, the city has developed new techniques and tools. Within the past decade, this has included implementing GIS technology to serve the management requirements of successful data integration and analysis.

The maps featured in this issue provide examples of the integration of Seattle's interagency base map, combined with utility data from the Seattle Water Department. The Water Department is using GIS technologies to meet its information processing needs in daily business functions, as well as a foundation in planning for more catastrophic occurrences. The maps shown here are visual examples of products developed for the analysis and modeling of complex urban problems and challenges.

Editorial Intent

Many of us derive great pleasure from viewing maps. Often we feel that the enjoyment maps bring us is something we have felt for a long time, something we grew up with. It may be difficult for us to pinpoint the precise appeal that maps hold, but often they may provide new understandings and stir our imaginations.

Even though well-designed and informative maps have existed for decades, the growth of computer mapping, and geographic information systems has allowed us to experiment and develop new and exciting ways of analyzing and displaying data in a map context. Computer mapping and geographic information systems play a key role in URISA's mission to help local, regional and state/provincial governments make the best use of information system technologies. Because computer-generated maps have become an important part of URISA's domain, the URISA Journal showcases the efforts of map-makers by featuring an exceptional map product in each issue. The word “map” is used in a very broad context and can include remotely sensed images or other graphics.

Our intent is to feature a wide variety of maps, hoping to inspire others to learn and apply good ideas and techniques. We look for maps that are easy to read, have a pleasing appearance and clearly communicate the map's purpose. New methods of analyzing and presenting phenomena through mapping techniques are also desirable, as is presenting a map that is particularly pleasing or attractive.

If you have produced a map or know of one you believe should appear in the URISA Journal, please contact the editors.

Ted W. Koch
Seattle Water Department: Building a Sound GIS

Karl Johansen

Editor’s Note: The map insert is on pages 73–74. It is located there because of the way the eight-page signatures fall in this issue.

The Pacific Northwest evokes images of an endless water resource: glaciers, rain, the Columbia River and Pacific Ocean. A somewhat different and ironic profile has emerged recently in the Puget Sound region of western Washington state. High urban growth coupled with lower-than-usual rainfall has put unprecedented pressure on the water resource in terms of both water quality and quantity. As a result, regional water utilities have imposed restrictions on water usage, a previously rare occurrence.

As reflected in regional policy, effective management of this resource has become a priority for planners and utilities alike. Understandably, new techniques and tools are aiding water resource managers in making better and more rapid decisions. And as in other management areas, GIS technology is fulfilling many of the data integration and analysis needs that are becoming so critical. In Seattle, supply and demand issues are compounded by other considerations facing water utilities.

Seattle Water Department

The Seattle Water Department (SWD), a major regional water supplier, provides water to a large portion of the Puget Sound region, including Seattle and numerous adjoining municipalities and suburban utility districts. The utility is charged not only with distribution, but also with monitoring and maintaining standards on water quality and other environmental factors throughout its network. Its infrastructure includes two major water supply reservoirs, miles of primary supply lines, and a distribution network serving approximately 175,000 residential and commercial customers. Like most utilities, SWD is continually balancing increasing demand from its customers with physical plant capacity. Stated differently, service levels must be maintained or increased through more efficient use of available agency resources, whether they be staff, equipment, or the distribution system itself.

As portions of SWD’s infrastructure reach the end of useful service life, intelligent decisions must be made about maintenance and replacement. The automation of this process is one of the clearest indicators of how facility managers are dealing with information systems in the course of meeting their business needs.

Integrated GIS

In the late 1980s, city of Seattle agencies jointly began developing a GIS to meet the increasing need for digital mapping and management of other infrastructure records. The interagency base map data layers comprise the Central Geographic Database (CGDB), including cadastral, hydrographic, topographic, and orthophotographic imagery features. This shared database is managed by the GIS staff within the Seattle Engineering Department.

Three city utilities, including SWD, City Light, and Engineering’s Drainage and Wastewater Utility have utilized the CGDB as a base for their department-specific GISs. The SWD GIS includes approximately 600 quarter-section utility maps covering the agency’s service area. Corridor mapping is underway to extend the GIS along supply line corridors to the SWD reservoirs in the foothills of the Cascade Mountains. The GIS maintains database linkages to numerous tabular files including property ownership, customer billing and maintenance. The automation and integration of these data sets has been designed to expedite map revisions, eliminate duplication of facility data, and provide analytical functionality to the utility managers.

Although the most visible product of any GIS is a map display, the power of the technology transcends this obvious initial benefit. SWD staff have already identified applications that were not evident in the early design and user-requirement stage of their project and, as such, may represent benefits to the agency. Further, GIS as a tool is slowly becoming embraced by users other than SWD GIS technical staff, a familiar pattern for those sites with a mature system in place.

Karl Johansen is a cartographer in Seattle, Washington. He is a project manager in the King County Department of Metropolitan Services (formerly METRO), and is responsible for database development activities on the countywide GIS currently in production.
Among the ways SWD is using GIS technology:

- **Property management**: delineation of easements, agency-owned property, and coordination with neighboring properties.
- **Engineering**: to analyze pressure zones using leak history and topography to formulate maintenance and replacement plans for the distribution system.
- **Street use**: tracking of city-wide capital improvement projects to aid in coordinating among agencies.
- **Customer service**: study of meter reader optimization.
- **Planning**: delineation of service areas.

**Map analysis**

Several Seattle utilities, as well as those within neighboring jurisdictions, are increasingly turning to GIS and other high-tech solutions to meet the requirements of ordinary business functions. As in other Pacific Rim areas, however, Seattle institutions have the additional burden of vulnerability to such catastrophes as fires, volcanic and seismic events. Thus, a new imperative for GIS practitioners is to tailor their methodology to the demands of not merely business needs, but those of emergency response. On the accompanying map page, two examples from Seattle utilities illustrate this situation. In one case, the Seattle Water Department performed an analysis of pressure zones relative to hospital locations and distribution mains to identify options in case of serious interruptions to water supply sources.

In another example, Seattle’s electric utility, City Light, has used customer billing databases and other sources to compile and characterize high-consumption locations within their service area, especially in regard to proximity to substations and major transmission circuits. Among other uses, such analysis will assist in planning for power outages due to natural crises. In both examples, utilities are studying spatial patterns of their customers’ usage in order to provide timely alternate supply scenarios in emergency situations.

Such examples, although simple by GIS standards, illustrate one of the basic justifications for GIS: automation and integration of existing spatial data result in at least minor improvements over existing methods. Typically, additional benefits—some clearly intangible—become evident. In these examples, it would be easy to link and query existing databases to determine the makeup of adjacent property owners, property sales history, proximity to environmentally sensitive areas or areasspecific ordinances, or relationship to other utility networks and critical transportation features. These are just a few of the geographically referenced features that make GIS a superior tool for routine planning and maintenance of utilities.

In the aftermath of an emergency event, the rapid accessing of such a wide variety of geographic data sets can often be advantageous if not critical. The Seattle Water Department and its sister utility agencies have committed to sophisticated infrastructure management tools; this is a natural outgrowth of providing better customer service through streamlined information systems in an environment of limited agency growth. GIS plays an increasingly visible role in this agenda.
In this issue...

With this issue, the Reviews section welcomes a new software editor: Jay Lee, an assistant professor at Kent State University. Jay's research interests and experience as a reviewer superbly qualify him to help the Journal's readers keep on top of the rapidly growing software market. His research interests stem from a broad area of geographic information systems and analysis, in particular, integrating operations research to enhance GIS analytic functions.

The In-Depth software reviews in this issue examine two packages widely used in both private and academic applications. MapInfo 3.0 has built on the strengths of its previous version to offer fast, versatile functions for processing geographic information. TransCAD 2.1 offers a set of useful procedures for various spatial analyses that are not available in most other comparable packages.

Editorial Intent

The Reviews section of this journal provides critical reviews and information concerning publications, information sources, and software in the field of urban and regional information systems.

General review categories include: Books, Publications, Information Resources, Videos and Software. Software reviews are of three types: "In-Depth," "Head-to-Head," or "From the Inside."

In addition to submissions of book, publication, video and software reviews, we welcome suggestions and insights pertaining to the identification, critical review, and recommendations of all information sources in the field of urban and regional information systems.

For complete submission guidelines, see pp. 91–92.

Rebecca Somers
Jay Lee
Software Review: In Depth

MapInfo 3.0 for Windows

Bill Thoen

Mapping software has been available for several years, but until recently this type of software has been considered either an expensive mainframe application, or if run on a PC, just a toy. This is no longer true. In this review we examine MapInfo, one of the leading products in the desktop mapping software market today.

There are six major feature categories to consider when evaluating a desktop GIS package:

- data visualization,
- data access and interchange capabilities,
- database management,
- geographic analysis,
- map data creation and data set availability, and
- presentation output.

Often most of the focus is placed on the data visualization and geographic analysis, but in the course of working on a mapping project, each of these areas becomes critical at times. Other things to consider are price, ease of use and learning, documentation, technical support, and training. Depending on your situation, it may also be important to consider the availability and usefulness of application-development tools, multi-platform capability,

third-party utilities and applications, user groups and other peer-support services such as on-line discussion groups and bulletin board systems (BBS).

Visualization

One of the main reasons for using a mapping package is to visualize your data so that you can clearly see the spatial relationships in your information. In MapInfo, mapped objects are presented as layers. Layers can be created directly from tables or created "on the fly" from combinations of other tables. You can order the layers so as to put certain objects above others (such as streets above color-shaded census blocks). In version 3.0, raster images such as aerial and satellite photographs, scanned maps, and computer-generated color shaded relief maps can be geo-referenced and also displayed as a layer.

A very nice feature is the "zoom level" option in the layer control settings. You can set certain layers to appear at pre-defined map scales, but remain invisible at others. For example, you might have a layer that contains interstate highways, and another that contains city streets. You could set the zoom level of the city streets layer so that it appears only when you view the map at a particular scale.

Objects on the map can be either symbols, lines, or regions, and you can attach data to any of these. The way it works is that graphic objects are actually special fields in a record stored in a table. To interactively see the data associated with a particular object on a map you simply point to it with the mouse, double-click, and all the fields associated with that object pop up in a small window. You don't need to select different procedures or tools to view different types of objects. The system is smart enough to know that when you want spatial information about an object, you will see coordinate locations for point objects; end points and length for line objects; and area, perimeter, and centroid location for region objects.

MapInfo does not limit the view to one map at a time, either. You can create several maps simultaneously to view data in different areas, or at various scales or containing different information. Nor are you limited to viewing just maps. Data can be viewed in a spreadsheet-like format (known as a "browser" window) of rows and columns or as bar or pie charts. All these views can be seen on-screen at the same time.

MapInfo maintains a link between data on maps and browser windows, and this is a particularly useful feature. You can select objects on a map and automatically find them in a listing, or vice-versa.

The program is also rich in thematic mapping features. You can display data as choropleth maps, dot density, graduated symbols, pie

Bill Thoen has been involved with the on-line world of earth sciences and GIS since 1985 when he started COGNet BBS for the Computer Oriented Geological Society. He is the author of "Internet Resources for Earth Scientists" which is available via anonymous FTP at ftp.csn.org in the /COGS directory as the file ores.txt. He now owns and operates GISNet BBS (modem: 303-447-0927), and writes application software for the mapping and GIS industry. You can reach him via e-mail on GISNet BBS or on Internet at bthoen@gisnet.com.
This Hospital Study Map uses GIS analysis to superimpose pressure zones, water distribution features including mains and reservoirs, and hospitals. The purpose of the study is to identify alternate scenarios for water supply to critical customers whose service may be interrupted by an emergency event. (Map display by Greg McFarland, Seattle Water Department, Water Systems Services Division, GIS Applications.)
A portion of the electric-usage study map done by a Seattle utility to compile and characterize high-consumption locations within its service area. The graduated circle symbology represents usage by census block; colors are used to show residential (blue) and commercial (brown) use as a proportion of total usage. (Map display by Fred Podesta and Susan Bevacqua, Seattle City Light, Information Technology Division.)

Seattle City Light
Geographic Information Systems

Density of Seattle City Light Accounts Within the City of Shoreline

City of Shoreline
Census Block Boundary (1980 Census Data)

Seattle City Light Owned Property

Shoreline Substation

Account Density (Accounts per Acre)

50
40
30
20
10
1

Circle size represents total density of Seattle City Light accounts within each census block (accounts per acre). The larger the circle, the higher the density. Circle shading indicates the proportion of residential and commercial accounts within a census block.

Residential
and bar chart symbols or in simultaneous combinations. Range categories can be created based on equal count, equal ranges, natural break, standard deviation, quantile and custom classes. Color spreads for ranges can be automatically generated in a smooth transition form one color to another including an optional inflection point to create smooth two-tier color transitions.

Thematic maps are not limited to fixed variables within physical tables, either. Themes can be created with results of selections or combinations of tables, as well as aggregate expressions including count, sum, average, min/max, and proportional values.

MapInfo automatically generates a legend for thematic maps. Since the legend is in a separate window, you can choose to display it at any position you wish, or remove it from the display. You can easily bring it back up at any time and/or modify the title and subtitles, fonts and class categories that appear on it as well.

MapInfo provides built-in support for graphic file types as well. The MapInfo Interchange Format (MIF) is an ASCII text format used for exchanging data between otherwise unsupported mapping and data systems. AutoCAD DXF format can be imported and exported as well.

MapInfo is designed to work in a networked environment as well as a stand-alone application so you can share MapInfo data files among several machines including those of different platforms. Even via “sneakers net” we were able to copy a data set onto a floppy disk from a windows version of MapInfo and bring it up directly on the Macintosh version, no translation needed! Access to remote database systems such as Oracle, Sybase and others is provided with an optional (595) “SQL DataLink” module that supports embedded SQL using O+ or Microsoft-standard ODBC drivers.

Data Access and Interchange Capability

If desktop mapping software can be considered the engine that powers a mapping project, the fuel would be digital data, and MapInfo provides a lot of flexibility in this area. MapInfo can read and use dBASE, FoxBase, Clipper (essentially any xBase file format), Lotus 123, Excel, and delimited ASCII files directly without the need for translating the data into its own format. Data in xBase files can be modified and table structures can be altered, but MapInfo does not use or modify any associated xBase index files. Data from Lotus 123, Excel, and delimited ASCII can be used in performing queries and mapped directly, but you will have to convert these files into MapInfo format before you can change any values in the data or modify the table structure.

Database Management

MapInfo database management is based on the relational database model and the SQL data manipulation language. The SQL implementation appears to be very complete, including table-level commands such as add, drop, commit and rollback. Indexes are also supported to provide higher performance, but these can only be assigned to full fields, and not to expressions.

There are some convenient SQL features missing from MapInfo’s command set. The ability to update a table using a ‘where’ clause in a single SQL command is not available, and the lack of a ‘union’ operator makes outer joins a bit awkward. Correlated subqueries are not directly supported either. However, these shortcomings can be overcome by using multiple SQL commands and an intermediary table or two. MapInfo’s SQL selections can also be sensitive to the order that tables are referenced. A simple table join is much faster when the smaller table is referenced first in the ‘from’ clause, even if both tables are indexed on the key field. Also the order of the key fields in the ‘where’ clause must follow the same sequence as in the ‘from’ clause or an error results.

On the positive side, the command set is sufficiently complete for just about every need, plus it’s not necessary to be an expert in SQL to access data with MapInfo. MapInfo provides an assisted procedure with syntax verification that greatly simplifies the task of properly constructing a valid SQL statement. You can also enter an SQL command directly if you wish.

Geographic Analysis

MapInfo’s SQL command set includes some very useful geographic and aggregation functions and operators in addition to the usual suite of DBMS tools. Geographic operators such as ‘contains’, ‘contains part’, ‘contains entire’, ‘within’, ‘partly within’, ‘entirely within’, and ‘intersects’ can be applied to any graphic objects in an SQL selection. Geographic functions include distance, area, object length, and perimeter as well as X and Y coordinate retrieval. Aggregation functions like count, average, sum, min, max, and weighted average can be used to create calculated fields in a selection.

Buffers can be created around points, lines or areas, and may be based on data associated with an object as well as fixed constants. Buffers can be used to perform geographic selections such as determining the number of people living within some many miles of a chain of retail stores or, say, a bus route. Polygons or region objects (including buffers) in MapInfo can be used in overlay operations to perform data combinations, splits and clipping. For example, you can use this feature to create population values for zip codes by using the popu-
lation numbers in census blocks. MapInfo allows you to split data values associated with regions based on the percentage of area overlaid by another region.

You can also use some special interactive button tools to easily perform geographic selections of objects. By clicking on one of these tools, you can select objects by a radius, rectangle or polygon. The resulting selection can then be used like any other temporary table.

MapInfo's latest release includes a lot more support for district management aggregation and disaggregation. This feature is handy for creating things like sales territories or service districts. It can be used on regions such as voting districts, lines such as roads or routes, or points such as retail sales locations to group objects together based on some common data attribute. The redistricting process begins with a map view of objects and a dynamic browse window. You select an object and make it the "target," which becomes the seed for an aggregate group. Then as you select other objects, you can see immediately the effect of combining objects with or removing objects from the aggregate. When satisfied with the result, you "assign" the objects to the group and move on to another target to build. When selecting objects to associate with a new target you can choose objects from a previous one and that gets reassigned automatically from the old group into the new.

**Map and Creation and Data Availability**

MapInfo comes with sample data sets including a map of the world and the United States, both of which include some 1980 and 1990 census data. You get a database of the largest 125 American cities, and street maps with addresses of San Francisco; a satellite photograph of downtown San Francisco and a scanned USGS map of the same area are also included. Similar data suites for London and Tokyo are available for European and Asian end-users, and these are used in the tutorial to provide examples of how to use MapInfo. Many other data products are available including all U.S. streets and addresses, political, demographic, business and marketing data sets either provided by MapInfo or through third-party data developers.

One of MapInfo's strongest features is its ability to automatically assign addresses to a map. Using MapInfo's StreetInfo data sets, you can map address locations right to the part of a block and correct side of the street they are on. Addresses can be also mapped based on other data such as ZIP code centers, city locations or other region or point locations.

If you wish to create your own data or enhance the data you have, MapInfo provides several tools to handle it. You can create data from any number of sources, and bring it into MapInfo in one of the file formats mentioned previously, or you can create it directly in MapInfo or through the use of a digitizer.

The drawing tools in MapInfo let you create symbols, lines, polylines, polygons, rectangles and ellipses and assign data to them. You can create records with up to 255 fields per record and build tables with over 2 billion records. MapInfo supports data types of string (up to 255 characters), integer, small int, float, fixed decimal, date, and logical. Graphic objects associated with each record can be created automatically or altered interactively on the screen; points can be snapped to other points or nodes; nodes along lines and regions can be dragged with the mouse; and polyline and polygon nodes and line directions can be made visible to aid in building data. New menu tools allow you to convert closed polygons into regions and vice-versa, and to split or clip regions and lines.

If you use a digitizer, you will need a "virtual table interface" device driver, which unfortunately is not included with MapInfo, but is available from a third-party vendor or in some cases, is supplied by the digitizer manufacturer with the digitizer. MapInfo's digitizer support is quite adequate. It can handle projected maps directly. You can view your progress on the screen as you go, and use the optional snap feature to anchor points to existing points. When setting up the map, you can establish multiple control points so that you can estimate relative errors that may be encountered across the map.

One aspect of creating map data sets with MapInfo that may be considered a shortcoming is that coincident region boundaries are actually stored twice. This is because MapInfo's data model is relational and there is no enforced topological structuring. It is quite possible to create lines that cross without a node at the intersection, or to have regions that don't join very well at common borders. Although MapInfo maintains a sense of line direction, it doesn't assume that connected lines are part of a network. The data developer may want to consider these issues and adopt special conventions when digitizing certain data sets, but that decision is left up to the operator.

**Presentation Output**

Usually the final product in a mapping project is the presentation. MapInfo's layout window makes this job easy by allowing you to arrange and scale map views, legends, data lists, charts, and graphs so that you can see exactly how it will look when printed. The layout window is actually sized according to the page size and orientation of
the output device that you have set up. But if you want to create a larger display, you can resize the window by increasing the number of page panels than will be used to create the final map. You can add or drop shadows to the window frames, graphic objects or text to the layout window as well as use the clipboard to paste logos and other MapInfo frames onto the final map sheet.

Even though the layout window produces nice-looking displays, it can be tricky to produce a map to an exact scale. To size a map frame so that it prints at a specified scale, you have to calculate the map size manually, and size the frame accordingly.

Ease of Learning, Documentation and Technical Support

The high quality of documentation, consistent application of an industry-standard user interface, detailed on-line help, and adequately staffed technical support hotline all help make MapInfo easy to learn and use. The 328-page User's Guide is well-designed and easy to follow, and is liberally sprinkled with illustrations and examples. It contains general overviews on subjects such as new features, general concepts in desktop mapping, map layers, data retrieval, map creation and so forth. It includes a section on frequently asked questions, a glossary of terms and an 11-page index. A second manual is the MapInfo Reference Guide which contains 428 pages of details on MapInfo commands, menus, tool buttons, window options and more, arranged in order of functional context.

Online documentation is complete and well-indexed and organized by operational task and user interface functions. It even includes a top-level menu item for the technical support number and fax line which is a surprising rare piece of information in most other software packages of any kind.

System Requirements

MapInfo's system requirements are designed to be relatively platform independent. The software depends on the local operating system to manage various peripherals such as video screens and plotters. For the PC platform, the minimum requirement is that you have Windows 3.1 or later, 4Mb RAM, and at least 12Mb of free disk space. A mouse and a VGA (or better) resolution screen is recommended. For the Macintosh version, you need to be running System 7.0 or higher, at least 4Mb RAM, 12Mb free disk space, and a graphics monitor capable of rendering 4-bit depth color or gray scale. The UNIX platform runs under HP-UX 9.01 or later X Window System and the Motif window manager on an HP 9000/ Series 700 or 800 workstation. You will need at least a 16-color/gray scale display, and 16Mb RAM. A tape drive and 20Mb free disk space is required for installation.

Platform and Global Support

MapInfo can run on most networks, and versions are available for Windows, Macintosh, and HP and Sun UNIX operating systems. Over a network, data sets may be shared between any of the different platforms, and even MapBasic applications can be written for multi-platform use so that they can be shared without specially re-compiling them for each environment.

Currently the software is available in three languages: English, German, and Japanese (Kanji), with more translations planned.

There are over 18 common world-wide coordinate projections with hundreds of pre-set projection configurations including state plane, and NAD 27 and NAD 83. You can also create your own projection configurations.

Development Environment

Perhaps MapInfo's most important feature of interest to consultants, programmers and corporate technical support groups is the MapBasic development environment. This is an optional programming language that allows nearly total customization of the entire MapInfo interface and functionality. You can create custom menus, tool buttons and cursors, and automate application-specific procedures by writing your own application. Your application can still use any MapInfo menus or tools. MapBasic also provides support for calling functions and procedures from external libraries such as Windows DLLs or Apple's XCMDs. Connections between applications such as DDE, RPC, and Apple Events are supported as well.

Even if you're not a programmer, you can take advantage of this in the form of hundreds of applications developed by third-party authors. Specialized applications for network routing, dispatch, market analysis, scientific applications, and many jobs are available from dealers listed in MapInfo's Applications Catalog.

Technical Support, Training and Peer Support

Free technical support is available for 90 days after registration, and is available over a toll-free number. Waiting to speak to a technician, we have found, is never more than a few minutes, and their knowledge of the product is relatively high.

MapInfo can also be reached over the Internet. Contact sales@mapinfo.com for sales and product information, and tech_support@mapinfo.com for technical support. Training at all levels is available as well.
The Internet is a popular place these days, so it's no surprise to see a public discussion list on MapInfo topics appear there. To subscribe to this free service, send e-mail to majordomo@csn.org and put 'subscribe mapinfo-' in the message. Associated with the mailing list is an anonymous FTP site where you can download data sets, news and information, and sample MapBasic applications. The address for the FTP site is ftp.csn.org and the public files are in the directory ‘mapinfo’. GISnet BBS sponsors the Internet services and also echoes the MapInfo discussion list and file archives for those who don't have Internet access. For more information, call 303-786-9961 or call the data line with your modem at 303-447-0927 (1200 to 14.4kbps 8N1).

Conclusions

Overall, MapInfo is a pretty solid product. Most of what might be called weaknesses are going to be in the area of differences of opinion rather than flaws in design. For example, the fact that MapInfo does not support or enforce topologically structured data is a weakness for some applications (particularly data creation), but for other applications where topological control is not so important, it frees the user from dealing with picky details that won't show in a final map.

One feature that could stand some improvement is the support for map export to desktop publishing systems (such as Adobe Illustrator format, which is supported by most DTP software) and large-format plotters (Sun Raster and RGB formats are very common formats). Another area that seems to be nearly unsupported is report generation. There is no way to generate formatted reports (other than simply printing the row and column listing as is) directly with MapInfo, nor can the user print a database schema.

The software's strengths lie in design features such as the integrated environment between its database and data views which results in an intuitive user interface and a powerful visualization tool. The company's commitment to providing a total solution shows through in everything from an amazingly bug-free and useful multi-platform software product to high-quality documentation, very accessible technical support, global awareness, and in providing a large and growing collection of data sets and applications. It's a class act.

The MapBasic programming language is potentially the strongest feature for some users, as it provides a route for developers to take desktop mapping and GIS to whatever their vision may be.
Early geographic information systems (GIS) were developed for the sole purpose of providing computerized tools to store, retrieve and display geographically referenced information. In spite of early calls for some analytical capability (Abler 1987; Goodchild 1987), few systems have so far evolved towards the integration of GIS functionality and modeling and analytical features. Caliper Corporation's TransCAD product is a remarkable exception. This article will describe the main features of this software package and assess its performance.

Overview

TransCAD Version 2.1 is described by the developers as "a geographic information system software package for planning, management, operation, and analysis of transportation systems and facilities" (Caliper Corp. 1990, p.1-1). It is an enhanced version of GisPlus, another Caliper product, from which it differs only by the extensiveness of the library of built-in modeling and analysis routines. The software runs in the DOS environment. It is recommended to use DOS 5.0 or above for access to additional memory.

My experience with TransCAD indicates that, while expanded RAM memory is not necessary for basic display functions, it becomes critically important for query, thematic mapping and labeling, and all the more so for analytical and modeling tasks. This software runs best with a minimum of 8MB RAM. Even so, the user remains at the mercy of unfortunate incidents that appear to be due to the software's poor management of available memory resources. I personally experienced a failure of the system to perform a polygon overlay involving 2 and 3 polygons, respectively, due to insufficient memory. The hardware configuration included a Northgate 80486 DX-33 desktop with 8MB RAM.

The software package is a vector-based geographic information system. Its core is made of one or more databases. The database engine combines coordinate, topological, and attribute data into proprietary structured formats (entities). The intuitive topological data structure is an advanced feature of TransCAD that helps streamline the maintenance of geographically referenced databases. Point, line and area entities are stored respectively in point, line and area databases. While a point database contains a single layer of data, a line database has two layers: one layer for points or nodes at which segments begin or end, and one layer for segments that connect pairs of nodes. An area database contains one or more layers, including a base layer and optional higher-order layers of entities that are aggregates of base polygons. An application file ties together all the database files and serves to define the range of coordinates covered by the application.

TransCAD is a suitable system even for some of the largest geographic databases. Size limitations are more likely to arise from hardware configuration than from software design. Each database layer can have 990 fields of attribute data and 16 million records. In addition, up to 20 databases and 40 data layers can be accessed in a TransCAD application and displayed.

Creating and Maintaining Databases

Most TransCAD functions are available from the main user interface designed around a series of pull-down menus, pop-up menus and dialog boxes activated by the mouse or the keyboard: Databases are set up and created by a free-standing utility program called TCBuild. This convenient and menu-driven module allows the user to describe the structure and contents of a new database by means of templates for the database, layers and fields or attributes associated with the entities. It also lets the user describe the ASCII data files from which the database is to be built. All this information is stored in a build file for later reference or use.

Once the build file is complete, a single key stroke builds the database. The developers of the software should be commended for their effort to build a database that is user-friendly and straightforward. Indeed, the operation is totally

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FIGURE 1. TransCAD provides a seamless interface between the GIS engine and numerous network and operations research procedures. For this map the "Allocate" procedure was used to assign TIGER/Line streets in Greensboro, N.C., to their closest store based on driving time. Driving time to the closest store is shown. (Original map was in color)

Database Conversion and Input/Output

One of the advantages of the software package is that it provides several data conversion utilities at no extra cost. ARC/INFO Export and Ungen files as well as Autocad DXF files can be translated into TransCAD databases in a matter of minutes with little input from the user. Also different line and area features of the TIGER/Line files, including address ranges used by geocoding and address-matching procedures, can be translated with great ease and speed in two different ways: an option of TCBuild allows the import of files one at a time, while another utility program can process many county files at once in batch mode.

Many users will find it useful to display raster images as a background to other data layers to facilitate their update or to place them in the proper geographic context. These images can be SPOT or EOSAT satellite images or scanned images in PCX file format. Utilities for import/export of other file formats are available for extra charge from Caliper Corp. With TransCAD it is also possible to visualize .PCX images associated with geographic entities in the database. This unusual display capability will be welcomed by facility management and real estate users especially.

Geographic entities can be added to a TransCAD database from a digitizer. Version 2.1 supports a large variety of digitizing devices and allows one to customize the digitizer device file for digitizers not included in the option list. While this latter feature makes it possible in principle to use any kind of digitizing hardware, its actual performance turns out to be disappointing. Indeed, in spite of extensive technical support from Caliper and CalComp, I was not successful in configuring the system for a CalComp Drawerboard II.

A distinctive feature offered by TransCAD is the interactive editing of geographic entities using a mouse. Adding, deleting, moving, splitting, joining or reshaping entities is a trivial operation which fully preserves the topological and data integrity of the database. Once the editing is completed, there is no need here for users to rebuild the topology, as it is the case with some other popular desktop GIS software.

This package only supports a handful of Hewlett-Packard and CalComp printing and plotting devices. Printing is slow and inconvenient. The user has little control over the layout of the final output. Also, device, port, and resolution options must be reset for each work session. On the positive side, any TransCAD screen can be captured to a .PCX file for further enhancement with a graphic package.

Attribute Data

Contrary to most other GIS packages, TransCAD does not rely on any standard file format to handle attribute data. It has its own proprietary format. Therefore, the short and easy linking operation of other packages may become an unwieldy import task in TransCAD. Version 2.1 permits data to be imported from ASCII comma-delimited text.
files, DBF format files, and Lotus 1-2-3 worksheets or compatible. TransCAD data can be exported to 1-2-3 worksheets, ASCII comma-delimited or fixed formats.

The data editor window provides a spreadsheet view of the current database layer. From this editor, records can be added, edited, annotated, or deleted. As with commercial spreadsheet software, a formula can be entered in a field to compute a value for each active record based on selected attributes. With a fairly extensive dictionary of mathematical functions and logical operators, the spreadsheet is suitable for many simple data manipulations as well as some modeling and forecasting.

Automated data query and selection of multiple entities involves two steps in TransCAD. First, a condition or logical statement on entities in a database layer is formulated on the basis of a particular attribute data. This condition is stored permanently for subsequent use. The selection function is then accessible from the data editor or the map display window. Selected entities are highlighted on the map and in the spreadsheet.

Records of the current database layer can be subjected to several types of statistical analysis. Summary univariate statistics (mean, minimum, maximum, sum and standard deviation) can be produced, as well as one- or two-way frequency tables. Correlation-regression analysis is also among the options available.

Alternatively, the SQL module performs some of the same functions of record selection and statistical analysis. Tables created by the interface can be sent to a printer or to a file.

Mapping and Display

In the map-display window, the user has full control over the color in which entities appear, line widths, icons and labeling, but annotation is not possible. In addition, a map can be displayed in polyconic, Albers or UTM projection, in state plane coordinates or on a rectangular longitude-latitude grid, while the entities coordinates can be converted from one system to another with a built-in procedure. The map legend and scale can be moved, reshaped or hidden to obtain the desired map layout.

Though thematic mapping of point, line and area entities is supported by TransCAD, it does not even come close to the capability of Atlas*GIS, MapInfo, or pcARC/INFO. Since cartographic deficiencies abound, I will limit myself to mentioning three of the most conspicuous ones. First and foremost, a limited assortment of predefined palette and style sets is available, with no possibility for customization. Second, standard classification methods by quantiles, equal counts or standard deviation are not available. Finally, TransCAD does not support dot-density maps.

If, overall, the mapping capability of TransCAD is rather primitive, the package excels in some specific areas by offering features seldom found even in the most recent desktop packages. For instance, multivariate pie charts can be displayed on the map for each entity in the current layer. Other features that are particularly valuable in transportation analysis include arrowheads to indicate the topological direction of arcs or the direction of flow along arcs, and the scaling of the line width in proportion to one or two numerical fields in the database. The program also allows one to visualize a variety of transportation objects created by other TransCAD modules, such as networks, flow matrices and paths.

A non-geographic graphic display of the database is possible.

FIGURE 2. TransCAD is well-suited for visualizing flows in a network. Average daily traffic on Minneapolis-St. Paul’s freeways are shown here with a cartography of the employment-to-residing-population ratio by traffic-assignment zones.
without exporting data to an external graphics package. Various settings are available for pie charts and bar graphs.

Geoprocessing

TransCAD has most standard GIS analytical functions one would expect of a general purpose GIS software. Spatial selection and query on entities of the current layer can be done in one of several possible ways: by pointing to an entity on the map, by enclosing in a circle with given center point and radius, by enclosing in a polygon of arbitrary shape, or within a buffer drawn around selected entities of any other layer. With the latter option, however, there is no built-in procedure to output newly-created buffers to a new database. This type of task would require a complex sequence of operations that makes it practically unfeasible in TransCAD.

The spatial aggregation of attribute data across levels of geography is a task commonly performed with geographic information systems. For instance, one may obtain the number of potential patients within five miles of hospitals from a census block database by a count of elderly people living in blocks located within this radius of each hospital and stored as an attribute in the hospital database. Other examples of data aggregation could include the computation of the square-mileage of residential land-use within a two-mile buffer along selected interstate sections, or the count of bus stops within a quarter-mile of subway stations. The "Column Aggregate" command of the TransCAD data editor is a perfect tool to handle these situations. It determines the aggregate characteristics (count, sum, weighted sum, mean, minimum and maximum) of point, line or area entities of one layer that fall within a set distance of entities of the current layer and stores them as attributes of the latter entities. Buffers can be drawn around points, lines or areas. By default, the command apportions on the basis of the relative area or length of entities, but does not allow for other options, such as total inclusion or exclusion of intersection entities. For polygon-polygon overlay, another procedure is also available, which creates a new database of all new sub-polygons. Caliper officials have indicated that the new release of TransCAD will fix the memory problems experienced with this procedure.

Another simple, but very convenient, geoprocessing command identifies the entities in one layer that are nearest to those in another. The distance of the nearest entity or one of its attributes is copied as an attribute in the latter layer.

TransCAD supplies additional procedures to perform more specialized geoprocessing tasks. One of these modules produces triangulated irregular networks (TINS) and Voronoi polygons based on points or area centroids. Short of having a 3-D capability, it also helps visualize an interpolated map by contours based on any attribute data (i.e., elevation, traffic, population, sale potential) of points or areas. Another procedure lets one automatically link entities in a point or area database to a line database with five connection options. Among the numerous situations where this procedure will find great use, I will only mention two: 1) the connection of potential fire station sites to a street network prior to location-allocation analysis, and 2) the connection of centroids of transportation analysis zones to a highway or transit network for traffic assignment modeling. Finally, a procedure will geocode records in a point database based on their street address and/or ZIP code. Users working under tight budget limits will appreciate that geocoding is a standard feature of TransCAD, not an add-on utility, and that the procedure is designed to work with standard street file formats rather than proprietary databases.

Table Objects

A unique feature of TransCAD is its ability to link tables of data to database layers. A table may, or may not, have database entities on one or both of its dimensions. A table may be made up of a commuter flow matrix between traffic assignment zones (TAZs), a distance matrix between urban centers, store attributes, or simply tabulation or correlation results. It contains no coordinate data but, provided that database entities are on one of its dimensions, its content can be linked to specific geographic entities via the database.

Table files serve several purposes in TransCAD. First and foremost, their matrix structure is the most convenient and natural medium for storing the large amounts of data that are transferred in and out of the transportation and spatial analysis procedures built in TransCAD. Tables can also serve to store sparse information that otherwise would clutter the database. Finally, layered data for the same set of entities, but relative to different time periods, are efficiently stored in multiple tables bundled in the same table file.

Data can be imported into a table from an ASCII comma-delimited file or from the database it is linked to, and vice versa. The table editor also allows data to be entered at the keyboard and supports basic manipulations over rows and columns.

Transportation Procedures and Procedure Toolkit

The TransCAD package includes over 40 fully integrated procedures designed for transportation modeling and spatial analysis. Transportation planners, traffic engineers and managers of transportation and communication facilities will find here all the functionality found in
PC-based urban transportation planning (UTP) software packages, such as TRANPLAN, and much more. In addition to the conventional, four-step UTP model, TransCAD has a powerful network builder and manager, shortest path, routing and scheduling algorithms, statistical estimation routines and location-allocation routines. Enhancements of Version 2.1 include a set of procedures to perform mile-posting and dynamic segmentation and procedures to create adjacency matrices and calculate spatial autocorrelation statistics.

By and large, built-in procedures are well designed and run efficiently. On the downside, the documentation does not always offer step-by-step instructions and, at places, contains erroneous information. In addition, two of the procedures that I tested were not in working condition. Following detection, the bugged files were promptly replaced by Caliper. Finally, I find that several procedures fall short of meeting my expectations and could dramatically benefit from enhancements aimed at their generalization.

For instance, spatial interaction models currently do not allow for destination attractiveness or origin propulsiveness variables. Also, the location-allocation algorithm is restricted to a one-median problem while more pragmatic multi-facility problems are out of reach.

To complement built-in procedures, user-designed modules can be embedded with relative ease in TransCAD. These DOS executable programs can be written in any programming language and accessed in the same way as built-in procedures. TransCAD has a script-processing language that lets one design menus, prompts and messages, and retrieve database and table data and pass results back to TransCAD.

Conclusions

TransCAD has many overlapping capabilities with other desktop geographic information systems. With its powerful GIS engine and extensive library of transportation models and spatial analysis procedures, this package is a very serious contender when it comes to choosing a product capable of network analysis.

Most of the frustration expressed by TransCAD users is related to the inadequacy of the documentation and the limited cartographic capability of the package. Caliper Corporation has plans to release Version 3.0 for Windows in summer 1995. While details on the new release are not available at the time of this review, company officials indicate that it will fix the deficiencies reported in this review and regain ground over other GIS packages that jumped earlier on the wagon of window-based operating systems.

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Guidelines for Manuscript Submission

REFEREED ARTICLES

1. *URISA Journal* welcomes manuscripts and accompanying graphics and illustrations on all topics that are germane to information systems, their evaluation and implementation. Articles must be based upon sound scholarship and provide information that is relevant to information systems and associated disciplines.

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3. Submit three (3) copies of the manuscript to:

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4. The cover page should include the title of the paper and the author’s name and address. Also include, on this page, a two- or three-sentence biographical sketch summarizing the author’s education, professional positions, current affiliation, and research interests.

5. Submit a one-paragraph abstract of approximately 100 words. Include the title of your paper with your abstract, but do not place your name on this page. Similarly, do not indicate your name on the first page of the manuscript.

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7. Within the text, references should be cited by using the author’s name and year of publication. When using direct quotations, also include the page number(s). For example: Many employers and corporations have chosen to pursue a hands-off policy (Taylor 1915). “City planning and unified architectural design,” according to Tumark and Reed (1955, p. 131), “were lost to these new communities.”

8. Multiple references in the text should be listed chronologically rather than alphabetically (Zube 1973; Jackson 1978; Tuan 1980).

9. References should be listed on separate pages at the end of the text. These should be alphabetized by using the authors’ last names. When an author has more than one publication, arrange the references by placing the most recent one first. For books, be certain to include place of publication and publisher; for a journal include volume, month, and pages. Do not abbreviate titles or citations.


10. If necessary, explanatory notes may be used. These should be numbered consecutively and must be included on separate pages at the end of the text.

11. First-order subheadings should be capitalized. (e.g., FIRST-ORDER) Text should follow on the line below the subhead.

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14. Long quotations (five or more lines of typescript) must be indented five spaces and double spaced.

15. All tables should be typed on separate pages. Indicate where a table or figure should be placed in the text by including notations such as (Table 1) or (Figure 1). Wherever possible, place these notations at the end of a sentence. Try to avoid sentences such as “Table 1 shows that...” Instead, use constructions that place the table or figure number at the end of the sentence:

“The data indicate that all species were susceptible (Table 1).”

16. Any acknowledgement must be included at the end of the text. The heading for this page should be: Acknowledgements.

17. Authors will receive two copies of the *URISA Journal* issue in which their article appears. Reprints of articles can be ordered, at cost, by the author.

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