# Applying Geographic Information Systems to Transportation Planning

LARRY D. ANDERSON

A technology crucial to better coupling of land use and transportation planning is that of the Geographic Information System (GIS). Because few documented practical applications of this technology have been developed, the Planning Support Branch of FHWA's Office of Environment and Planning, with the Transportation Planning Division of the Maryland-National Capital Park and Planning Commission (M–NCPPC) in Montgomery County, Maryland, conducted a 3-month case study examining M–NCPPC's application of the GIS Spatial Analysis System (SPANS) software to its transportation planning activities. This case study comprises one module within FHWA's GIS/Video Imagery Demonstration Project 85. SPANS was used to disaggregate the county's traffic analysis zones (TAZs) into smaller subzone components to produce finer-grained modeling data. The primary goal was to compare current and planned housing and employment with prescribed development ceilings. This activity permits creation of future scenarios based on the amount of remaining legally developable land, as well as the future demand for transportation by mode (automobile, bus, rail, walking, bicycle, etc.). The results indicate that using GIS-produced disaggregate socioeconomic data with travel demand modeling techniques improves the planner's ability to model both trip generation and modal choice. Further work by planners and GIS software developers alike will expand the application of the GIS well into the future.

Montgomery County, Maryland, is an urbanizing county located to the immediate north of Washington, D.C. Now encompassing 350,000 jobs and 700,000 inhabitants in 270,000 households, the county was once composed of bedroom suburban communities, self-sufficient towns, and fertile agricultural areas. However, in the past several decades, Montgomery County has witnessed rapid growth both in employment and in housing as the Washington, D.C., area has developed a more multinucleated metropolitan form. Like many other urban and suburban areas, the county recognizes traffic congestion and regulation of land development as its top local political issues (*1*).

In response to this rapid growth and development, the county council passed the Adequate Public Facilities Ordinance (APFO) in 1973. The APFO mandates that the county planning board cannot approve a preliminary plan or subdivision if the existing public facilities (or those programmed in the local and state capital improvements programs) will not adequately serve the applicant subdivision and all previously approved projects. Under the county's annual growth policy (AGP), the county council establishes criteria and standards for administering the APFO and approves staging ceilings for each of the county's 17 policy areas (districts) on the basis of the adequacy of transportation and public school facilities. The staging ceiling for a given policy area is the maximum amount of land development accommodated by the existing and programmed public facilities serving the area without exceeding policy standards for adequacy of public facilities (*2*).

FHWA, U.S. Department of Transportation, 400 7th Street, S.W., HPN-22, Washington, D.C. 20590.

Once the policy area ceilings are established, the remaining capacity for development in the respective policy areas is calculated by subtracting the pipeline (approved but unbuilt developments) from the ceiling. When the pipeline has risen to meet the ceiling, the planning board cannot approve additional subdivisions in that policy area, except under certain circumstances. Therefore, development potential is a measurable entity with definite limits.

Faced with these policy restrictions, the transportation planning modeling staff of the Maryland-National Capital Park and Planning Commission (M–NCPPC) in Montgomery County needed both a tool and a procedure to manage and process large amounts of data in monitoring current development patterns, as well as to construct future development scenarios quickly yet accurately.

Like many other urbanized (and urbanizing) areas, Montgomery County possesses vast amounts of usable data in one form or another. However, in the past, the actual use of these data was typically limited to specific software formats (*3*). Recent advances in computer hardware and software have improved this situation. Moreover, because transportation-related data contain spatial components, the best way to associate elements from different datasets is through a consistent spatial referencing system. A technology capable both of georeferencing and of data base management is that of the Geographic Information Systems (GIS). By definition, a GIS is "a computer-based system for the storage and retrieval (and usually the analysis and display, as well) of two- and three-dimensional geographic data" (*4*).

Performing travel demand modeling ranging from master plan models at one extreme to the Baltimore-Washington super network at the other, M–NCPPC's transportation planning modeling staff was concerned that their traditional four-step, zone-based regional transportation models ignored the varying socioeconomic compositions of these aggregate zones by applying single zonal values representing average characteristics (*5*).

Wanting to take advantage of these intrazonal data variations, M–NCPPC believed using a GIS could assist in disaggregating the county's existing 246 traffic analysis zones (TAZs) into 945 component subzones, allowing for the creation of more flexible zonal systems for varying levels of analysis.

Therefore, using data such as the county tax assessor land parcel file records within a GIS to allocate zone-level land use data to the disaggregated subzone components better estimates the subzonal share of TAZ land uses. Representing a bottom-up approach, disaggregation of zonal socioeconomic data better accentuates the relative housing and employment allocation and variation between and within the respective analysis area configurations. TAZ disaggregation also creates smaller, more homogeneous analysis zones, permitting finer network detail. From a travel demand modeling perspective, improved trip assignments subsequently result from smoother loadings onto the network.

Once M–NCPPC made the commitment to GIS, the next step involved selecting a particular microcomputer-based software package. After some deliberation, M–NCPPC chose the Spatial Analysis System (SPANS), developed by TYDAC Technologies Corporation.

SPANS (version 4.302) is like other GIS software in that it imports, manipulates, and exports data from raster and vector structures. However, unlike most other GISs, SPANS uses a quadtree data structure. For example, a given map's geographic information is divided into four equal areas (the first level in the quadtree). If any of these areas are homogeneous, then the quadding of that area stops. All of the areas that are not homogeneous are further subdivided by four (the second quad). This partition process continues until all of the areas are homogeneous, or until a user-specified level of quadding is reached. The quadtree structure then is like a raster structure, but with variable-sized grid cells. Where a map is uniform, the grid cells are large to save memory space; however, where a map is complex, the grid cells are small to preserve resolution (*6*).

M–NCPPC uses the following hardware and software to run SPANS: Compaq Deskpro 386/20 microcomputer with a 300-Mb hard disk, 1-Mb RAM, 80386 math coprocessors, DOS version 3.3, parallel ports for SPANS hardware key and printers, serial ports for the digitizing table, color VGA monitor, monochrome monitor, and Tektronix 4696 color ink-jet printer.

## MONTGOMERY COUNTY CASE STUDY

### Data Requirements

Like other GIS software packages, the power and flexibility of SPANS allow the user to specify the type and amount of data input into the system, as well as that of the information output from the specified analyses. One advantage of GIS is its ability to use existing spatial data bases residing in various formats. Thus, the initial existence of the necessary datasets is the only data-oriented restriction facing agencies interested in establishing GIS applications.

However, data conversion remains a somewhat time-consuming and less-than-perfect procedure. With no prior proven method, M–NCPPC initially developed a prototype procedure to convert the datasets, then perform the TAZ and subzone calculations and projections. Most of this data sorting and calculating was performed in Lotus spreadsheets, exported as ASCII files, then imported as SPANS attribute data files. Processing over 14,000 records in this manner consumes more than 100 person-hr. However, M–NCPPC is currently developing more automated methods, such as writing small programs in-house, which should eventually reduce the processing time by over one-half.

Once the data are processed and formatted into SPANS, the creation of maps and accompanying analyses proceeds at a less cumbersome pace. Assuming staff adequately trained in the GIS in general and SPANS in particular, this operation consumes significantly less effort than the initial data preparation. The planner's preferred level of specificity influences the amount of time devoted to performing the spatial analysis. Therefore, the key for transportation planning agencies interested in using the GIS is identifying its available resources (data, staff, time, computer hardware, software, etc.) from the outset, and later determining the amount and type of work to follow.

### Montgomery County's Input Data

Among the input data included in the Montgomery County case study are the following:

- The 255,000-record county tax assessor parcel file (of which north Bethesda's 14,013 records were used), containing data on all registered land parcels in the county (including acreage, zoning category, land use codes, assessed value of land and buildings, traffic zone number, and census tracts and blocks).
- A data attribute (pipeline) file containing all approved subdivisions in the county, including size of approved subdivisions. The status of these projects was also included.
- Existing Geographic Information Manipulation and Mapping System/Geographic Area Data Structure (GIMMS/GADS) vector line graph files of parcel boundaries for approved subdivisions that were later polygonized.
- Existing GIMMS/GADS vector line graph files of TAZ boundaries, as well as subzone boundaries digitized into SPANS. Both files were then polygonized.
- MetroRail and commuter rail station points digitized by M–NCPPC into SPANS.
- The county's Topographically Integrated Geographic Encoding and Referencing (TIGER)/Line street vector file.
- Montgomery County's Road Maintenance File containing sidewalk and street mileages. From this file, M–NCPPC calculated subzone level ratios of sidewalk mileage per street mileage.

### Case Study Methodology

Focusing on the north Bethesda policy area (one of the county's 17 aggregate policy planning areas), a household and employment forecasting model was used to allocate the aggregate zone-level forecast data from north Bethesda's 14 TAZs directly to the policy area's 59 more disaggregated subzones. The model's primary goal was to map the policy area's current household and employment compositions on both TAZ and subzone levels in relation to the county's prescribed development ceilings. The results provide the planner an indication of the amount of developable land remaining for formulating future development scenarios.

Setting these subzone housing and employment levels to full buildout of the current zoning required using predetermined zoning yields. For each commercial zoning category, the assumed floor area ratio (FAR), assumed number of square feet per employee, and employment type were necessary to estimate maximum employment. On the other hand, the residential zoning yield factors defining the maximum number of dwelling units per acre of land for each zoning category were used to project housing per land parcel. The model's variables and relationships are as follows (M. Replogle, unpublished data):

For Zones $i = 1, \ldots n$ in policy Area $p$:

$B_i$ = base-year parcel file containing number of dwelling units and jobs,
$C_i$ = parcel development completions,
$U_i$ = approved but unbuilt (pipeline) developments,
$F_i$ = development floor $(B_i + C_i + U_i)$,
$R_i$ = zoning capacity (the allocation potential) for vacant and redevelopable parcels not in the pipeline,
$Z_i$ = anticipated zoning ceiling $(F_i + R_i)$,
$Q$ = policy-based decision variable ranging between 0 and 1 applied uniformly to all Zones $i$ in policy Area $p$ that allocates a fraction of $R_i$,
$S_i$ = staging ceiling value for Zone $i$, such that $S_i = F_i + (R_i * Q)$, and
$S_p$ = staging ceiling for policy Area $p$, such that $S_p = \Sigma S_i$.

$R_i$, therefore, represents the maximum potential of residential or employment development that may occur in a given TAZ or subzone. Uniformly allocating a specified portion of $R_i$ for all zones in policy Area $p$, the variable $Q$ can then be adjusted by the planner to construct various development scenarios based on different possible policy orientations. This procedure allows the planner to play multiple what-if games with the model's data in developing planning alternatives.

### Uses of the Model and Data

Once the zones and subzones are established and the various residential and employment totals are converted, calculated, and projected, data analysis and display follow. The planner can then construct SPANS modeling equations and algorithms to produce output maps. Because M–NCPPC is more concerned with pattern than pace of development, housing and employment densities are closely examined. With SPANS, selected attribute data can be aggregated or disaggregated, as well as calculated with itself, yielding output such as density analyses at either the parcel, subzone, or TAZ levels.

Depending on the desired analysis, several data manipulation and display strategies may be used. In order to examine development densities, the M–NCPPC uses three such methods. First, in simple choropleth maps, spatial information is assumed to be homogeneously distributed within a TAZ or subzone and represented by different class values. Because spatial distribution of particular data items is not considered within every subzone or TAZ, class-specific colors or shading patterns are assigned zonally. The primary objective of these maps is to symbolize the magnitudes of the data as they occur within the TAZ or subzone boundaries. In other words, these maps provide only the spatial organization of the statistical data (7).

An add-on module in SPANS developed by TYDAC for M–NCPPC entitled "pointquad" groups parcel-specific data points into aggregate quads, and derives as a value the mean "average" of the grouped points. Relying on more point-specific data (over 14,000 data points), pointquad maps provide a less aggregate view of the distribution of the data among subzones.

In addition, SPANS produces isarithmic maps, which use point data to build maps resembling traditional topographic maps. This method, in contrast to choropleth and pointquad mapping, better displays the contours in the differences between adjacent map attribute values. Smooth and continuous peaks and valleys, not simplistic and sudden breaks between data attribute values, are differentiated with this mapping strategy. Isarithmic mapping requires the following three components: (a) The location of the control points, (b) the assumed gradient, and (c) the number of control points (7).

In addition, potential maps, computed by allocating several data values at dispersed locations to a single location and summing the values, may be produced. For example, concentric rings emanating at specified distances from each of the digitized MetroRail Station points are input into SPANS, allowing for subsequent overlays with any of the existing housing or employment maps to provide output maps or reports specifying the number of dwelling units or jobs at certain distances from transit stations at either the TAZ or subzone level. Table 1 provides examples of this overlay and analysis technique.

This SPANS-generated output then serves as input into the A-Logit model, reestimating M–NCPPC's logit mode choice model. Previously considering only travel times (both in- and out-of-vehicle) and travel cost, the model did not accurately estimate walk access to transit in the county's suburban centers, where typically fewer pedestrian facilities (sidewalks, for example) are provided. For M–NCPPC to better estimate walk access in the new mode choice model, transit serviceability (also known as "pedestrian friendliness") is examined. Using the concentric ring overlay maps and reports created in SPANS, and the county's sidewalk-to-street mileage ratios, M–NCPPC can examine additional factors previously overlooked by the A-Logit model.

## INTERACTIVE USES OF SPANS

Because data files from various sources (not to mention other GIS packages) are pulled into SPANS, first-hand data collection is not necessary. Instead, M–NCPPC's transportation planning modeling staff converts and imports data residing in other digital formats into SPANS. For example, the existing GIMMS/GADS polygon data relieved M–NCPPC's modeling staff of a great amount of data input and digitizing. As a result, significant data sharing exists between individual agencies and departments within Montgomery County owning other GIS software, such as ArcInfo.

Moreover, there seems to be numerous opportunities for interaction not only between SPANS and other GIS packages, but with the various transportation planning modeling software as well. The main requirement is some form of georeferencing (such as points, lines and vectors, and polygons). However, one difficulty associated with this cross sharing of

TABLE 1 SPANS-GENERATED (AND TEXT EDITOR–ENHANCED) REPORT OF EXPECTED EMPLOYMENT IN NORTH BETHESDA APPROVED COMMERCIAL PIPELINE BY 0.10-mi INTERVALS FROM METRORAIL STATIONS

| Class | Distance to Metro | No. of Jobs | % |
|---|---|---|---|
| 1 | Less Than .10 Miles | 0.00 | 0.00 |
| 2 | .10 - .20 Miles | 97.94 | 1.03 |
| 3 | .21 - .30 Miles | 1235.86 | 13.03 |
| 4 | .31 - .40 Miles | 719.62 | 7.58 |
| 5 | .41 - .50 Miles | 683.57 | 7.20 |
| 6 | .51 - .60 Miles | 1871.92 | 19.73 |
| 7 | .61 - .70 Miles | 238.19 | 2.51 |
| 8 | .71 - .80 Miles | 16.89 | 0.18 |
| 9 | .81 - .90 Miles | 0.00 | 0.00 |
| 10 | .91 - 1.00 Miles | 0.00 | 0.00 |
| 11 | More Than 1.00 Miles | 4624.00 | 48.74 |
| Total | | 9488.00 | 100.00 |

information is the use of different locational referencing schemes among individual data bases. For example, EMME/2 network nodes are represented as cartesian matrix coordinates, not as state plane or latitude-longitude coordinates as is the case in SPANS.

Even though SPANS version 4.302 does not contain standard transportation network modeling capabilities, future versions will permit internal travel demand modeling. Until then, SPANS will continue to be used primarily for disaggregating model data input to EMME/2, and for using the various existing data bases to better estimate model variables used in trip generation and mode choice. In addition, these disaggregate data are visually displayed in SPANS to provide an immediate presentation of the values of the various map layer attributes for local officials.

## CONCLUSIONS

Although the GIS has existed for several years, its fullest potential has yet to be realized. With many innovative applications to explore, the M–NCPPC's early application of GIS to its traditional transportation planning activities represents only a first step in better integrating land use and transportation planning issues and variables within the overall modeling context.

Using the GIS to create smaller network subzones not only exploits the intrazonal disparities often submerged in more aggregate zone-based models, but also improves trip assignment onto this finer-grained network. With GIS, planners (either for the sake of convenience or inadequate computing capability) need no longer ignore the varying socioeconomic compositions of aggregate zones by applying single zonal values representing average characteristics.

M–NCPPC can now perform a finer-grained analysis of origin and destination characteristics related to both trip generation and mode choice modeling. Therefore, greater attention can be given to the pattern of county growth than to the pace (magnitude) of development. For example, current, approved, and maximum potential residential and commercial development are now mapped at either parcel, subzone, or TAZ levels in SPANS to monitor the amount of development near the county's transit stations.

However, some issues remain. Although possible GIS applications to transportation planning and modeling seem limitless, interested agencies should not assume the existence of adequate data in one form or another guarantees immediate subsequent outputs. To the contrary, a significant amount of work is required to retrofit existing data bases into a GIS. Like other large-scale, data-intensive computer models, the GIS is relatively easy to maintain once established. However, long-term commitment to the GIS is essential. Thorough analysis of the agency's needs and available resources must be conducted before initiating the GIS. After the decision to use the GIS is made, a secondary decision-making process concerning which particular software to select must follow.

The GIS possesses vast potential in urban transportation planning and modeling, although the current applications developed by M–NCPPC mark only the beginning. In the future, planners and GIS software developers alike need to better adapt current GIS software and develop new software that addresses specific transportation planning needs.

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## REFERENCES

1. M. Replogle. *Computer Transportation Models for Land Use Regulations and Master Planning in Montgomery County, Maryland.* In *Transportation Research Record 1262*, TRB, National Research Council, Washington, D.C., 1990, pp. 91–100.
2. *Montgomery County's Pipeline of Planned Development: 1989 Sta-*

*tus Report and Inventory*. Planning Department Research Division, Montgomery County, Md., 1990, p. 1.
3. T. Nyerges and K. Dueker. *Geographic Information Systems in Transportation*. FHWA, U.S. Department of Transportation, 1988.
4. M. Monmonier. Technological Transition in Cartography. The University of Wisconsin Press, Madison, 1985, p. 256.
5. M. Replogle. *Integration of a Geographic Information System With Computer Transportation Models for Land Use and Transportation Planning. Proc., 2nd Conference on Application of Transportation Planning Methods*, University of North Carolina, Charlotte, 1989, p. 3.
6. *SPANS Version 4.3 User's Manual*, Vol. 1, Tydac Technologies Corporation, pp. 3–14.
7. A. Robinson, R. Sale, and J. Morrison. *Elements of Cartography*, 4th ed., John Wiley, New York, 1978, pp. 225–245.

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