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GIS and Transportation Planning

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ABSTRACT

Two main objectives of transportation planning are to simulate the current traffic volume and to forecast the future traffic volume on a transportation network. Traffic demand modeling typically consists of the following tasks (1) defining traffic analysis zones (TAZs) based on land-use characteristics, (2) building the transportation network, (3) collecting traffic data for calibration, and (4) performing the four-step traffic demand modeling process of trip generation, trip distribution, mode choice, and trip assignment. The first two tasks used to be time-consuming because paper maps and aerial photographs were the primary tools for constructing TAZs and the transportation network. In recent years, transportation planners have used geographic information systems (GIS) to perform the tasks. A GIS is a tool capturing, storing, and analyzing spatial or geo-referenced data. It also has the additional capability in data integration, such as integration of socioeconomic and traffic data for traffic demand modeling.

This paper describes our experience of using a GIS to prepare TAZs and the transportation network for an Idaho statewide traffic demand model. ARC/INFO is the GIS software package for our pilot study, Latah County. We have used ARC/INFO to construct TAZs from TIGER files at different spatial scales and to build the transportation network from different data sources. Using AML programs, we have run experiments to automatically assign TAZ centroids and centriod connectors, and to measure the effect of centroids and centroid connectors on traffic demand forecast. Overall, GIS has proved to be an efficient and effective tool for our study. It should be noted, however, GIS cannot by itself improve the quality of input data, a critical factor in transportation planning.

GIS and Transportation Planning

Introduction

In recent years, efforts have been made to integrate the geographic information system (GIS) technology with transportation planning modeling. GIS has assisted in building the transportation network and traffic analysis zones (TAZs) (1, 2). GIS has made it easier to perform sub-area analysis and to modify the TAZ structure (3, 4). A number of transportation agencies have used GIS for network coding, socioeconomic data manipulation, and display of data from travel forecasting models (5, 6, 7, 8, 9, 10). The advantages and the ways of integrating GIS with traffic demand modeling have been studied by Anderson et al. (11), Anderson (3), Bailey and Lewis (1), Basile et al. (5), Lewis (12), Martin and McGuckin (13), Prastacos (14), and Sutton (15).

The literature suggests that GIS applications in transportation planning are primarily in the following three areas:

To prepare input data for traffic demand modeling

Input data for traffic demand modeling include a transportation network, TAZs, TAZ centroids, and centroid connectors. GIS can help build a transportation network from different data sources, such as road networks maintained by state or local transportation agencies and the TIGER files. TAZs usually follow available census data boundaries, such as census tracts, block groups, or blocks, so that data collected in the decennial census can be used with minimal manipulation. However, these census data boundaries are sometimes not well suited for analyzing proposed development sites. Tracts or blocks must then be split by community plan boundaries, zip code boundaries, and/or planned roadways. GIS can help create a TAZ map interactively or automatically by overlaying the necessary boundary files and performing query and analysis of socioeconomic and land use data. To connect the transportation network with TAZs, it needs centroids and centroid connectors. Again, GIS packages offer commands and macro programming capabilities that can automatically define centroids and centroid connectors.

To establish an integrated database

A GIS can be used to maintain and manage all map layers and their attribute data related to transportation planning as long as the map layers are geo-referenced. The database may include the transportation network and related traffic data, zonal boundary files such as census tracts and blocks and associated socioeconomic data, and other layers on land use, hydrography, soil, and elevation. Increasingly, image data, such as digital orthophotos and satellite images, are used in transportation planning. A GIS allows integration of data from different sources and different scales. It can also aggregate forecasted traffic data and produce cross-reference files between different levels of geography.

To Display Modeling Output

GIS is an excellent tool for displaying transportation data and model results. The graphic presentation is important for effectively communicating the results of a transportation model to the public and elected officials. GIS's query capabilities make it possible to quickly respond to questions that arise during meetings, and to focus attention on affected areas.

Case Study

We are developing a statewide traffic demand model in Idaho. To help us design the model and to anticipate potential problems at the state level, we have conducted a pilot study using Latah County as the study area. We use ARC/INFO as the GIS software package and TRANPLAN as the traffic demand modeling package. In the following, we describe our work so far in linking GIS with transportation planning.

Traffic Analysis Zones (TAZs)

TAZs link travel with population, land use, and socioeconomic data. They represent geographic units that have similar land use activity characteristics. Traditionally, transportation planners have used land use maps and aerial photographs to define TAZs. The manual process is, however, time consuming. With the use of a GIS, preliminary TAZ boundaries can follow census statistical boundaries, such as block groups, census tracts, or counties.

In our study of Latah County, we used the GIS to first establish an integrated spatial database with boundary files of census tracts and block groups, and a land use map. The database enabled us to experiment with TAZs at either the census tract level or the block group level. It also allowed us to integrate spatial data, such as aggregating block group data to be used at the census tract level. We overlaid census block group files with the land use map and found that some census blocks were not homogeneous in land use. Those census blocks were split into two zones using the map overlay and editing capabilities of the GIS.

Transportation Network

A transportation network is a digital format of road centerlines. It consists of nodes and links. Nodes are intersections and critical turns and links are road segments between nodes. The digital file of a transportation network must also contain node coordinates and link characteristics such as speed limits, capacity, and functional classification. For our study, road centerlines were available from several data sources, such as the TIGER/Line files, the USGS Digital Line Graph (DLG) files, and data files from the Idaho Transportation Department (ITD). Link characteristics such as speed limit, capacity, and functional classification were available from ITD.

We decided to use MicroStation DGN road centerline files and the MACS\ROSE database, containing all link attribute information from ITD. Dynamic segmentation was performed in ARC/INFO to attach the link attributes with the coordinate file. Because ITD maintained rural road and city street files separately, we had to put all files together to create a single file in ARC/INFO. An Arc Micro Language (AML) program was written to prepare node coordinate and link attribute files in the format required by TRANPLAN.

Assignment of Centroids

A centroid represents the "center of activity" of a TAZ and is used as the specific location of the origin and destination for all trips to and from the TAZ. A centroid may be a city, a town, or a shopping center, depending on the spatial scale used in transportation planning. In practice, however, it is often difficult to define a centroid if the TAZ is large and contains more than one center of activity. Optionally, a centroid may be defined as a center of gravity or the geometric center of a TAZ.

This section describes our experiment of automatically assigning centroids using the center of gravity concept, i.e., how to assign centroids to TAZs at the census tract level by using the household data at the block group level. We used the City of Moscow as our study area. The equations for the center of gravity are as follows:

$$\bar{Y} = \frac{\sum_{i=1}^{n} yP}{\sum_{i=1}^{n} P}$$

$$\bar{X} = \frac{\sum_{i=1}^{n} xP}{\sum_{i=1}^{n} P}$$

In which:

$\bar{X}$ and $\bar{Y}$ are the x,y coordinates of the centroid,
x and y are the x,y coordinates of a point,
n is the number of points,
P is the value at the point.

Although it was possible to use the equations directly by assigning a point, such as the geometric center, to each of the block groups in Moscow, we decided to conduct the experiment in raster format for the following reasons. First, raster data analysis was more efficient than vector data analysis. Second, raster data analysis allowed cell by cell, neighborhood, and zonal functions, which were particularly suited for hierarchically structured spatial data such as census data. Third, raster data simulated a continuous surface and, as such, avoided the problems of area partition and weighting, common in vector data analysis with different spatial scales.

We chose a cell size of 100 x 100 meters. The initial steps in our algorithm involved the preparation of input grids. The household density grid was converted from the Moscow block group coverage using its household density attribute as the cell value. The X grid contained the X value of each cell in the household density grid, and the Y grid contained the Y value. The fourth input grid, called the TAZ grid, was converted from the Moscow census tract coverage. The next phase in our algorithm performed analyses with the input grids. We multiplied the household density grid by the X grid and Y grid, respectively, to derive the XH and YH product grids. We then used the TAZ grid as the zone grid to sum the product grids and the household density grid for each zone, i.e., for each census tract. The X coordinate of the centroid was then calculated by dividing its zonal sum of the XH product grid by its zonal sum of the household density grid. The Y coordinate of the centroid was calculated in the same manner. The final steps in our algorithm prepared the centroid grid by setting all cells in the grid to no data except the centroid cell and converted the centroid grid to a point coverage. Figure 1 shows the centroids derived from our algorithm.

Assignment of Centroid Connectors

A connector attaches a centroid to the transportation network. It is usually treated as a dummy link, connecting the centroid to the closest point on the network in a straight line. The ARC/INFO command "NEAR" is used to identify the closest point on the closest link of the surrounding network to the centroid. Then the "GENERATE" command can create the centroid connector from both X, Y coordinates of the centroid and the closest identified point on the network. In our pilot study, we wrote an AML macro to automate the process of building centroid connectors.

Measuring the Effect of Centroids and Connectors on Traffic Demand Forecast

The primary purpose of our second experiment was to measure the effect of centroid location and number of centroid connectors on traffic demand forecast. As mentioned earlier, a centroid may represent a real object such as a city or a town, a center of gravity, or a geometric center. A centroid may be linked to a transportation network through a single connector or multiple connectors. Multiple connectors are preferred if a TAZ is served by more than one road in its vicinity.

We chose Latah County in Idaho for our experiment. We used 33 block groups as the TAZs. About half of the TAZs were located within the city limit of Moscow and the rest in the rural area of the county, see Figure 2. We prepared four data sets to represent four different scenarios with respect to centroid location and number of connectors. The first data set, or geocen1, consisted of centroids at the geometric centers of the TAZs and one connector per centroid. The second data set, or geocen2, was the same as the first except that a centroid could have two connectors, as long as two roads were present in the vicinity of the centroid and the closest point of the road to the centroid was within 8 km (5 mi). The third data set, or towncen1, used towns as centroids in rural TAZs as long as the town had a population of greater than 100. Nine such towns in rural areas of Latah County were chosen as centroids; they were combined with other geometric center centroids. The fourth data set, or towncen2, was the same as the third except that it allowed two connectors per centroid. The NEAR command was used directly in the case of one connector per centroid. We had to write an AML macro to generate two connectors per centroid. Essentially, the macro builds the first connector, drops the link to the first connector from the network, and finds the second connector among the remaining links. We also wrote AML macros for data exchange between ARC/INFO and TRANPLAN, a software package for traffic demand modeling.

We ran TRANPLAN with one data set at a time to generate traffic demand forecasting for each scenario. The TRANPLAN output showed the estimated traffic volume for each link on the transportation network. The Latah County network had over 300 links. To measure the rate of change in estimated traffic volumes between different scenarios, we used the following root mean squared formula:

$$C = \left[\sqrt{\sum_{i=1}^{n} \left(\frac{T_{1i} - T_{2i}}{T_{1i}} \right)^2} \Big/ n \right] * 100$$

Where T_{1i} is the estimated traffic volume of a link under scenario 1; T_{2i} is the estimated traffic volume of the same link under scenario 2; and n is the number of sampled links. The C value measures the rate of change in traffic demand estimates when the model is changed from scenario 1 to scenario 2.

We selected 28 links from the Latah network for the preliminary data analysis. Fifteen of these links were located in the rural area; they were all near centroids and road intersections. The other 13 links were located within the city limit of Moscow; they were randomly selected.

Table 1 summarizes the C values from data analysis. The change from geocen1 to geocen2 resulted in a 4.2 percent change in the estimated traffic volumes of the 28 sample links. The rate of change increased to 8.1 percent from geocen1 to towncen1, and 8.7 percent from geocen1 to towncen2. The results suggest: (1) centroid location was a more important factor than number of connectors in traffic demand forecasting, and (2) the change in both factors such as in the case of towncen2 resulted in the largest change in the estimated traffic volumes of the sample links.

The second part of Table 1 shows that the use of nine town locations as centroids resulted in a 15.1 percent change in the estimated traffic volumes of the 15 rural links. The rate decreased to 9.2 percent in the case of two connectors per centroid. The third part of Table 1 shows that the effect of the change from one to two connectors was relatively small, and even smaller when town locations were used as centroids.

Table 1. Rates of change (%) in estimated traffic volumes of sample links between scenarios

Part	Sample (Links)	geocen1/ geocen2	geocen1/ towncen1	geocen1/ towncen2	geocen2/ towncen2	towncen1/ towncen2
I	28	4.2	8.1	8.7		
II	15 rural		15.1		9.2	
III	28	4.2				3.6

Conclusion

We have described in this paper our experience in using a GIS to prepare a transportation network and TAZs as input to traffic demand modeling. We have also experimented with the automatic assignment of TAZ centroids and centroid connectors, and measured the effect of centroid location and number of centroid connectors on traffic demand estimates. GIS has proved to be an efficient and effective tool for our pilot study. However, we have realized at the same time that GIS cannot by itself improve the quality of input data, a critical factor in transportation planning. Our pilot study should help us in building a statewide traffic demand model.

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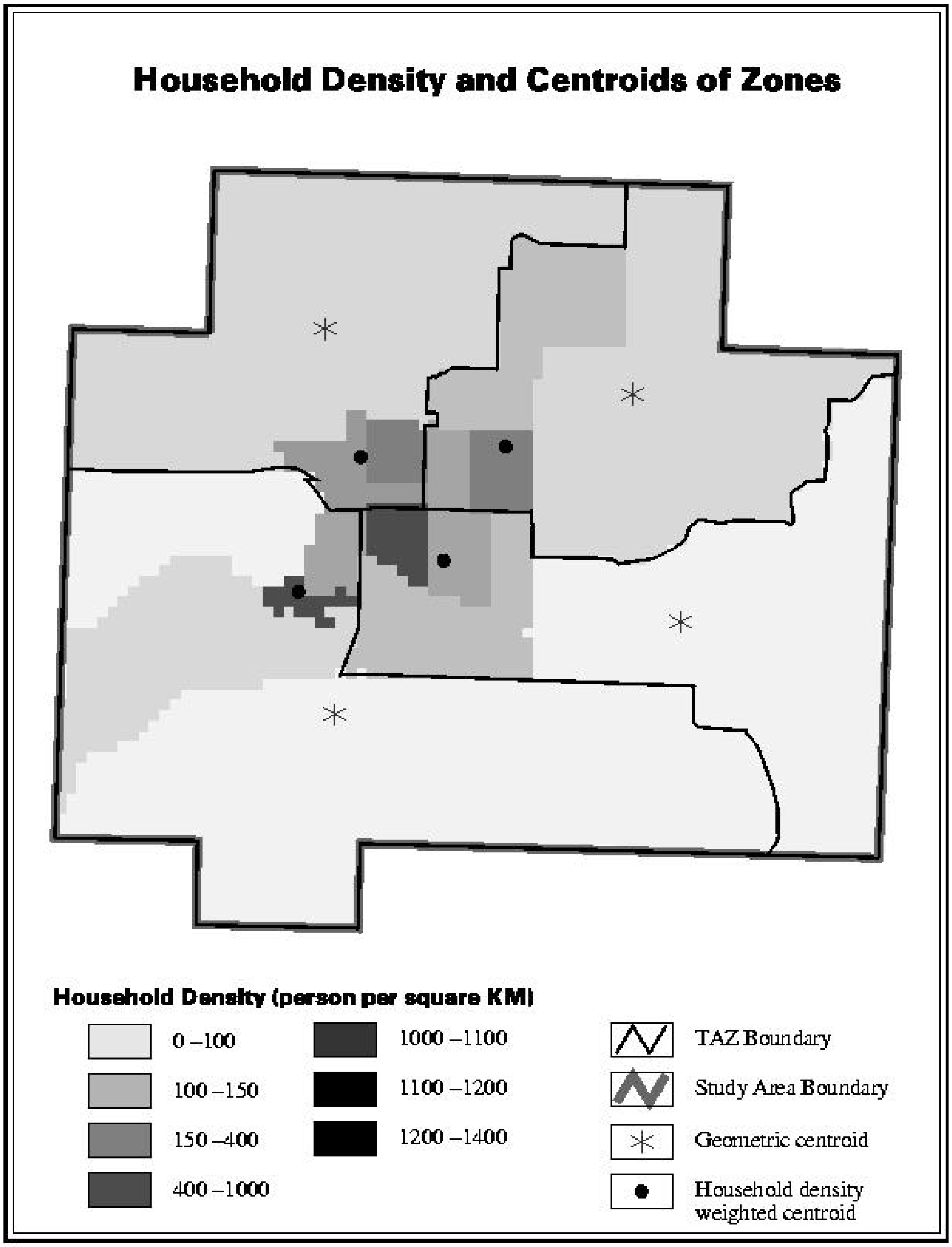

Figure 1 Household Density weighted centroids vs geometric centroids

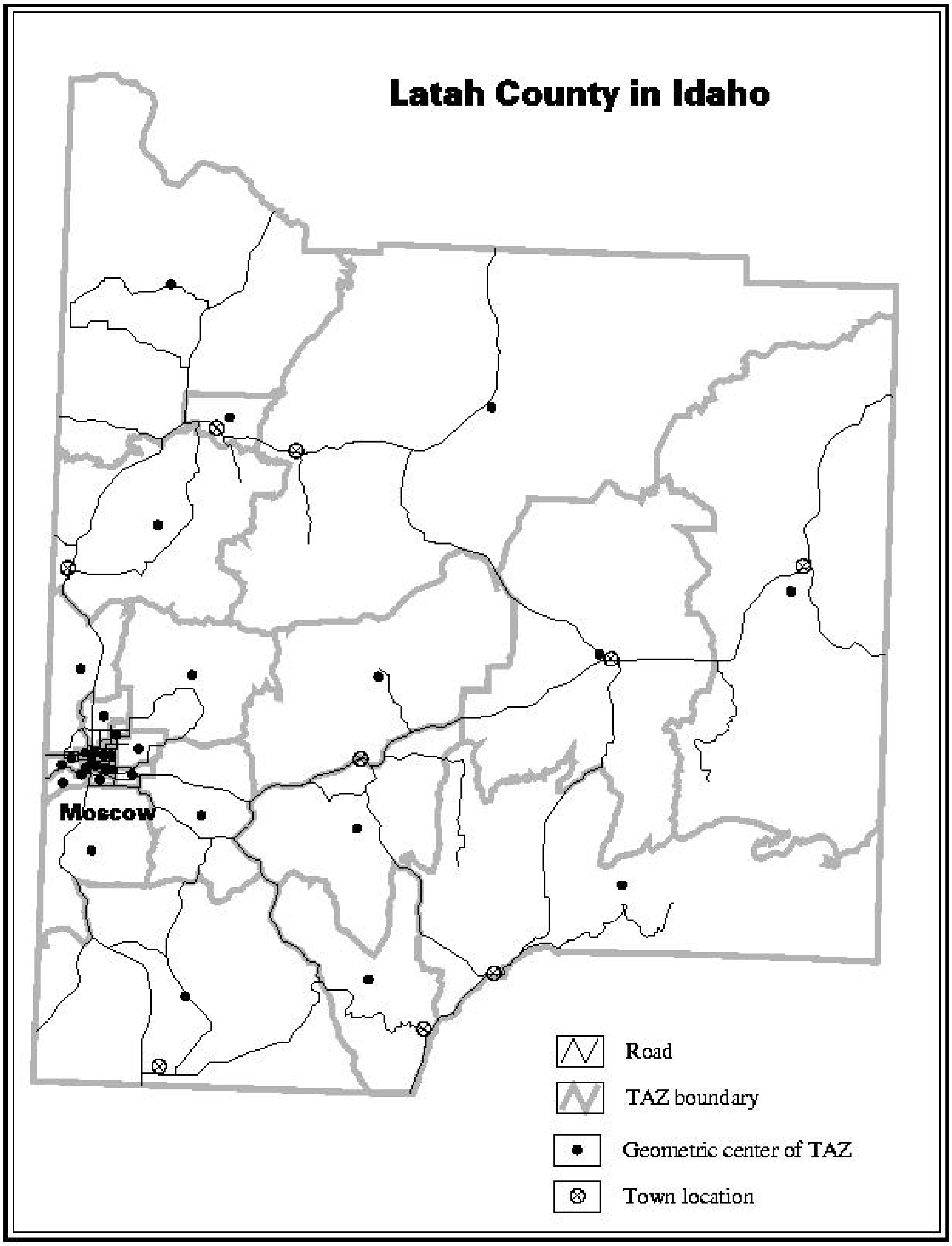

Figure 2 TAZs and centroids in Latah County traffic demand model

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