Applications of Geographic Information System–Transportation Analysis Packages in Superregional Transportation Modeling

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"Superregions" are large areas 50 to 100 mi across containing several large cities that function as an integrated group. Transportation planning for such regions has typically been minimal, limited to the planning efforts of the separate urban area metropolitan planning organizations. As the area grows, however, interarea commuting patterns and integrated economies increase the need to analyze the entire region as a unit. The use of new Geographic Information System (GIS)-transportation packages to conduct such an analysis for the Charlotte, North Carolina, area, an emerging superregion of 1.6 million people, is discussed. The impetus for the study is a proposal for a 150-mi (or more) road around the region, called the Carolinas Parkway. Using the GIS package TransCAD, a sketch network for the region is developed by merging data from a variety of sources. Traffic is simulated over the network using a doubly constrained gravity model technique, calibrating simulated traffic to existing traffic counts. Preliminary forecasts of the parkway traffic are then made. An additional procedure, LANDSAT imagery, is being used to identify and categorize land uses in several alternative corridors for the parkway. The problems and opportunities presented by superregional modeling are discussed, and ways by which transportation planning will be changed by both the need for such models and the availability of the software to build them are suggested.

Historically, regional planning traces its roots back to the 1930s. The Federal Highway Act of 1962 mandated that "regional" (i.e., urban area) multimodal transportation planning be carried out in urban areas; this was the forerunner of local metropolitan planning organizations (MPOs). In most communities, these MPOs consisted of representatives of the major city, the major county, other major towns in this central county, and the city's extensions into rapidly growing rural areas and suburban towns in nearby counties. Cooperative state ventures were formed in cases in which the metropolitan areas encompassed more than one state.

Through the 1970s and the early 1980s, such organizational structures served well. However, in the late 1970s, changes in regional growth patterns began. Propelled by a generally healthy economy, lower land values on the fringe, and increasing interstate transportation system access, rapid development on urban fringes began to occur and space inside the large metropolitan areas began to fill. These changes accelerated demands on the ability of the metropolitan area to handle commuter traffic on its transportation network. Thus, additional pressure was placed on the organizations responsible for the management and planning of the affected transportation system. From this experience, the older 1960s style of urban planning process was noted to be ill equipped to plan effectively for the transformed metropolitan area or new "superregion." Increasingly, metropolitan areas recognized the existence of a broader scale of influence extending far from the city proper.

The superregional area can be roughly defined as an area encompassing several counties 50 to 100 mi across, often spreading over several states. It may be thought of as the "influence" area of the major city, larger than the MPO boundary, more like the "television market" or "maximum commuting market." Charlotte, North Carolina, an emerging superregion, is the center of a 13-county transportation planning coalition known as the Carolinas Transportation Compact (CTC). A study initiated by this group, the Carolinas Parkway Study, is of the superregional scale and was studied and analyzed using TransCAD, a newly developed geographic information system (GIS)-based transportation network analysis package, and ERDAS, a satellite imaging system for land use planning.

With the advent of such packages, different levels of analysis are now possible when conducting studies. Projects that were limited to analysis on mainframe systems can now be solved in the microcomputer or minicomputer environment at a fraction of the cost and time required by the larger systems.

With the need for an increase in superregional planning, the demand for the tools to handle superregional analysis increases concurrently. As this need increases, computer programs designed to analyze these issues continue to improve. Costs (measured in time required for analysis, person hours needed for such projects, software expense, and processing requirements) have consistently been decreasing over the last 20 to 30 years. Additionally, the ability to work with more complex analyses on smaller machines has been growing. Examples of new transportation analysis programs to work in the microcomputer environment included TRANPLAN, TMODEL, Microtrips, and TransCAD. TransCAD is a transportation analysis program that is GIS-based; that is, data in the form of point, line, and polygon layers can be tied to sets of coordinates that are tied to the transportation network being analyzed. TransCAD also has the ability to read TIGER files that are generated by the U.S. census, convert these files into usable formats, and perform various transportation network analysis procedures on the basis of such data. Through the use of this program, a high-level superregional analysis of the Charlotte, North Carolina, area is being conducted.

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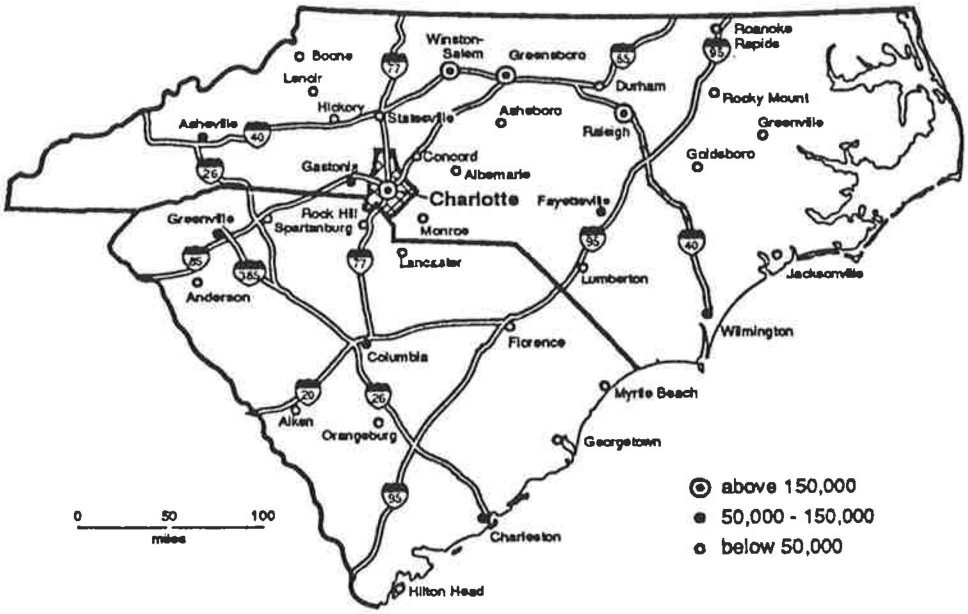

FIGURE 1 Charlotte-Mecklenburg and Carolinas region.

FORMULATION OF CAROLINAS PARKWAY STUDY

The greater Charlotte metropolitan area encompasses two states and covers a broad multiple-county area of the Piedmont region in south-central North Carolina and north-central South Carolina (Figure 1).

Growth was rapid in this region during the 1980s: the region's population grew by 15.89 percent. Such growth was not confined to the central cities or their suburbs but occurred throughout the 100-mi region. As expanding cities and their associated urban areas began to touch, boundaries began to blur, resulting in the formation of integrated economies. This new form of metropolitan area, known as a superregion, congealed, with growth occurring not only on the fringes but also within the region (*1*). As this growth occurred, a radial character for this region evolved along with an increasing imbalance in the jobs-to-housing distribution. Commuting patterns, which once were almost entirely within the individual counties, shifted to an intercounty pattern, and larger cities served as employment magnets and smaller communities acted as bedroom communities. This commuter-oriented radial traffic began to engulf previously adequate radial Interstates and increasingly came into conflict with cross-town and cross-region circumferential traffic using inadequate circumferential road systems. Thus, pressures from this growth encouraged a regionally thinking "mind set" for transportation planning. Existing urban area MPOs are responsible only for their respective areas, not the entire region, so some new form of organization was needed. Such thinking manifested itself in the December 1989 formation of the CTC and the planning areas for the individual MPOs located throughout the region (see Figure 2).

High on the agenda of the CTC is improvement in the circumferential access of the region. The placement of a regional ring road that encircles the region would improve this type of access. Envisioned as an interstate, limited-access expressway, this road would circumscribe Charlotte about 30 to 50 mi out, connecting the major towns and cities of the region (Figure 3). With an estimated length of about 140 to 180 mi, construction costs of the road have been estimated to range from $2 to $4 billion.

The idea for a Carolinas Parkway has encouraged the cooperative assessment of its impact. Beginning in fall 1991, the North Carolina Department of Transportation and the South Carolina Department of Highways and Public Transportation with the help of a feasibility study are expected to begin studying the feasibility of a ring road that encircles the region. This study will include corridor analysis, alternatives, corridor scanning, effect of facilities, and estimated costs of construction. The planning process for modeling the parkway contained eight elements: (a) very long modeling time frame (20–40 years); (b) great uncertainty in population and employment forecasts; (c) undefined alternatives; (d) separate multiple urban areas; (e) no common base-year data; (f) limited regional travel information; (g) large and distant major nodes (e.g., other cities) at the edge of the region; and (h) unknown feedback between transportation and economic growth. These features introduce great uncertainties in the analysis but also permit more rapid sketch planning.

BUILDING THE MODEL'S GIS DATA BASE

Data necessary for model development consisted of several types: network description and related data, population and employment data, and trip data. Traffic forecasting was accomplished by (a) coding in a base network for the region, (b) developing trip "load nodes" (generated from population and employment data) on the network, (c) generating flows between these origins and destinations through the use of a gravity model, (d) assigning the traffic to the network, (e) calibrating the base model by using observed traffic counts, and (f) assigning projected traffic on the future networks.

FIGURE 2 Carolinas Transportation Compact.

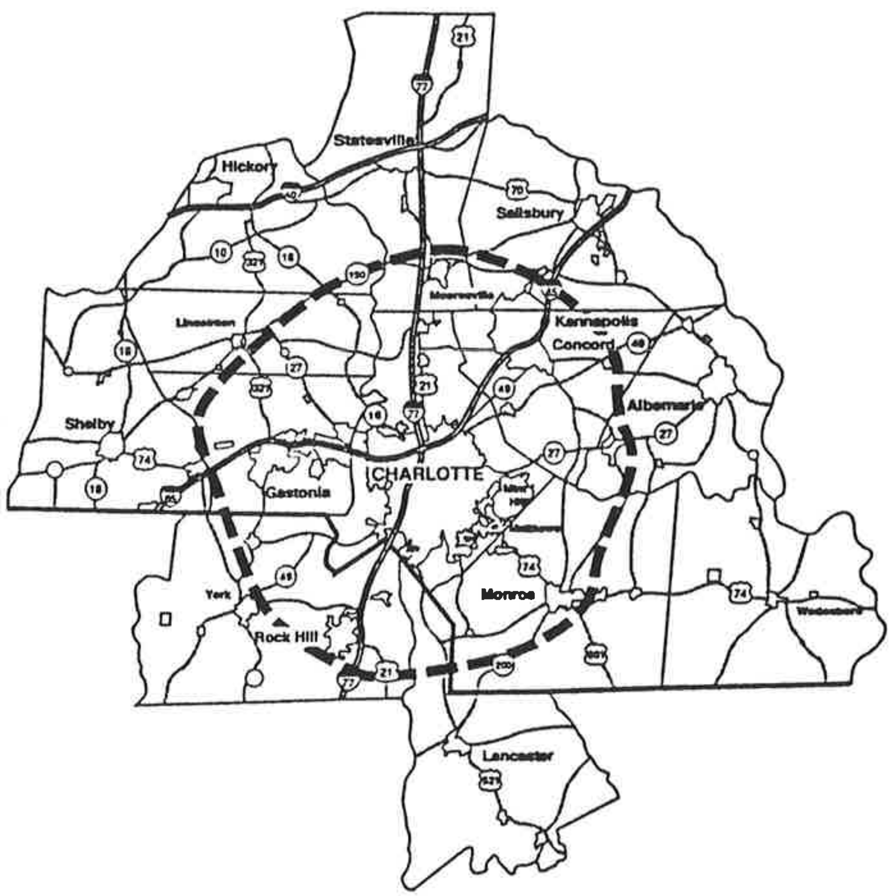

FIGURE 3 Possible location for Carolinas Parkway.

Network Data

The strategy for modeling was to create several networks reflecting the construction of several transportation projects. These networks can be summarized into the following categories: (a) the 1988 base network, (b) the formalized transportation improvement plan (TIP) network additions, (c) additional possible transportation improvements under discussion but not yet on the TIP, and (d) the Carolinas Parkway corridors and their alternatives. Data describing the base network and its additions (e.g., location, lanes, and traffic counts) were supplied by local agencies, state highway departments, and the TransCAD vendor.

The initial starting point in building the GIS data base consisted of developing a base transportation network. Two options were available to accomplish this task. One option was to begin with digitized TIGER files describing the region's complete road network and strip out the unnecessary links. The other option was to begin with a simplified regional network by digitizing additional links. This initial base network for both states consisted of parts of the U.S. Interstate and highway systems in addition to parts of the state highway systems and originated from Oak Ridge National Labs. The second option, network tailoring by densification, was chosen because the analysts wanted specific control over which link sections to incorporate. Basic data for each link included speeds and lengths, number of lanes, capacity, and traffic.

One useful feature of TransCAD is its ability to store many (literally hundreds of) characteristics describing links included within a network. One link characteristic variable used in the model was link travel costs or link impedance factors, intended to account for node delays as highways pass through towns. During the coding of the regional transportation network, each link was assigned to a link-type category. These categories consisted of U.S. highway rural links, U.S. highway urban links, Interstate highway rural links, Interstate highway urban links, state highway and local rural links, and state highway and local urban links. For each link type, a corresponding link-type travel time penalty (LTTTP) was estimated and added to the data base. The travel time was then calculated as

$$\text{TRAVEL TIME}_l = [\text{LENGTH}_l/(\text{SPEED}) - 5)] + (\text{LENGTH}_l * \text{LTTTP})$$

where

TRAVEL TIME_l = travel time for a given link l (hr),
LENGTH_l = length of link l (mi), and
SPEED_l = posted speed of link l (mph).

LTTTPs were estimated by assigning a time delay factor associated for each link type. These factors were initially estimated and subsequently adjusted slightly during the calibration phase of modeling. The final values used in the model are listed in Table 1.

As an example, consider a 1-mi section of urban U.S. highway with a posted speed of 45 mph. The travel time on this link would be $(1.0/(45 - 5) + (1.0 \times 0.0100) = 0.035$, implying an effective average speed (with delays) of 28.6 mph. Thus, the travel time penalty effectively accounts for delays that otherwise would not be observable in a high-level sparse network.

TABLE 1 Link-Type Delay Factors

Link Type	Delay Factor in hours/mile	(sec/mile)
US Rural	.00416	15
US Urban	.01000	36
Interstate Rural	.00100	3.6
Interstate Urban	.00800	30
State/Other Rural	.00416	15
State/Other Urban	.01666	60

Figure 4 shows the final sketch network. Note that it is very sparse, showing only major routes. Also note that some towns are shown as single nodes. This is consistent with the high-level and long-range nature of the forecast.

Population and Employment

In addition to the transportation network, a method is needed to include population and employment data. Such data are used to generate trips for assignment to the network. Traditionally, this is accomplished by delineating traffic analysis zones (TAZs), and both population and employment data are then aggregated to the TAZ. The centroid "loading node" for each zone is then defined and the data are attached to this point, which is in turn tied to the network using loading links. In the development of data for this regional model, population and employment data were directly tied to loading nodes found on the network. This technique eliminated the need for zones and zonal loading links and helped to eliminate the calibration problems associated with using these pseudolinks.

The 1988 population estimates from the Census Bureau were used as the control data source for base population futures. This data source provided population data by county

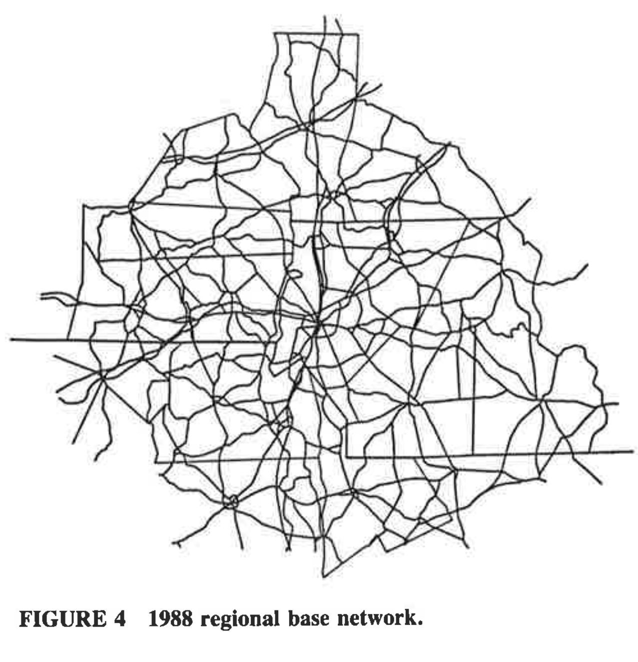

FIGURE 4 1988 regional base network.

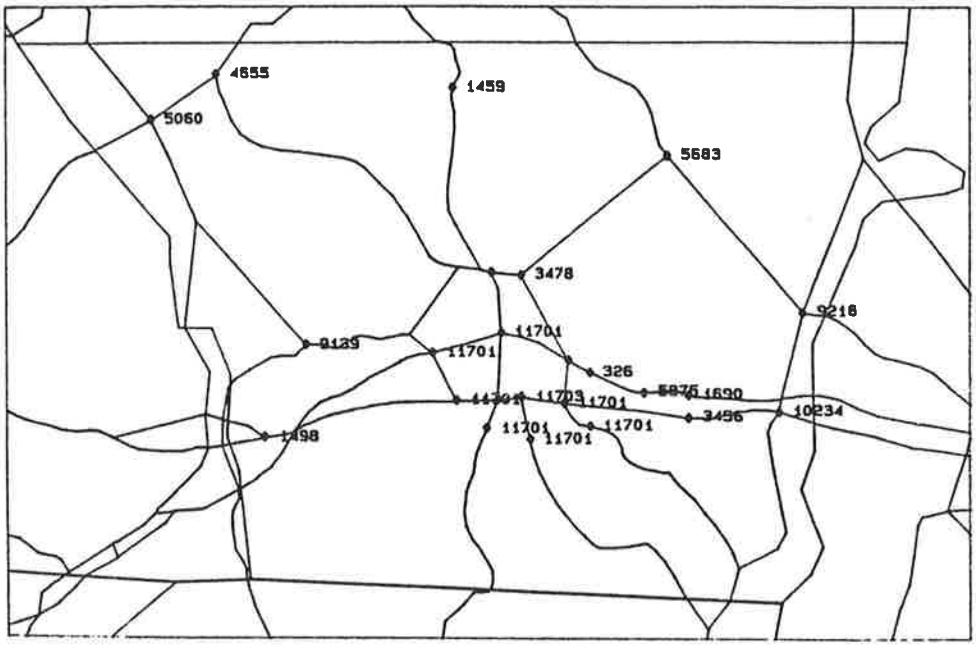

FIGURE 5 Population loading nodes for Gaston County.

and incorporated place for 1980 and 1988. Later checks with 1990 data show good agreement. From these data, each place's share of a county's total population was determined and used to distribute the remaining county population found outside the incorporated places within the county. The rationale behind this procedure was that in the area surrounding these incorporated places is a band of population living just outside the incorporated limits. Population density maps were used to help in "attaching" a town's population to the network notes that make up the town. Figure 5 shows the population loading nodes for Gaston County, North Carolina.

Future baseline trend population distributions were projected using a shift-share analysis: that is, historical changes in the share of population in each incorporated place within a county were assumed to continue in the future. North and South Carolina county population projections were used as controls for distributing total population growth or reductions. Sources for these county control projections were *North Carolina Population Projections: 1988–2010* and *Population Projections for the Census County Divisions in South Carolina: Number of Inhabitants, 1985, 1990, 1995, 2000* (*3*).

Unlike population, employment data by place of work are not publicly available between census years. The source for these data was the North Carolina Economic Security Commission (*4*). These data were distributed on a subcounty level using ZIP code distributions of retail and nonretail employment provided by a private data vendor—Equifax, Inc. (*5*). By overlaying a ZIP code map with a map of the network, the employment by ZIP code could be assigned to loading nodes. Employment data were broken down into retail and nonretail categories, using the classifications in an NCHRP report (*6*). Retail employment was defined as any industry that attracts commercial or trade traffic off the streets (e.g., retail establishments, professional service offices, government service offices), and nonretail was defined as everything else. Figure 6 shows employment assigned to loading nodes in Gaston County.

Future baseline employment projections were developed using current county population-to-employment ratios and applying such a ratio to projected future county populations. These projections were then distributed to subcounty nodes proportionally according to each node's proportion of the current employment.

Trip Generation

In development of the regional model, trip production and attraction estimates were used for each loading node on the transportation network. Person productions and attractions for these nodes were estimated using the areawide procedures from an NCHRP report 187 (*6*), based on dwelling units (derived from population counts), retail employment, and nonretail employment. These estimates of productions and attractions were developed for home-based work trips, home-based nonwork (HBNW) trips, and non-home-based (NHB) work trips. Vehicle occupancy rates by trip purpose (e.g., HBW, 1.13; HBNW, 1.55; and NHB, 1.44) were used to convert person trips to vehicle trips. Total vehicle productions and attractions for each trip type were added and converted to vehicle trips per node for use in the sketch network. A sketch factor was required to "scale down" vehicle trips to fit the sketch network on which they were assigned (i.e., there was not enough network to show the full vehicle miles traveled (VMT) unless productions and attractions were also adjusted). This conversion was made by using FHWA's Highway Statistics, 1989 (*7*) to develop a ratio of federal system VMT to total state VMT. Federal system VMT was used because the sketch network consists largely of the federally supported streets. A sketch factor of 0.721 was calculated for North

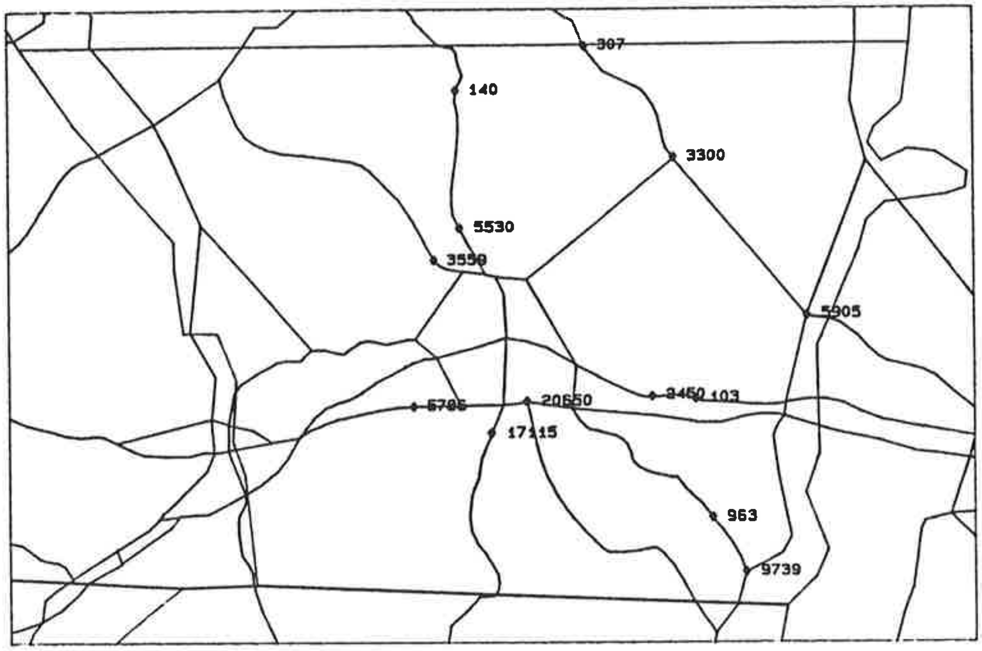

FIGURE 6 Assignment of employment to Gaston County loading nodes.

Carolina and then applied to the vehicle trips. For all trip calculations (person, vehicle, and sketch), total productions and attractions equaled each other for the region. By balancing these productions and attractions, a doubly constrained gravity model was used in developing an origin-destination (O-D) flow table. Table 2 shows the regional summary of productions and attractions.

An additional issue involved trips with origins or destinations outside the region. External-cordon O-D traffic surveys are suggested in the literature in syntheses of travel movements (*8*). However, this region does not have an external traffic survey. With prohibitive cost and time constraints of conducting one, and the reduced need to use such a survey because of the region's large size (about 5 percent of trip ends are external), an alternative method of synthesizing external trips was used. External trips were estimated by treating the

TABLE 2 Summary of Superregional Sketch Travel Data

County Name	Vehicle Productions 1988	Vehicle Attractions 1988
Anson	39450	34380
Cabarrus	124074	99226
Catawba	193980	229613
Cherokee (partial) *	77047	55028
Chester *	57257	46498
Chesterfield (partial) *	33800	25406
Cleveland	118987	93105
Davie (partial) *	14550	14550
Gaston	225385	190402
Iredell	132317	115476
Lancaster	81247	55278
Lincoln	62749	38075
Mecklenburg	631412	912627
Rowan	159638	124971
Stanly	71732	56377
Union	108680	83797
York	164315	121811
Total	**2296620**	**2296620**

* Not a Member of the Carolinas Transportation Compact

nodes on the edge of the region because loading nodes have both productions and attractions. These productions and attractions were set such that the annual average daily traffic (AADT) on these links, which connected them to the rest of the network, was accurately estimated.

A possible result of not having an external O-D matrix involves likely shorter trip lengths and the possible underestimation of traffic on major roads and Interstates throughout the region. As external-external traffic enters from the edge, it would find destinations within the region rather than travel directly across the network as an external-external trip. In an analogy illustrating this effect a superregion is compared with a lake with many islands scattered throughout. If a rock is dropped into the lake at the edge and waves are generated, they travel across the lake's surface until they are absorbed or deflected by the islands. The net result is that very little, if any, of the wave is able to reach the far side of the lake or region. The problem would be most severe for interstate or other long-distance travel routes—possibly such as an outer belt.

CALIBRATION OF REGIONAL MODEL

Calibration of the regional model consisted of balancing the simulated traffic generated by the model on the base network with actual measured AADT found on the network. Traffic counts rather than a trip length distribution were used, because of their available, low-cost nature. This is different from many simulations that calibrate to an O-D matrix or to a trip length distribution: in superregional modeling, such a matrix generally will not be available because the areas cover more than just the urban region. Our procedure of calibrating to the AADT approximates the procedure suggested by Willumsen but does not produce the optimum O-D matrix or optimum calibration (*9,10*). Instead, we develop a reasonable (not

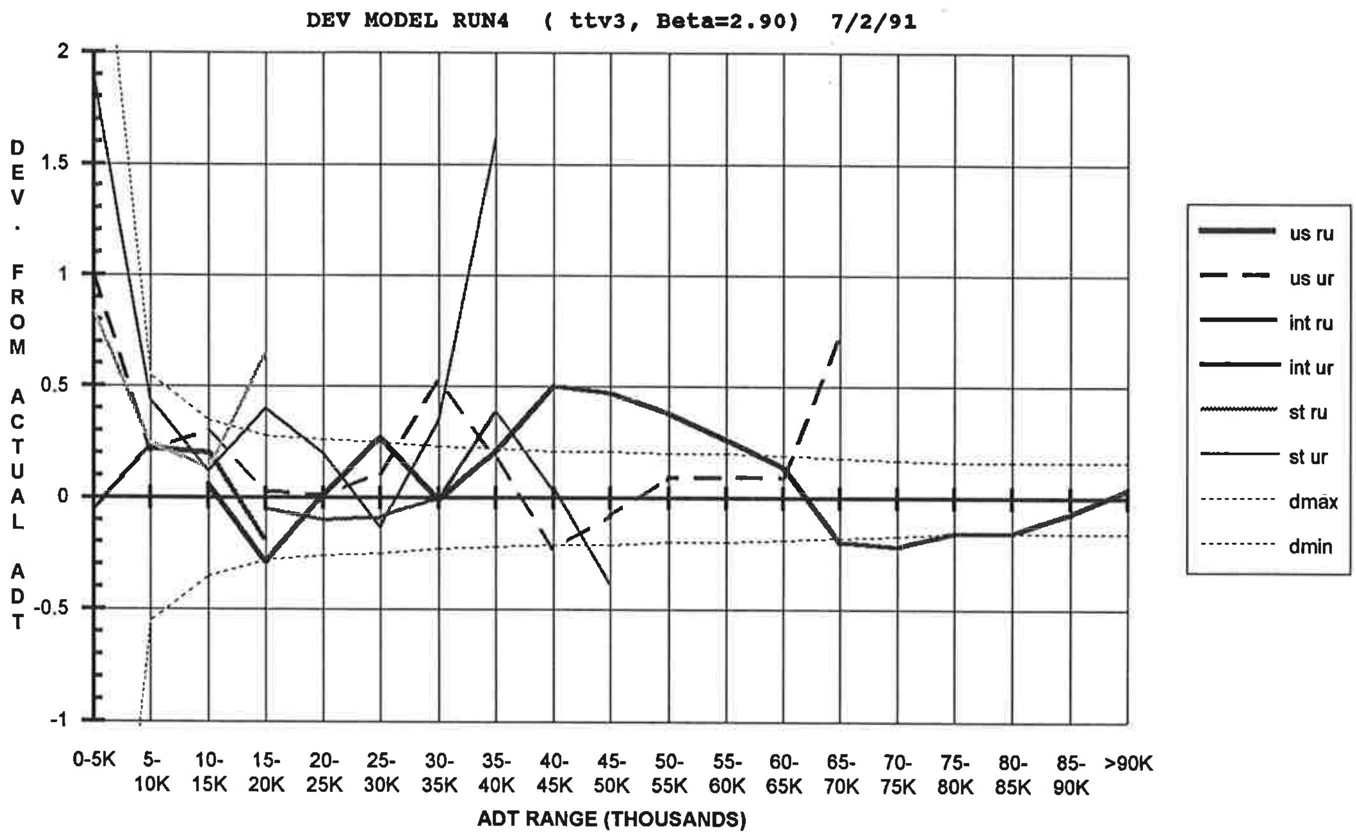

FIGURE 7 Link-type estimated ADT deviation by volume ranges for model 4.

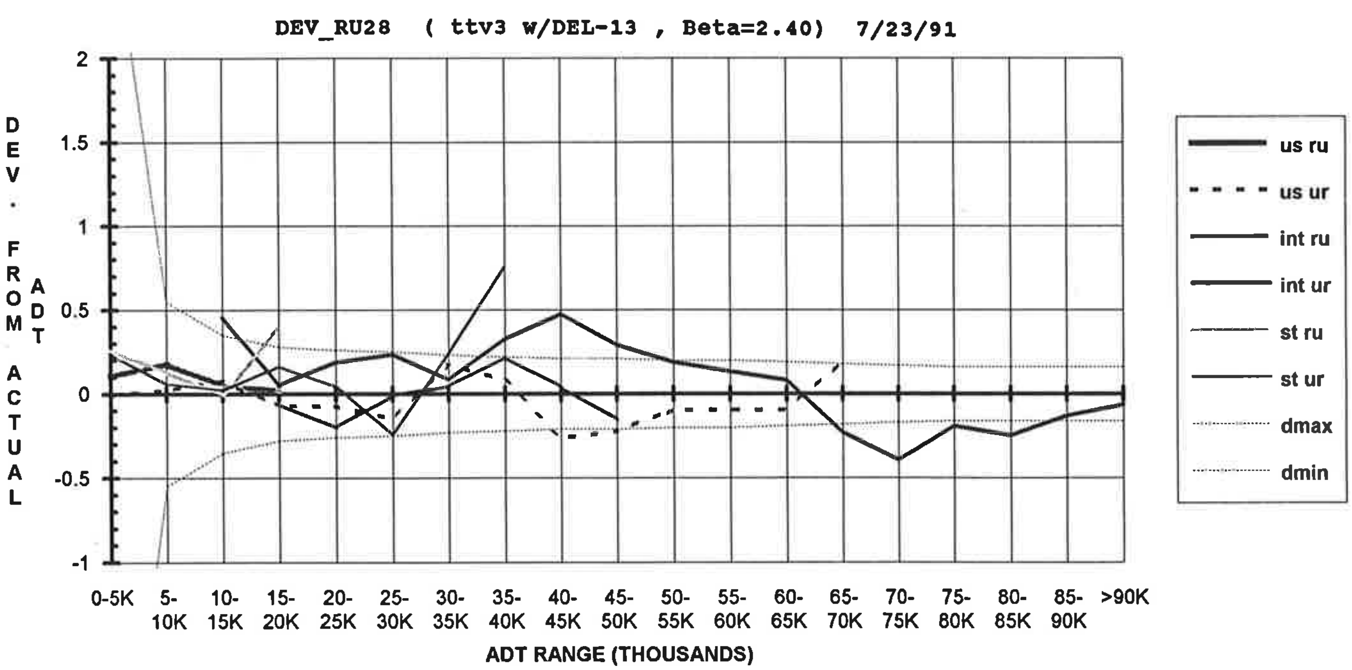

FIGURE 8 Link-type ADT deviation by volume ranges for Model 28.

optimum) simulation through iteration using different beta (decay) coefficients inserted into the gravity model. To compare actual and estimated traffic, an NCHRP report was used to develop acceptable deviation ranges for links with different volume ranges (*11*). Such tables were produced for each link type. By overlaying each of these link-type deviation graphs, a tool was developed to help calibrate the model. Figure 7 displays the deviation graph of an early run of the model. Figure 8 shows a later run of the model with adjustments made to both the beta value and the LTTTP.

By minimizing these deviations between estimated and actual values, additional corrections to the model were made. These corrections consisted of adjusting several parameters of the model, which included changing the beta value of the gravity model, and changing link-type travel time impedance values for individual links. Individual link deviation review also led to finding errors in network coding and more even distribution of the population and employment data. Over a number of trials, a decay coefficient of 2.4 was ultimately selected. Summary tables of VMT and vehicle hours traveled (VHT) deviation by link type, county, screen line, and region were used to assist in the calibration effort. The resulting final individual link deviations (ratios of estimated to actual VMT) were then used as pivot points to adjust model output for future traffic forecasts.

NETWORK ALTERNATIVES

For the analysis for proposed highway systems, including preliminary alternative corridors of the Carolinas Parkway, an additional set of links and nodes was added to the data base. The preliminary locations for the parkway were determined by the two state highway departments. Included in these additions were TIP improvements (i.e., new facilities and capacity upgrades), post-TIP proposals currently under discussion, and alternative alignments of the proposed Carolinas Parkway. For each of these three categories, unique codes were developed within the data base allowing various combinations of network improvements to be selected for analysis. Figure 9 shows the base network and all the proposed network additions.

PRELIMINARY SIMULATION RESULTS

A simple uniform balloon expansion of population and employment was used to show a preliminary estimate of traffic likely to use the Carolinas Parkway in 2010 (Figure 10). The parkway appears to be serving circumferential traffic, but the analysis is too preliminary for firm conclusions.

EVALUATION OF EFFECTS

Procedures used for evaluation of user effects will be based on traffic forecasts, using criteria familiar to analysts. User effects are broken down into travel time costs, operating costs, and accident rates. These effects are developed by converting VMT and VHT data into estimates of operating costs, fuel use, and user savings in a spreadsheet environment.

Indirect effects include changes in land use, business activity, and environmental effects. Induced effects are developed by converting VMT and VHT data into estimates of operating costs, fuel use, and user savings in a spreadsheet environment.

Indirect effects include changes in land use, business activity, and environmental effects. Induced effects consist of population and economic development within the region, the development of second-order traffic, environmental changes within the region, and change in land use patterns.

Both indirect and induced effects will be evaluated using economic impact models in conjunction with satellite imagery data. SPOT and LANDSAT satellite imagery will be used to classify land use in each likely corridor according to land cover. High-resolution satellite imagery has been widely used

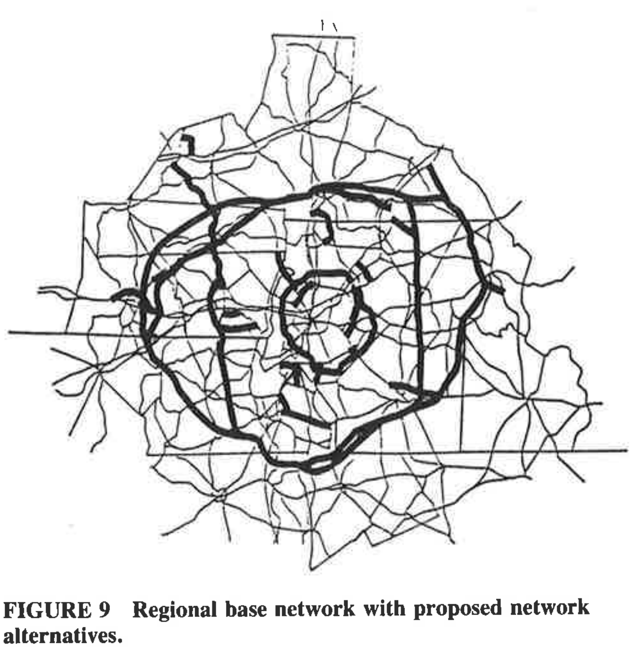

FIGURE 9 Regional base network with proposed network alternatives.

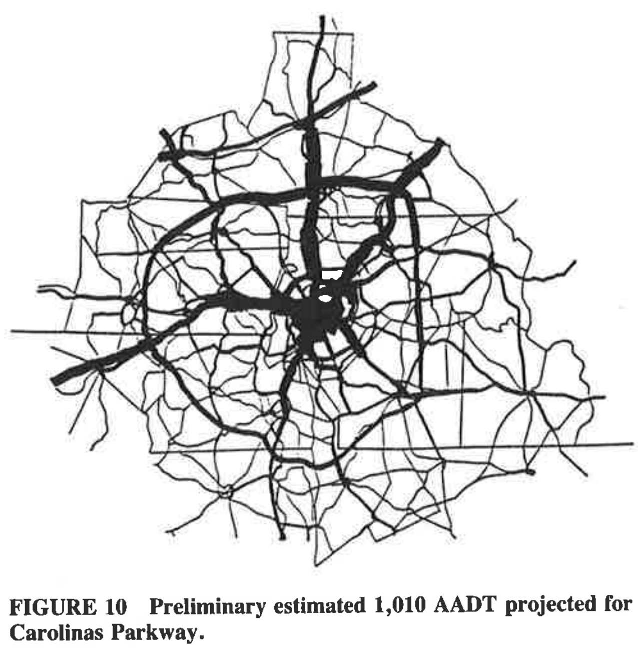

FIGURE 10 Preliminary estimated 1,010 AADT projected for Carolinas Parkway.

for land use and land cover analysis. It provides both timely and accurate information.

The objectives of this part of the study are to develop and apply a method of classifying land cover and analyze land use in the proposed corridors of the parkway by using satellite images. The procedure is divided into two phases: (a) develop a method of analysis in a test area, and (b) apply the method in the whole corridor area. Initially, the data require preprocessing, which involves image registration. Registration is done by rectifying the digital data to ground control points (GCPs) common to both U.S. Geological Survey 1:24,000 scale topographic maps and the digital image itself. From this registered set of data, a subset image can be drawn for further analysis and serve as the test area. For this study, the initial area chosen for analysis is located in both Rowan County and Cabarrus County, northeast of Charlotte, and includes the towns of China Grove, Landis, Kannapolis, and Concord.

ERDAS image processing software, hosted on a Sun workstation, is the platform used in the project. Both supervised and unsupervised classification algorithms were used to classify the land cover. The land cover is being classified into seven types: water, softwood forests, hardwood forests, croplands and grasslands, wetlands, open areas, and urban or built-up areas. To obtain more detailed land use classes, both visual interpretation and field verification will be needed since the resolution of the multispectral image is only 20 m. Existing aerial photographs are a good reference for assisting in determining conventional land use categories (e.g., residential, commercial, agricultural, transportational, etc.).

IMPLICATIONS AND CONCLUSIONS

The use of GIS-based packages in transportation planning and analysis has altered the scale, scope, methodology of analysis, and, with that, the relative power of planning organizations. Smaller cities or towns that had been analyzed individually can now be integrated into larger areas for analysis called superregions. Included in these aggregated regions are areas that could be missed during previous studies or that would be analyzed with differing underlying data and assumptions.

With the aggregation, information can be shared among different organizations and towns. An example would be step-down transportation planning for counties along a rim or crescent of the region, or more detailed modeling for urban areas. The use of GIS transportation packages allows and promotes the integration of data and analysis together. The data base for a given project is now an integral part of the GIS programs that works with those data. Additionally, the GIS package itself is now part of the evaluation and analysis process used in transportation research and problem solving. The use of study boundaries and research methodology can be thought of as the horizontal integration of study areas and the vertical integration of analytical functions.

GIS-based superregional modeling also has spatial, technical, and procedural implications. Since regions must work together to conduct the analysis, compromises of technique, data, base year, future year, alternatives designation, and a host of other issues are required. The price of regional modeling is therefore loss of independence and control over the separate forecasts once done in isolated fashion. The gain, however, is a much better understanding of how the region functions and a corresponding increase in the probability of building regional concerns on transportation futures. In this sense, superregional modeling can be viewed as an opportunity to enhance the region's competitiveness and improve long-term performance. In a nutshell, the goal of the Carolinas Parkway Study is to evaluate broad future visions for the region as a whole, setting aside the historic view of an isolated set of superregional areas.

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