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16. Abstract

The Texas Travel Demand Package is a set of computer programs used to perform travel demand analysis and forecasting. This document demonstrates the applicability of a Geographic Information System for Transportation to the Texas Travel Demand Package. First, a brief overview of GIS is described. Then, variables and functions which can be directly applied to a GIS are outlined. A description of the possible enhancement to the functionality and efficiency of the travel demand forecasting environment follows. Finally, an annotated bibliography of GIS applications in travel demand modeling is listed.

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GIS PROTOCOL AND DATA STRUCTURES FOR THE TEXAS TRAVEL DEMAND PACKAGE

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IMPLEMENTATION STATEMENT

The information contained in this document can be applied to the design and implementation of a Geographic Information System for Transportation (GIS-T). The improvement of the operational aspects of the Texas Travel Demand Package are intrinsically tied to the application of package programs within graphical user interfaces, geographic information systems, and other technology. This document outlines several methods of enhancing the functionality of the Texas Travel Demand Package using existing GIS software.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation. Additionally, this report is not intended for construction, bidding, or permit purposes. Tom A. Williams was the Principal Investigator for this project.

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SUMMARY

This document describes some of the protocols and amenities which can be achieved through the implementation of the Texas Travel Demand Package within a Geographic Information System for Transportation. Many of the enhancements to be gained through application of GIS-T to a travel demand model cannot be predicted and will not be understood until after implementation. Other documents have described in detail various applications of GIS-T to travel demand forecasting and other aspects of transportation planning which are summarized in an annotated bibliography as part of this report.

I. GEOGRAPHIC INFORMATION SYSTEMS FOR TRANSPORTATION

INTRODUCTION TO GIS

A Geographic Information System for Transportation (GIS or GIS-T) is a set of computer programs used to collect, store, and analyze spatial geographic data related to travel and transportation systems. The Texas Travel Demand Package (TTDP) is a set of computer programs used to estimate current travel patterns and behavior and forecast future travel patterns mostly related to ground transportation systems. The Texas Travel Demand Package is used to forecast vehicular traffic volumes and associate a set of performance measures to those volumes to be used in developing and evaluating Long-Range Metropolitan Transportation Plans, evaluating Transportation Improvement Programs, and aiding in developing detailed, corridor-level traffic volumes for highway design.

The Texas Travel Demand Package was developed as a set of mainframe programs which is operated as a batch file processing system. Automated mapping of networks and zones in support of the Texas Travel Demand Package has been developed using independent work stations and Intergraph graphics software. Most of the data elements associated with the Texas Travel Demand Package are spatially oriented geographic entities. Most of the data for the Texas Travel Demand Package can be tied to a specific geographic location. Also, most of the elements of the Texas Travel Demand Package can be related to a specific point in time.

A GIS can accomplish three very important functions if used in conjunction with a travel demand modeling system such as the Texas Travel Demand Package. First, it can serve as a comprehensive data base of geographic data where users can add, modify, and analyze data in a visual, graphical environment. This is probably the most important aspect of GIS which most state departments of transportation and metropolitan planning organizations realize after implementation of a GIS. Second, it can be utilized as a tool to process geographic information in a much easier manner than other methods. This aspect is often realized after implementation and is normally an unexpected benefit from GIS.

Finally, the application of GIS to travel demand modeling can serve as a tool for future applications generated from applied research activities. The advent of large-scale networks like the Internet will eventually allow communication between agencies and organizations with ease.

New technology such as Global Positioning Systems and Intelligent Vehicle Highway Systems will offer reliable data for travel demand models which will require the data management capabilities of GIS.

Other areas of transportation planning and engineering can also benefit from GIS. Pavement management is probably the most widely implemented application of GIS for transportation analysis. Another important application is the maintenance of other types of information, like traffic monitoring for the Highway Performance Monitoring System.

The application of GIS to transportation planning and engineering is coupled with the manner in which data flow through a transportation agency. The eventual application of a GIS in a transportation agency would entail a structuring of departments and their functions in such a manner that they efficiently share information and data resources on a common system at a common scale. Thus, an agency should have an overall implementation plan for GIS. However, agency-wide implementation planning should not hinder the dissemination of the technology at the user level.

The National Cooperative Highway Research Program (NCHRP) document "Report 359: Adaptation of Geographic Information Systems for Transportation," 1993, is a comprehensive analysis of the technological and institutional issues that transportation agencies face when implementing a GIS. These issues are divided into two problem areas: 1) problems related to technology, and 2) problems related to institutions. These two problem areas are paraphrased as:

- Technologically, three issues are identified. First, the "moving target problem" where technology of computing systems is advancing rapidly, making it difficult to justify large scale purchases that become obsolete quickly. Second, the "multiple technology problem" of a full-functioning GIS cannot be implemented without other technology, like small area networks. Because GIS is so widely applicable to transportation planning and engineering, many agencies want to integrate all application areas under one GIS umbrella creating the "data integration problem." This is a solution which GIS brings to the table, but it also hinders development and implementation of the technology.
- Institutionally, NCHRP 359 identifies six problems. These are quoted below:

1) determining the most critical applications that must carry the brunt of initial GIS spatial data acquisition costs,
2) sharing the costs across applications,
3) gaining and retaining support of high-level management and of the public,
4) coordinating with other state agencies and with external organizations,
5) utilizing standards developments, and
6) integrating GIS introduction and development into an information systems plan that covers all aspects of information technology for the entire organization.

While an overall information systems plan is important, it is the opinion of the researcher that the loss of efficiency from lack of implementation of certain GIS advances because of the absence of an overall plan is not justified. Most of the literature on application of GIS to travel demand modeling is from organizations which have implemented GIS technology without an overall information systems plan. All of the literature states that a great deal of accuracy and efficiency has been gained by the immediate implementation of GIS to travel demand modeling.

In essence, the Texas Travel Demand Package is a crude geographic information system as it exists today. The Texas Travel Demand Package was programmed to perform spatial analysis of transportation networks and urban activity for the purpose of forecasting travel demand under various scenarios. What is lacking in the current Texas Travel Demand Package system is a user-oriented graphics analysis system from which the analyst can efficiently derive information about models. Many currently available GIS packages can bring generic applications that can aid in the spatial analysis of Texas Travel Demand Package data.

The purpose of this research is to list and analyze the various data elements and processes associated with the Texas Travel Demand Package and determine which can be made more efficient through the application of GIS. From this starting point, the determination of software packages, information systems planning, hardware acquisition, and institutional issues can be resolved in the context of how GIS can make the Texas Travel Demand Package more efficient.

A GIS is not a replacement for the Texas Travel Demand Package. The Texas Travel Demand Package has been developed to provide specific processing for travel demand analysis. Currently, a GIS does not have the wide range of travel demand tools offered by the Texas

Travel Demand Package. Some of the tools developed in specific GIS packages are similar to Texas Travel Demand Package programs but have not yet developed to the level of functionality offered by the Texas Travel Demand Package.

Chapter V, Annotated Bibliography for GIS-T: Travel Demand Modeling Integration, contains an annotated bibliography of literature found to be related to application of GIS to transportation modeling.

MANAGEMENT INFORMATION SYSTEMS

Much attention has been focused on management systems since the passage of ISTEA. A GIS is an ideal environment for application of a management information system. The Texas Travel Demand Package, in conjunction with other data collection and analysis functions of the Transportation Planning and Programming Division, is a travel data management information system which can be further coordinated using a GIS environment. Figure 1 is a model management information system to which the traffic analysis function (using the Texas Travel Demand Package) can be applied, or the entire scope of transportation planning can be applied.

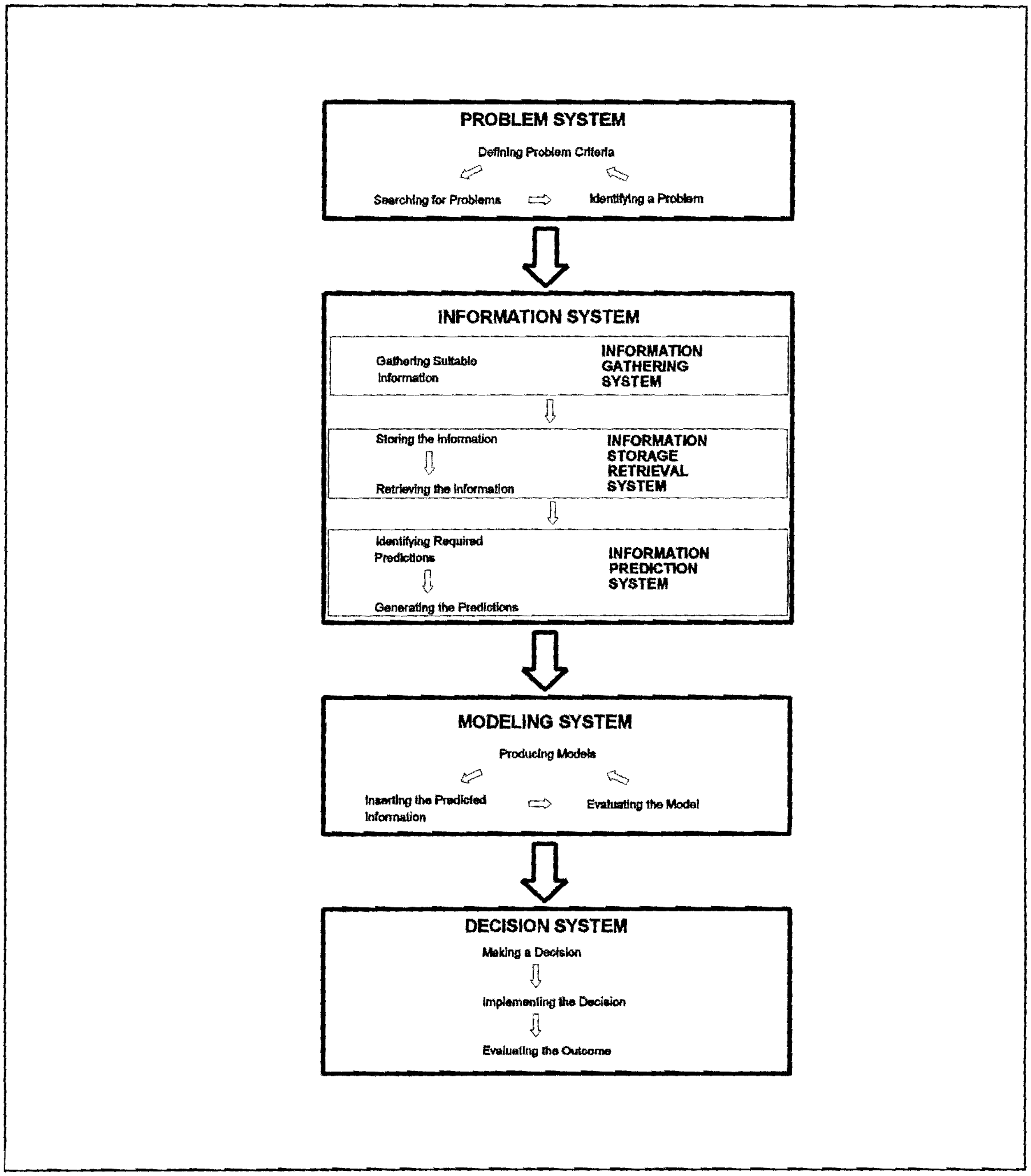

Figure 1 A simplified management information system.

Source: Adapted from Neils B. Christiansen, William A. Duerr, and Carlton M. Newton, Forest Resource Management, p. 147, OSU Book Stores, Inc., 1982.

II. APPLICATION OF GIS TO THE TEXAS TRAVEL DEMAND PACKAGE

A comprehensive and exhaustive analysis of the application and eventual implementation of GIS technology to the Texas Travel Demand Package is outside the scope of this report. This report brings to light the available algorithms and processes that can be readily applied to the functionality of the current Texas Travel Demand Package. Hardware issues are the most apparent omission. However, with knowledge of the functions desired, hardware and software interactions can be designed.

SPATIAL DATA ELEMENTS

A GIS organizes data into a structured spatial environment. Therefore, only data that can be associated within a spatial context can be maintained in a GIS. A data element must have a location for a GIS to be of any aid in storing and manipulating the given element. Data items such as roadways, households, and intersections can be associated with specific locations. GIS can be helpful in managing such data and their attributes. Other data, such as production cross-classification tables and trip length frequency curve data, cannot be associated with a specific location; however, spatial data (such as trips) can be categorized by non-spatial attributes and displayed using GIS.

The most obvious spatial data elements in the Texas Travel Demand Package are the roadway networks, consisting of links and nodes with attributes, and zones, consisting of zonal boundaries with the attributes of categorized households and employment. Other spatial data elements are not as apparent. These include trip origin-to-destination lines and routes through a network. Other possible spatial data items are extensions of the "route" concept: path trees and selected link path trees.

The challenge, which is both the objective and the requirement of a GIS, is to define all data items in a system such as the Texas Travel Demand Package in a spatial context. In many existing systems this is not easy. In the Texas Travel Demand Package, however, most of the data are already in a structure which is directly applicable to a GIS. The Texas Travel Demand Package already has a defined topology (how each spatial element relates to another) through its system of centroids, links, nodes, and sector equals cards. In fact, the Texas Travel Demand

Package has a defined coordinate system: the State Plane coordinate system. Although there is no required scale for the Texas Travel Demand Package to be functional, it is generally understood that 1:24,000 is accepted. Thus, as stated before, like most travel demand modeling systems the Texas Travel Demand Package is a crude GIS in itself; although it lacks much of the graphical sophistication of most pre-packaged GIS products.

AREA DATA

Area Input Data

The Texas Travel Demand Package uses the traffic serial zone (TSZ) as its basic unit of area data. The TSZ is an aggregation of households or employment locations generally defined by surrounding roadways, streams, railroads, and other linear data. Aggregations of TSZ's are called "sectors." Sectors are used to calculate area types and other attribute data used for modification of modeling parameters. Table 1 lists the basic Texas Travel Demand Package input data set for zones.

Table 1
Input Data Associated with Traffic Serial Zones

Name	Model Step	Notes
Zone size (Acres)	TRIPCAL5	Currently calculated using Intergraph
Population	TRIPCAL5	Base Year and Forecast Years
Households	TRIPCAL5	Base Year and Forecast Years
Average Household Size	TRIPCAL5	Base Year and Forecast Years
Median Household Income	TRIPCAL5	Base Year and Forecast Years
Total Employment	TRIPCAL5	Base Year and Forecast Years
Employment by Category	TRIPCAL5	Basic, Retail, and Service
Comments	TRIPCAL5	Description of Zone
Special Generator Data	TRIPCAL5	Acreage, Households, Employment
Special Generator Trips	TRIPCAL5	Productions and Attractions
Zonal Radius	Trip Distribution	

Area Input Data Analysis

The zone size in the map units of the GIS (feet in the State Plane coordinate system) is held by most GISs as a permanent data item. Calculating acreage is a simple task from these data. As in the Intergraph graphics system, a GIS will maintain zonal boundaries to the accuracy of the base map used. The base maps which are used for the Texas Travel Demand Package Intergraph are the TxDOT County Map series.

All of the input zonal data can be placed on thematic maps, by unit range or density. A GIS, because of its data base functionality, will allow calculation of additional variables from the basic input set, such as densities or even variables which are not normally analyzed (e.g., population plus employment to derive a total activity measure). This activity measure can be used to develop area type estimates which can also be graphically displayed using a GIS.

In addition to the basic input data, other data from various sources become more useful in a GIS environment. The 1990 Census Transportation Planning Package and the 1980 Urban Transportation Planning Package can be extracted and placed into the zonal data base. The Census Bureau Topologically Integrated Geographic Encoding and Referencing (TIGER) digital map files can be extracted and put into the GIS environment. This would allow for the almost seamless integration of Summary Tape File 3 (STF-3) census data to the application of the Texas Travel Demand Package.

Boundary systems and zonal structures are greatly facilitated with the use of a GIS. The collapsing of zonal boundaries to derive aggregations of larger zones is a quick manipulation of the inherent topology of a GIS. The GIS keeps track of which boundary belongs to each zone, called topology. Levels of zone structures can be hierarchically created. Although in some urban areas census tract boundaries are too large to be integrated with TSZs, census block boundaries often are not too large. Census blocks (block groups) can be aggregated to form TSZs, which in turn can be aggregated to form sectors, and so on. The North Central Texas Council of Governments (NCTCOG) has recently completed digitizing over 6,000 traffic survey zones to conform to census geography in a seamless system. This type of project opens up the travel demand model to the wealth of data from the Census Bureau.

Area Output Data

The outputs from the Texas Travel Demand Package are as applicable to the GIS environment as the inputs to the Texas Travel Demand Package. Table 2 lists some of the output data from the Texas Travel Demand Package which is aggregated by zones or other areas.

Table 2
Area Output Data from the Texas Travel Demand Package

Name	Model Step	Notes
Productions and Attractions by Trip Purpose	TRIPCAL5	Base Year and Forecast Years
Special Generator Ps and As	TRIPCAL5	Base Year and Forecast Year
Autos per Household per Person	TRIPCAL5	
Households by Income Group	TRIPCAL5	
Accessibility Indices	Trip Distribution	Reciprocal of Model Denominator
Travel Times to or from a Zone	Trip Distribution	Travel time contour mapping
Sector Mapping	Trip Distribution	from Equals Cards
Various Factors	Trip Distribution	Peak factors, HOV Factors, Attraction multipliers, etc.
Intrazonal Trips	Trip Distribution	
Various Traffic Assignment Data	Traffic Assignment	Congestion, etc., summarized by zone or sector
Interzonal Trips	Trip Distribution	"Star Burst" diagrams

LINE DATA

Line Input Data

Data organized into simple linear events, such as roadway network links, can be represented in a GIS. A large amount of time is spent in developing and maintaining computerized roadway networks through various systems. A GIS can simplify a large amount of the tedium currently involved in developing and maintaining travel demand model networks.

The basic data items needed for Texas Travel Demand Package roadway networks include the physical elements of links and nodes and the attribute elements. The physical elements are currently digitized from the TxDOT County Map series base maps using Intergraph software. The attributes which can be associated with the current software are limited to physical distances. A GIS would bring a multitude of enhancements to the attribute data storage, manipulation, and retrieval for modeling from Texas Travel Demand Package networks. A GIS would provide for virtually unlimited data fields to be associated with links and nodes.

The essential link attributes needed for the Texas Travel Demand Package include distance, speed, functional classification, and number of lanes. Subsequent calculation of travel time on each link can be performed using the distance and coded speed. Subsequent calculation of capacity on each link can be performed using the coded functional classification, number of lanes, and an associated area type value from zonal data. A GIS would greatly facilitate the latter calculation.

Because a GIS is designed not only to store spatially-referenced data but to process it, the zone in which a link fell could be automated. The use of overlay technology present in all GIS packages would greatly enhance the Texas Travel Demand Package. The automated posting of the associated zone on each link leads to the automation of area type and sector posting. The same overlay function can be used to automate air quality grid cell location and subsequent display of emission estimates.

Many GIS packages currently have the capability of aggregating links into sections and routes. Attribute items which are common along an entire route could be changed in aggregate, saving time and tedium.

Another labor-intensive aggregation of links is the development of screenlines and cut lines for validating assigned traffic volume flows to observed traffic counts. A GIS can manage such aggregations of link data.

Line Output Data

Perhaps the greatest and most widely appreciated GIS function is its ability to merge many data sources and display effective graphics for communicating information from travel demand models. Many of these functions are already being performed using data generated from the Texas Travel Demand Package and Intergraph. The separate hardware platforms for the Intergraph and the Texas Travel Demand Package create a degree of difficulty in transfer of traffic assignment data from the Texas Travel Demand Package. This issue cannot be resolved with implementation of a GIS.

A GIS, however, can allow for the creation of a multiple data item link output set. This data set can then be used to display results from the Texas Travel Demand Package and further allow for data manipulation. The assigned volumes, resulting volume-to-capacity ratios (congestion measures), and speeds are often processed for various other functions. Refinement of volumes for corridor analysis purposes is one example. Use of assignment volumes for vehicle miles of travel calculation at given speeds, and subsequent application of MOBILE5 emission rates to derive link-based emission estimates, is another example use of Texas Travel Demand Package output line data. A GIS could enhance the current process by integrating the various uses of output Texas Travel Demand Package line data into a single user-oriented environment.

Node Output Data

A GIS is organized into three basic spatial entities: polygons, arcs (lines), and nodes (points). A polygon without any area is a point. This is similar to the manner in which zones and their associated data are reduced to centroids for the purpose of travel modeling.

Attributes can be associated with nodes as easily as they can be associated to the other types of spatial entities. The reason for attaching input data to nodes would be its use in a modeling function (such as a nodal capacity restraint) which would be implemented. Output data that can be attached to nodes include data which are normally associated with links, such as volumes and speeds. In the case of intersection nodes, the sum of the approach volumes can be attached to the nodes.

III. GIS ENHANCEMENT FUNCTIONS

DYNAMIC SEGMENTATION AND OTHER GIS FUNCTIONALITY

GIS technology is advancing rapidly for transportation applications. Many GIS functions have been used for various aspects of transportation planning and routing of freight shipments as separate functions in the past. GIS software is bringing all of the algorithms together into a single package. Routing algorithms not normally used in travel demand modeling may find applications utilizing the forecast details of packages such as the Texas Travel Demand Package.

Many routing and spatial-referencing functions of a GIS are single-use applications of transportation algorithms. Such functions include path and tour building, resource allocation, limited spatial interaction modeling, and dynamic segmentation. Much of the following discussion is specific to Arc/INFO GIS software because of the author's experience, but other software packages have similar functions.

Path and Tour Building

The Arc/INFO data model distinguishes a "path" from a "tour" in that in a path the order in which stops are visited is predetermined, while in a tour the order of stops is calculated and impedance is minimized for the entire tour.

The Texas Travel Demand Package uses a "tree builder" (BUILD TREES) which is similar to these functions. A tree builder builds a "paths" file exactly the same way the path function does it in Arc/INFO. The "stops" are all other zone centroids besides the origin, or root centroid. The other distinction between the Arc/INFO path function and the Texas Travel Demand Package tree builder is that the tree builder does not allow paths to be built through zone centroids. The path function will allow paths to be built through the stops designated. The Arc/INFO path builder is an interactive, single path function; while the Build Trees Texas Travel Demand Package routine will build the trees from each zone to all other zones and create a matrix of cumulative travel times.

The Arc/INFO tour is a function whereby the user specifies a beginning node or zone, intermediate nodes, and an ending zone or node. The function then builds a tour route through the specified nodes, calculating the minimum total impedance path by automatically ordering the sequence of stops. This is an analogy for the "trip chain," where the primary origin-to-destination trip purpose may be different from the trip purposes of the individual trip legs. For instance, the analyst can determine the shortest tour from home to the day care center, to the grocery store, and finally to work. Trip distribution modeling using tours instead of paths is a current topic which warrants research for future travel model enhancements.

Another feature of the Arc/INFO data model is that the network, stops, and impedance value which are used to build the paths or tours can be modified interactively. For instance, the analyst can determine the shortest path between one node and another based on travel time and then determine the shortest path based on distance and compare the two visually.

The path or tour is stored in the GIS as a separate geographic entity (route), much like a link is stored. This allows for the further analysis and computation of measures associated with the path or tour entity along the route, such as average speed, cumulative VMT, average traffic volume, and cumulative travel time. Another application of the route entity could be the cumulative emission estimates of various pollutants along a specific corridor.

Resource Allocation

Arc/INFO also includes a routine used to allocate demand for resources through a network. The example used is the allocation of students to a system of schools. A walk time is calculated from each school not to exceed 30 minutes, and the demand for space in each school is coded on each of the network links. In this way, the fixed supply of space in each school is allocated to the demand, as coded on the network links, within the constraints of a 30-minute time interval.

The allocate function can be used to determine travel time contours based on speeds coded into the Texas Travel Demand Package networks. The function is used without the supply characteristics, such as school seating availability. Arc/INFO will determine the travel time from a point of origin to each link within the maximum time specified or to all links in the network. The links can then be aggregated into isochrons (travel time contours). This type of data is very useful in displaying the differences in travel times between alternative future networks.

Demand Lines

Demand lines refer to the representation of travel demand derived from a trip table as width of line from the point of origin to the point of destination. One row (or column) of the trip matrix is extracted from the Texas Travel Demand Package; and the data are converted to a "starburst" diagram, which instantaneously displays the flow of trips from an origin to all destinations.

Buffering

Buffering allows polygons inside or outside any of the three basic spatial entities (points, lines, and polygons) to be created. The buffered polygons can be determined using a constant value for the distance around the buffered object, or they can be created using the value of a variable. Each link or selected links in a network can be buffered based on Texas Travel Demand Package model output data. The width of each link (band width) is relative to the magnitude of the variables or speed, capacity, volume, or volume-to-capacity ratio.

Other elements which can be buffered include zone centroids and nodes.

Overlay

Overlay refers to the GIS function of matching two or more spatial elements to create their intersection or union. Each of the three basic spatial entities can be overlayed onto each other. The output elements created by overlays retain the characteristics and attributes of the input elements.

A very common function for overlays exists as a batch program for the Texas Travel Demand Package. The placement of links within Texas Natural Resource Conservation Commission air quality grid cells is performed by the ancillary programs used for emission estimation developed in recent years. A GIS implementation of this Texas Travel Demand Package function can duplicate the link in polygon overlay while adding better functionality. Any attribute from the grid cells, zone polygons, census geography, and network data can be merged proportionally into common geographic elements. Values of speeds, cumulative travel times, population and employment, vehicle miles of travel, and lane mileage can be summed by grid cell. The attachment of link-level emission estimates can also be accumulated by grid cell, zonal polygon, or any other topological organization.

Combining buffering and overlay functionality allows the user to develop analytical tools which are otherwise very difficult to implement. A corridor polygon can be created by buffering a specific route for one mile to either side of the centerline of the route. The corridor polygon can be overlayed onto a gridded emissions inventory and will quickly derive the total emissions within one mile of the route selected.

Spatial Interaction Modeling

The modeling function of spatial interaction is used in the Texas Travel Demand Package and TRANPLAN to accomplish trip distribution. Several GIS packages have functions related to spatial interaction modeling ranging from a single origin marketing tool to estimate accessibility to a full trip distribution function. The spatial interaction functions used in the Texas Travel Demand Package and TRANPLAN are highly developed tools which are more advanced than many GIS-packaged spatial interaction tools.

Dynamic Segmentation

The functionality that a GIS can add to any travel demand modeling system (as they exist today), including the Texas Travel Demand Package, lies in the concept of GIS topology. Topology refers to the manner in which spatial elements relate to each other, including linear spatial elements such as roadways. A GIS allows sections of roadways to be aggregated into series of links and treated as a "route."

A GIS is not only limited to the definition of links by their end nodes, however. The pieces of roadway can be defined based on attributes, like speeds or traffic volumes, along the route. Thus, the definition of each "segment" is based on a measure of distance from the beginning of the route. This is similar to the concept of "milepoints" used in reality, but the milepoints are not limited to the single measuring unit of distance. The measuring units can be anything, most notably time.

This concept has not yet been fully researched as a data structure available for travel demand models. It is conceivable that in future development of data for travel demand models, dynamic segmentation of routes for each trip could be implemented. However, it is yet to be fully understood what advantage this would bring to a new generation of models.

Address Matching and Geocoding

One of the most highly regarded functions of GIS is its ability to address match very large data bases. A network can be coded with address ranges for each link on each side of the roadway the link represents. For instance, a given link could represent Main Street from the 100 block to the 200 block.

Many surveys, including the Texas travel surveys, are compilations of addresses for each observation. In travel surveys, individuals report in a travel diary their home address and the address of each place they visit during the survey day.

The task of aggregating the addresses into zones or other polygon areas has traditionally been a tedious, manual process known as "geocoding." A GIS can automate this process, and it is currently used by most consulting firms performing travel surveys. Each record from the travel survey is matched with the addressed network spatial data in the GIS to produce a coordinate location point. The resulting points can be aggregated by polygon overlay into any polygon structure, such as TSZs.

The mapping of survey data and display of travel surveys has not been performed. Research is needed to analyze the spatial attributes of travel survey information utilizing address matching to combine the travel data with other data associated with the GIS, such as census data.

GIS DEPARTMENTAL ENHANCEMENT

Data Integration and Simplification

The Wisconsin DOT has implemented and described a GIS-T as reported by Petzold and Freund ("Potential for Geographic Information Systems in Transportation Planning and Highway Infrastructure Management," Roger G. Petzold and Deborah M. Freund, TRR 1261, 1990). The Wisconsin DOT seeks to use GIS-T in five areas:

1) Integration of data bases
2) Reduction of repetitive data entry
3) Integration of new technology

4) Improvement of analysis results
5) Quicker application development

Areas of data integration enhancement from implementation of GIS-T to the Texas Travel Demand Package include:

1) Development of modeling networks using TxDOT County Maps and other base map sources, as well as softcopy aerial photogrammetry
2) Consistent cross referencing of spatial network data from the HPMS traffic monitoring, corridor analysis, and travel demand modeling and other functions
3) Addition of seamless data referencing of external data sources with the Texas Travel Demand Package, such as the Census Transportation Planning Package and other U.S. Census Bureau products, and data bases from Texas MPOs
4) Direct integration of expensive travel survey data bases, from raw data to Texas Travel Demand Package implementation stages

Reducing repetitive data entry can be accomplished using GIS-T with the Texas Travel Demand Package. Network coding can be a tedious, resource-intensive, and time-consuming process. A GIS-T can be designed such that many of the repetitive tasks used in coding networks can be reduced and/or eliminated. For instance, zonal polygon and network overlay can be used to automate the coding of zone numbers on links; and, therefore, association of area types from zonal population and employment densities can be performed easily.

New technology can be applied to the Texas Travel Demand Package through the use of GIS-T. Implementation of image scanning and analysis, photologging, Global Positioning Systems (GPS), and IVHS-related tools can be done by implementing GIS-T with the Texas Travel Demand Package. GPS can be used to collect data necessary for accurate functioning of the Texas Travel Demand Package by associating other data capturing technology with the locational data provided by the GPS. Accurate collection of speed data, for instance, could be automated with such a system.

The most readily available application of GIS-T to the Texas Travel Demand Package would be in improving analysis results. The graphical environment of a GIS-T and the ability to pull together various data elements into one spatial system allows a GIS-T to show various relationships of Texas Travel Demand Package variables. This is perhaps the best enhancement which a GIS-T could bring to the Texas Travel Demand Package.

Applications can be developed more quickly and with greater functionality with the integration of GIS-T to the Texas Travel Demand Package. Most GIS software packages allow the user to develop tailored applications to meet their own immediate needs, rather than relying on programming staff. The use of "macro" commands allows the user to relate variables and functions together to meet their specific needs for analysis.

Job Description Enhancement

One of the least recognized enhancements of GIS-T implementation to transportation is that of job improvement. A GIS-T opens up a highly analytical and functional set of tools to the transportation analyst/planner, allowing for greater job satisfaction and enjoyment. Removal of tedium associated with travel demand modeling can only be beneficial. The GIS-T would reduce the time spent on data manipulation and coding and allow the modeler to perform the more pertinent tasks of analyzing and communicating results.

IV. GIS: TRAVEL DEMAND MODEL INTEGRATION EXAMPLE

An example data base was prepared using Texas Travel Demand Package networks, zones, and other data to provide samples of the functionality of a GIS and its usefulness to the travel demand modeling process. A fully functional implementation of a travel demand model and GIS could require years of work. The purpose here is to demonstrate some of the most readily available tools which a GIS could bring to the Texas Travel Demand Package environment.

DATA SOURCES

Data for the example implementation of the Texas Travel Demand Package to a GIS environment came from various sources. Data obtained directly from the Texas Travel Demand Package were initially converted to the TRANPLAN format and subsequently to Arc/INFO. The Arc/INFO software was chosen for the example because of the author's familiarity. The Bryan-College Station networks were converted from TRANPLAN in State Plane coordinates directly from TRANPLAN. The El Paso networks were converted to UTM coordinates for application examples of air quality grid cell overlays. Zone boundary data were converted from TxDOT Intergraph files using Arc/INFO conversion modules. Arc/INFO projection utilities were used to transform the Lambert Conic projections to either State Plane or UTM systems.

Figure 2: Polygon Aggregation

Zone, district, and sector systems can be developed easily with GIS. A GIS stores information about each polygon, including information about the polygons which share common borders. Using on-screen tools, the zone centroids were interactively selected for each sector (district). Each zone centroid was interactively tagged with a sector number. A "dissolve" function was used to quickly merge the zone polygons which shared common sector numbers and create sector polygons. The following graphic shows the original zone polygon boundaries shaded by each sector number. The sector numbers are overlayed onto the map of zonal polygons.

Figure 3: Zonal Analysis

The most readily available tool for application to the Texas Travel Demand Package can be used for analyzing data associated with polygons. Zone population, employment, households, productions, attractions, and other data can be displayed using GIS for analytical purposes. In the following graphic the total zonal attractions for all trip purposes were combined within the GIS data base. An attraction density in trip attractions per acre was calculated using the GIS polygon area variable (the GIS maintains the area for all polygons in projection units, feet or meters, automatically). The GIS display capability (Arcplot) was used to shade each polygon relative to its attraction density. Zones with high attraction density are shaded red and orange, while zones with lower attraction density are shaded yellow and tan.

Figure 2 GIS Polygon Aggregation Example

Figure 3 Zonal Analysis Example

Figure 4: Trip Table Mapping

Data from the total purpose, origin-destination trip table for the Bryan-College Station urban area were used to produce the following graphic. First, the district (sector) system developed interactively using the GIS was converted to a table of equivalency for input to TRANPLAN (similar functions exist between the Texas Travel Demand Package and TRANPLAN). The table of equivalency was used to aggregate the 325-zone trip matrix into the 35-sector system. A report was generated and used to obtain the trip attractions for a sector of interest, in this case sector 1, Texas A&M University campus. Two elements are necessary to produce this type of "starburst" map: the linear arcs between the sector of interest and all other sectors and the number of trips between the sector of interest and all other sectors. The linear arc data were generated for all sector interactions. The GIS can select only those arcs (lines) which are associated with the sector of interest. The trip data were interactively related, or merged, into the linear spatial data to produce a width of line displaying the magnitude of the trips between all sectors and the sector of interest. The GIS buffering function was used to develop the width of lines.

Figure 5: Spot Mapping of Polygon Data

A useful method of communicating and analyzing polygon data is incremental circles. Thematic mapping of this type has been used extensively to show population in urban areas. The GIS allows for the application of this type of mapping to Texas Travel Demand Package data, such as productions and attractions. The GIS automatically scales the size of the circles according to an exponential scale so as not to misrepresent the values associated with the circles. The modeler can easily show areas of trip production and trip attraction, and their relative magnitude, across all 325 zones in the Bryan-College Station urban area. The scale of the circles is generated automatically, using a value of 10,000 trip ends for each 0.5 inches of circle.

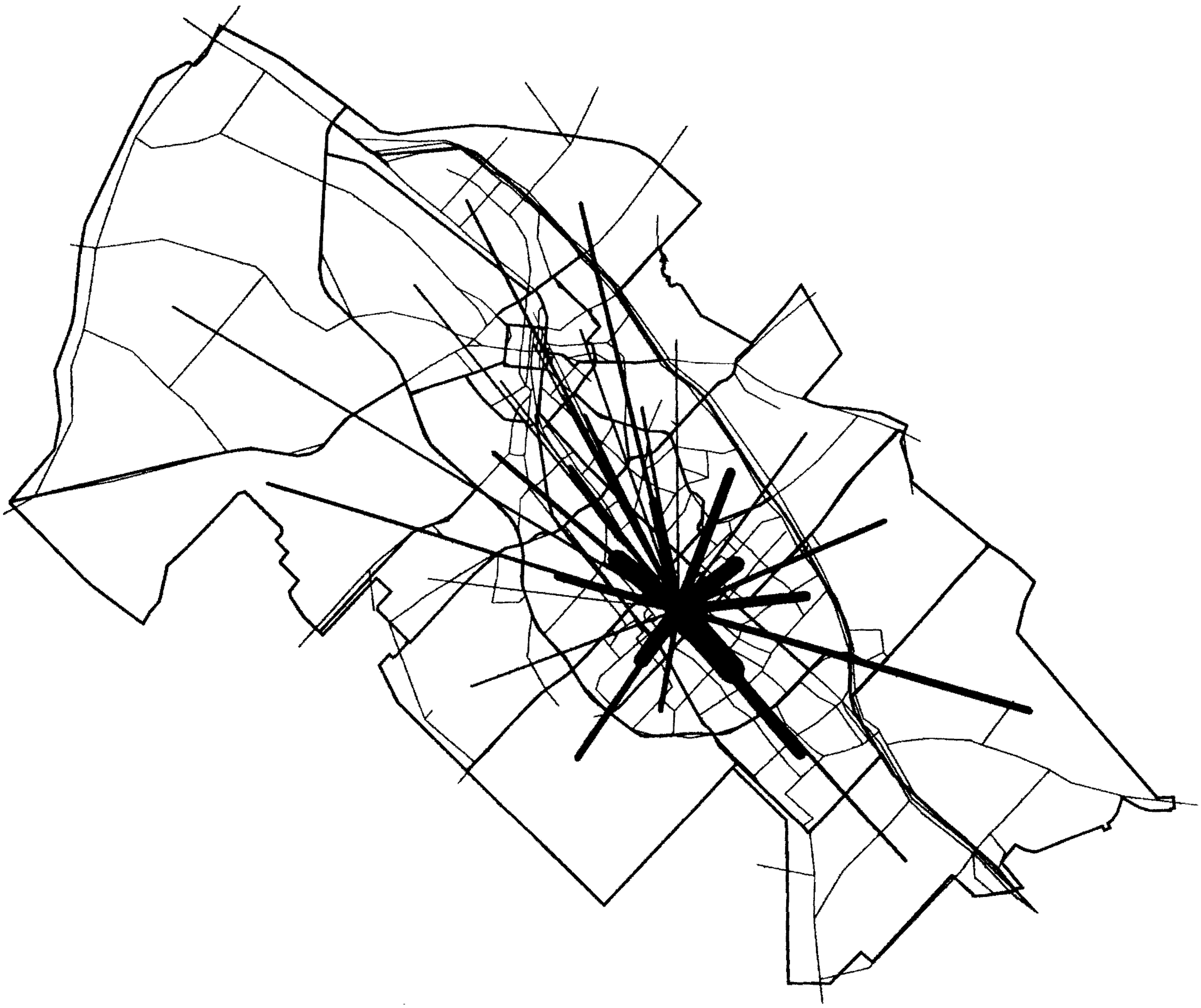

Figure 4 Trip Table Mapping Using a "Starburst"

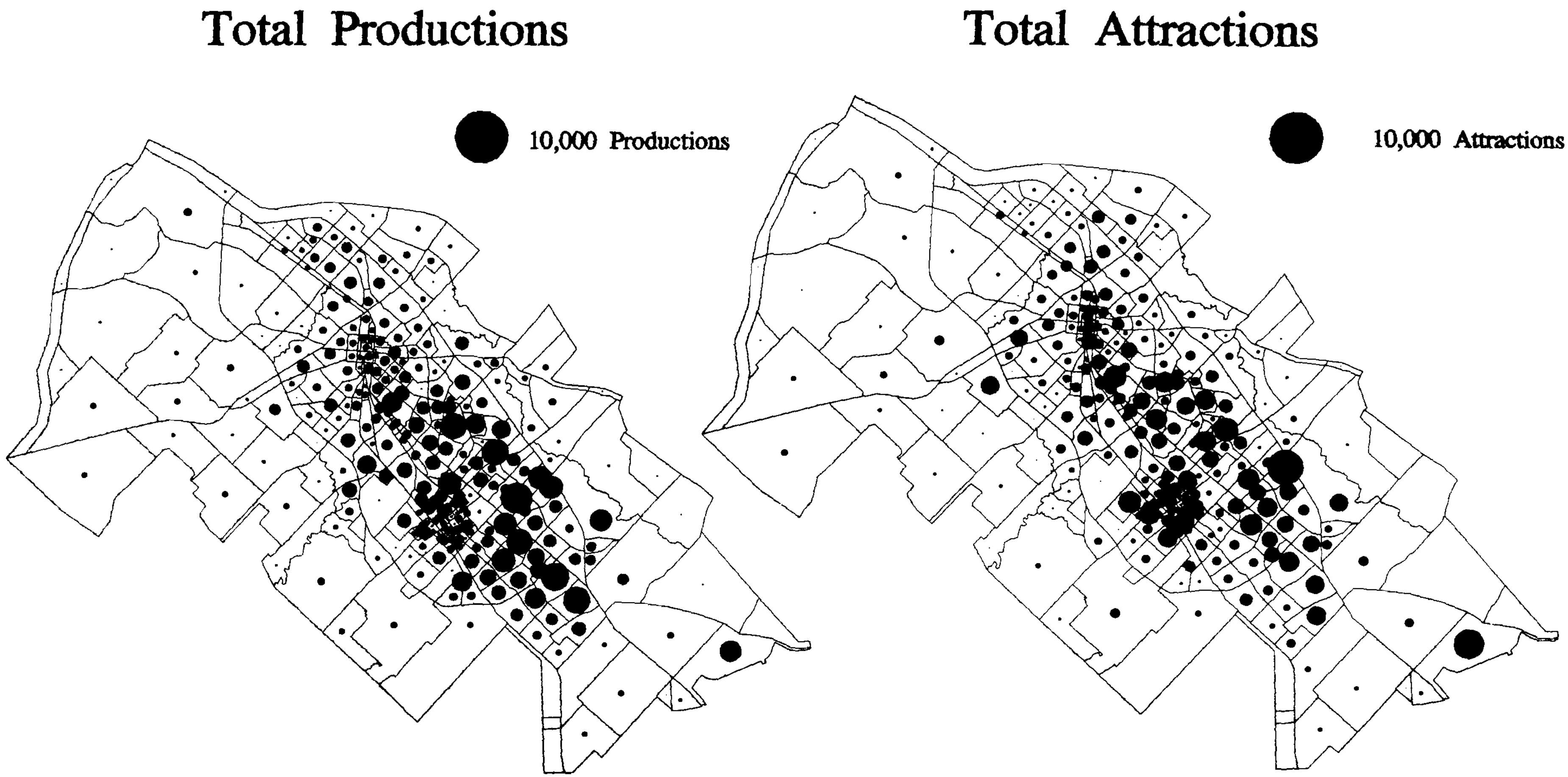

Figure 5 Spot Mapping of Polygon Data

Figure 6: Node Data

Data mapping using circles can be attached to any spatial element type. In this example, the size of the circles shows the magnitude of the approach traffic volume at each intersection. The approach volumes were summed from the Bryan-College Station travel model for each three-leg intersection. Centroid connectors were removed from the set of possible intersections. After conversion of the network to a GIS data base, data could be associated with nodes. This type of mapping could be very useful in analysis of congestion based on intersection volumes.

Figure 7: Traffic Volume Mapping

The following graphic shows the capability of a GIS to map traffic volumes using the width of lines to display the traffic volume magnitude from the model. The band widths were generated using the GIS buffer function, which will create a buffer around any spatial object (in this case, links) with a distance proportional to any attribute attached to the object (in this case, modeled traffic volume). Similar maps could be used to display coded capacities, traffic counts, or speeds. The base map for this graphic is selected roadways from the TxDOT County Map retrieved from the Texas Natural Resource Information System data base for Brazos County.

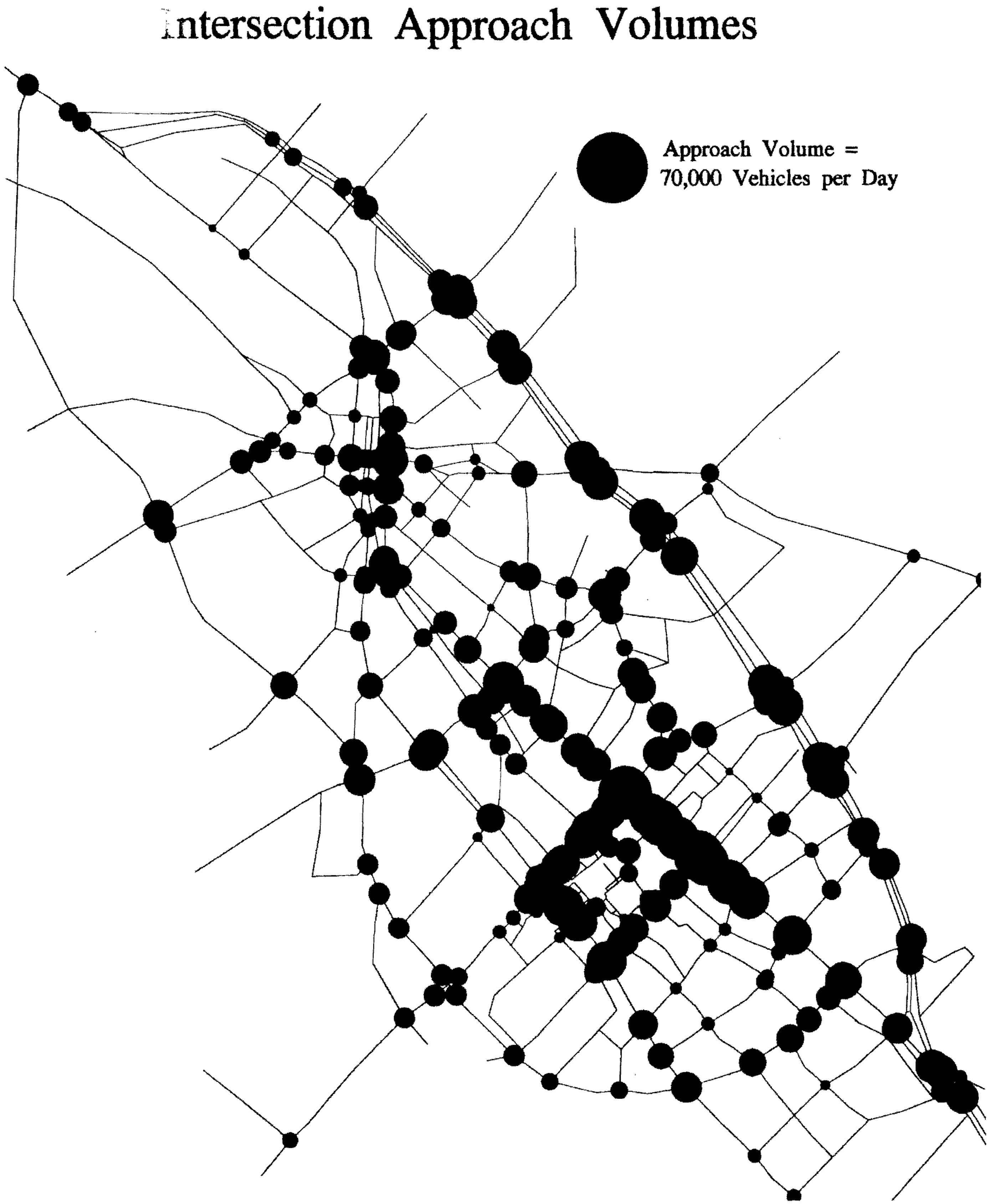

Figure 6 Mapping of Node Data

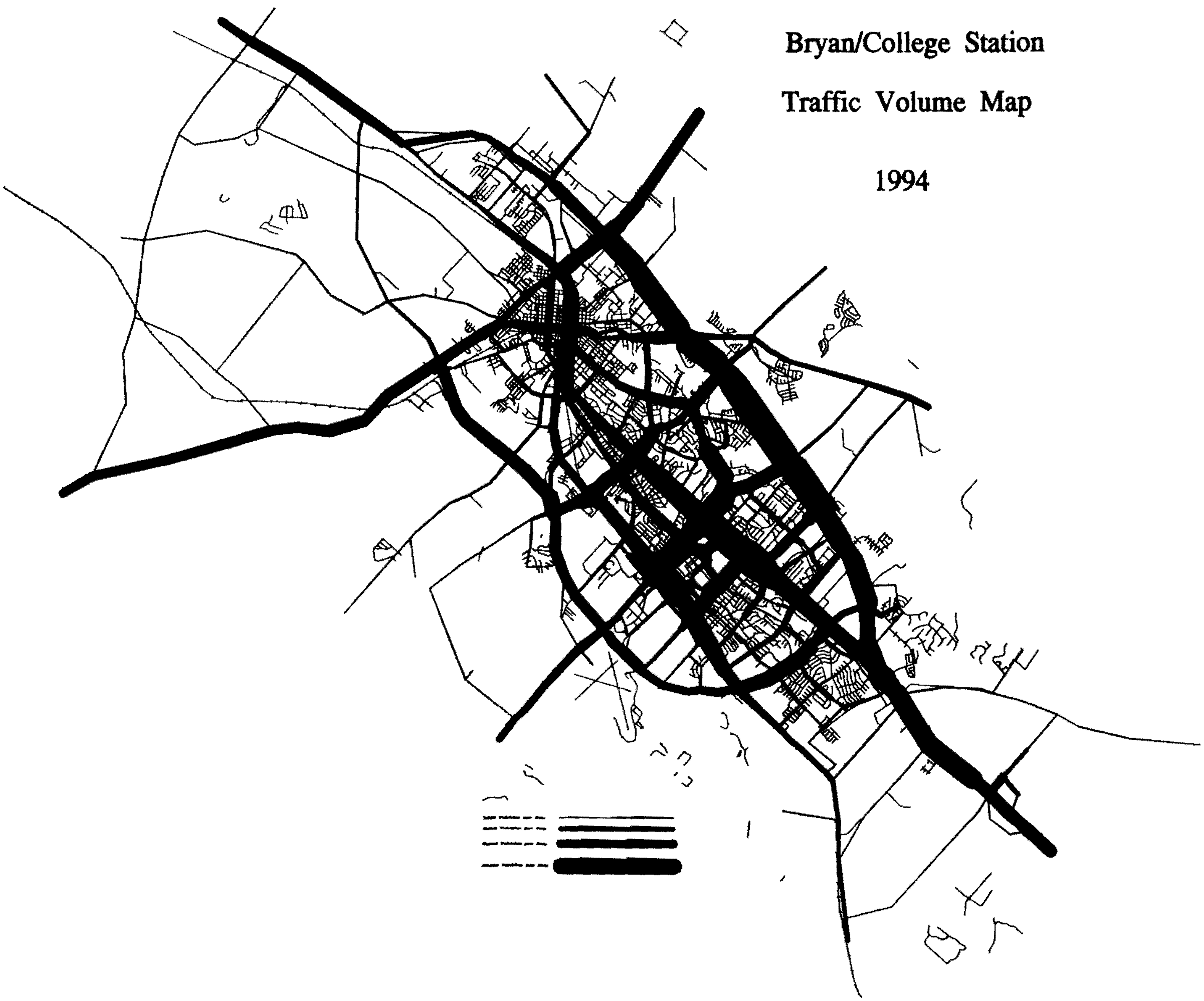

Figure 7 Band Width Traffic Volume Map Using the GIS Buffer Function

Figure 8: Air Quality Grid Cell Analysis

Four separate data bases were used in conjunction to produce the following graphic: the El Paso Texas Travel Demand Package network, the Juarez TRANPLAN network, a GIS air quality grid cell structure, and the TxDOT El Paso County Map. First, the grid cells were overlayed on both the El Paso and the Juarez networks, and the VMT was summed within each grid cell. When a link traverses two or more grid cells, the value being summed is distributed proportionally to each grid cell. After the GIS overlay, the mapping module (Arcplot) was used to display the magnitude of VMT within each grid cell, along with the networks and the Rio Grande separating Juarez and El Paso.

Figure 9: Corridor Analysis

A major benefit of a GIS is its ability to organize several different layers of information. In the following graphic the UTM air quality grid cells were overlayed onto the 1990 El Paso Texas Travel Demand Package network. A subset of freeways from the El Paso network was selected using the coded functional classification. Using this selected network set, the grid cell data base was overlayed, and only those cells through which a freeway passed were selected. The total vehicle miles of travel were summed for the entire El Paso network using interactive statistical calculations within the GIS. An example calculation was made using an estimated emission rate for all grid cells through which a freeway passed. This type of analysis could be used for any corridor analysis procedure, including measures of congestion and speed calculations.

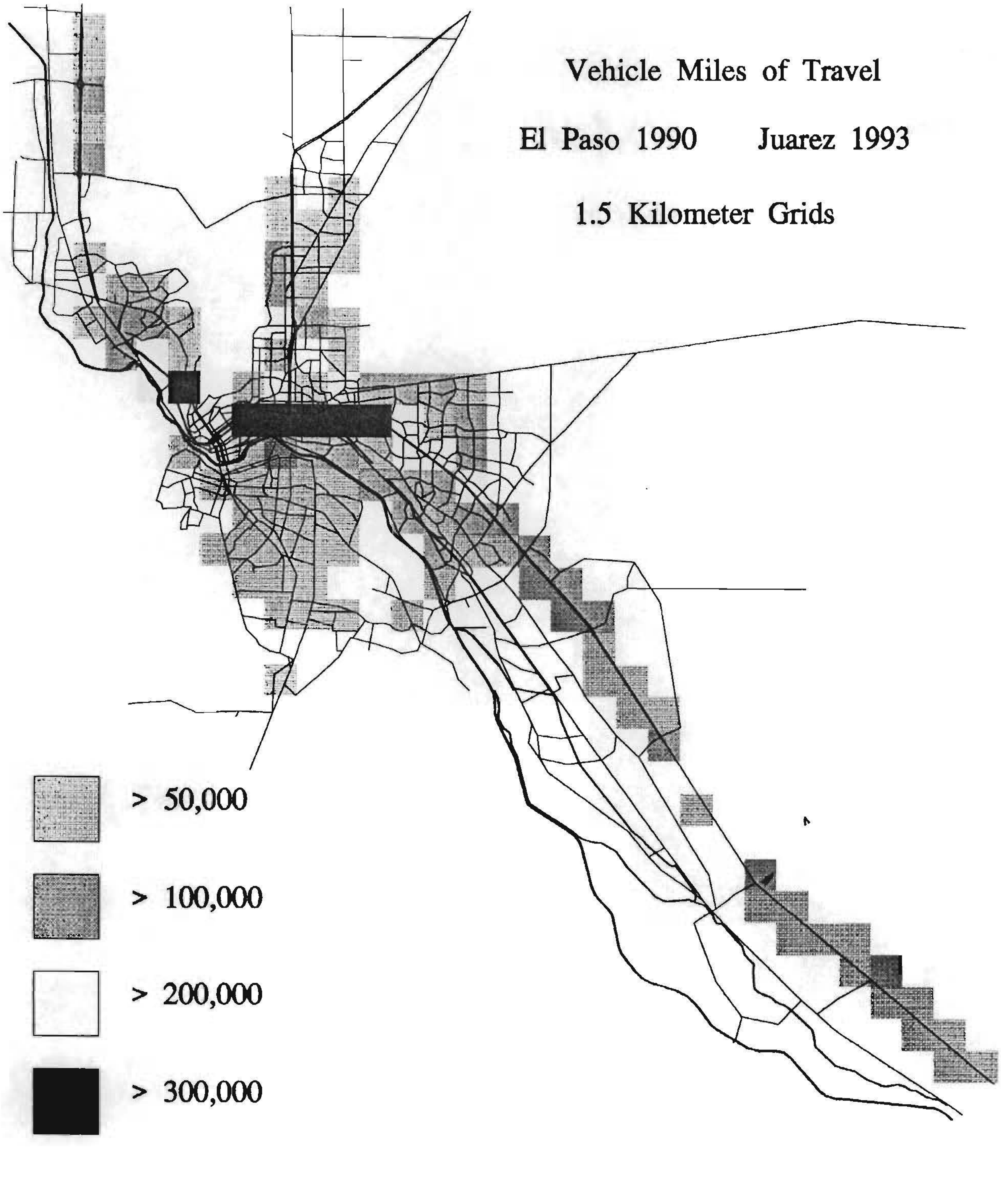

Figure 8 Air Quality Grid Cell Analysis

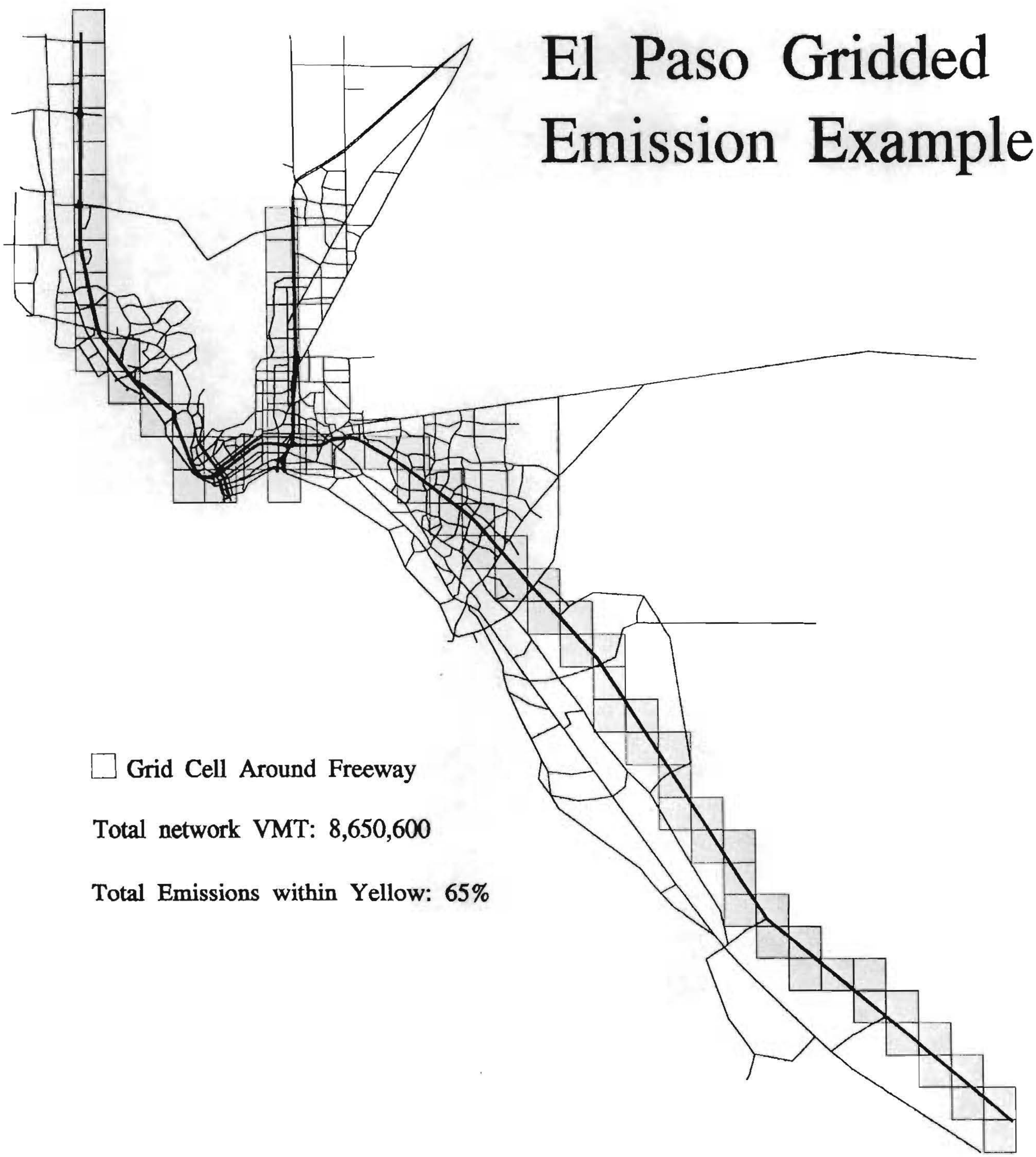

Figure 9 Example of GIS Overlay for Corridor Analysis

V. ANNOTATED BIBLIOGRAPHY
FOR GIS-T: TRAVEL DEMAND MODEL INTEGRATION

Literature regarding Geographic Information Systems and Transportation Modeling shows several areas where the unique capabilities of a GIS can improve the efficiency and productivity of several steps in the traffic demand modeling process. This is not an exhaustive bibliography.

Anderson, Larry D. *Applying Geographic Information Systems to Transportation Planning.* From **Transportation Research Record #1305**. Washington, D.C.: National Academy Press, 1992, 113-117.

This article summarizes Montgomery County, Maryland's GIS-T efforts. The county used GIS to aid in their growth management system. They used SPANS and EMME/2 to create a denser zone structure, improving their trip assignments. They report finer grained analysis and better O-D estimation. The project used tax appraisal data for their demographic work.

Bailey, Marc and Simon Lewis. *Creating a Municipal Geographic Information System for Transportation: Case Study of Newton, Massachusetts.* From **Transportation Research Record #1364**. Washington, D.C.: National Academy Press, 1992, 20-29.

This article summarizes the city's efforts to implement a GIS-T. The primary information is the illustrated differences between the old and new methods.

Barrett, William. *Building a Regional Transportation Model with GIS Software.* From **1991 Arc/INFO User's Conference**. Redlands, CA.: ESRI, 1991, 80-88.

This article summarizes MINDOT's efforts to improve the Minneapolis-St. Paul travel model. It contains general descriptions of the steps using Intergraph's MGE. This article may be the most helpful, but unfortunately it does not elaborate enough on the subject. MINDOT loaded their TDM functions into work stations MGE/MGA. The author repeated this for several other cities. Also, Dr. Souleurette of Iowa State

University or UNLV is doing the same thing with Arc/INFO. A TRANPLAN-Arc/INFO translator will be on Version 7.0, which is due out sometime around Fall 1994.

Breedlove, Michael J. *Utilization of a Parcel-Based Geographic Information System for Small Area Demographic Estimates.* From **GIS/LIS 1991**. Bethesda, MD.: ASPRS, 1-8.

This article illustrates for what GIS-based information can be used. Current population and land use forecasts still have quite a way to go. In small area estimates, there needs to be a very accurate and thorough count in each zone (i.e., who/what in each zone).

Elliot, Artie V. *Planning for Texas' Needs Using Highway Performance Monitoring System Analytical Process.* From **Transportation Research Record #1364**. Washington, D.C.: National Academy Press, 1992, 20-29.

This paper mainly describes how HPMS was used by TxDOT. Time management and reducing wish lists is discussed. The report indicates problems with transferring different data base formats.

ESRI. *Improving Transportation Decision Support: Making Informed Choices Using GIS Technology.* Redlands, CA.: January 1994.

This source is similar to an "infomercial" and primarily discusses management issues and some strengths of GIS.

ESRI. *What is a GIS? Basic Concepts of Spatial Analysis.* From the "Spatial Analysis Seminar," Austin, TX., February 15, 1993.

This answers the question of what a GIS is, but does not help to expand on any further knowledge pertaining to a GIS. It illustrates the limitations of current GIS and how spatial models, i.e., TRANPLAN and Texas Largenet, can be linked.

Fernando, Emmanuel, Miguel Paredes, and Tom Scullion. *An Initial Evaluation of the Feasibility of a GIS to Support PMS Applications.* College Station, TX.: Texas Transportation Institute, August 1989.

Roughly 70 pages, this paper goes into the technical aspects of Pavement Management Systems. More like a thesis than a summary, this paper gives many details on setting up a GIS.

Galimore, Paul W., David T. Hartgen, and Yuanjun Li. *Applications of GIS-T Analysis Packages in Super Regional Transportation Modeling.* From **Transportation Research Record #1364**. Washington, D.C.: National Academy Press, 1992, 122-130.

This report suggests how to use TransCAD to create a sketch network for a 40 by 150 mile corridor, and links it to TRANPLAN, TMODEL, Microtrips, and UTPS. It developed a different TAZ system loading demographic data directly to the network. This technique reduces data loss and suggests a way to reduce the number of loading links by using ZIP codes as the initial zone system.

Hartgen, David T. and Yuanjun Li. *GIS Applications to Transportation Corridor Planning.* UNCC Center for Interdisciplinary Transportation Studies, 1993.

This article summarizes the results from two UNC studies. It was found that a GIS-T greatly facilitated the display of and understanding of the information. The GIS display aided in the decision-making process. GIS overlay and buffering capabilities were used. The project went faster, and cost less than if manual techniques had been used.

Ho, Eric P. *The Linkage between Travel Demand Forecasting Models and Traffic Analysis Models.* From **1992 Compendium of Technical Papers**, by the Institute of Transportation Engineers, 1992, 393-397.

This article discusses the differences between large network models (TDFM) and the more focused Operations Models (TOAM). The author suggests how to link the output of the more accurate TOAM with segments in the larger TDFM, hopefully improving the accuracy of the TDFM.

Horowitz, Alan J. *Integrated Traffic Flow and Region-wide Travel Forecasting Models.* From **1991 Compendium of Technical Papers**, by the Institute of Transportation Engineers, 1991, 476-481.
This paper discusses how to use different data as input to a large network model. Traffic Flow Models produce more accurate link estimates and use HCM procedures. No results are recorded, but it does suggest improvements.

Ingham, D.J. *Quantifying the Effect of Congestion Relief Measures.* From **1992 Compendium of Technical Papers**, by the Institute of Transportation Engineers, 1992, 382-386.
This report describes a TSM model and shows that coarser zones can be used with a minimal loss of data accuracy.

Insignares, Manuel A. and Terry C. Douglas. *Geographic Information Systems in Traffic Control.* From **1991 Compendium of Technical Papers**, by the Institute of Transportation Engineers, 1991, 504-508.
Using GIS techniques, signal data are collected, organized, and interpreted. It suggests data sharing and using TIGER for networks. IVHS-GIS applications are briefly suggested. (Cites TRB 70th Annual Meeting report, Paper # 910469, January 1991. GIS-Model integration.)

Kriger, David, Mike Hossack, and Mike Schlosser. *Integration of Geographic Information Systems with a Travel Demand Forecasting Model.* From **TAC Annual Conference**, 1991.
Although a somewhat simple GIS was used, the authors discovered many advantages of combining a GIS with a TDM. Geo/Sql and TMODEL were used for a GIS-T.

Lane, Scott and David T. Hartgen. *Diffusion of Transportation Planning Applications in Metropolitan Planning Organizations: Results of National Survey.* From **Transportation Research Record #1364.** Washington, D.C.: National Academy Press, 1992, 45-52.

This report consists primarily of a description of a survey and a review of existing technology. MPOs seem to be leading the GIS-T movement. Very few agencies have had a fully functional GIS for more than two years. Also, most MPOs use PC systems. A standard TDM manual is needed.

Li, Yuanjun. *Using TransCAD Data to Establish an Arc/INFO Transportation Geographic Information System for the Charlotte Metro Region.* From **1992 Arc/INFO User's Conference.** Redlands, CA.: ESRI, 1992, 459-462.

This project's purpose is to establish an Arc/INFO GIS for the Charlotte Metro Region. The GIS-T requires a great deal of information; automatically entering the data will save time and money. TransCAD is used to create base maps and to produce some transportation analysis. An AML is used to create separate county, census tract, ZIP codes, and roads data covers. AML is used for spatial data inquiry. This paper describes the data organization, conversion, and processing needed.

Li, Yuanjun. *GIS-Based Spatial Representation and Trip Pattern Analysis of the 1985 Charlotte Household Travel Survey.* M.A. Thesis, University of North Carolina, 1993.

This contains a good general description of integrating a GIS with a TDM. It stresses the strengths of GIS, i.e., visualization, data base integration, dynamic segmentation, and relative ease of operation. This report also contains a good description of general steps in creating the GIS-T. It recommends IS as an improvement to a general TDM process.

Logie, Miles. *Network Management Using GIS.* From **1992 Compendium of Technical Papers**. Institute of Transportation Engineers, 1992, 437-431.

This is a rather short article with several graphics which explain this project's purpose. It has a general discussion of network scales (details and types), changes in networks, and theoretical links between a network and a data base.

Lolonis, Panagiotis, et al. *Accuracy of a GIS-Based Small Area Population Projection Method Used in Spatial Decision Support Systems.* From **1992 Arc/INFO User's Conference**. Redlands, CA.: ESRI, 1992, 473-483.

This article does not directly deal with GIS-T, but subarea estimating procedures are used in the network models. This paper suggests some ways in which to improve the inputs with GIS.

McAdams, Michael A. *A Geographic Information System Application to Regional Subarea Transportation Modeling.* UNCC Center for Interdisciplinary Transportation Studies, 1992.

This article summarizes a North Carolina project which uses GIS. The GIS is used to speed up the project, allow for easy visualization of alternatives, and simplify focusing and windowing.

Meyer, Michael D. and Wayne Sarasua. *Geographic Information System-Based Transportation Program Management System for County Transportation Agency.* From **Transportation Research Record #1364**. Washington, D.C.: National Academy Press, 1992, 104-112.

This article summarizes a GIS-T by department and lists applications for traffic engineering, accident monitoring, pavement management, linking TPlanning and land use, and transit. It also develops an interface between TRANSYT-TF and TRANPLAN.

NCHRP. *Management Guide for the Implementation of GISs in State DOTs.* **Research Results Digest #191**. Transportation Research Board, October 1993.

This report outlines how state DOTs may implement a GIS-T policy. It also describes current problems with transportation data and how GIS may help. This paper is a must for implementation of GIS at TxDOT.

O'Neill, Wende A. and Balakrshina Akundi. *Automated Conversion of Milepoint Data to Intersection/Link Network Structure: An Application of GIS in Transportation.* From **Transportation Research Record #1261**. Washington, D.C.: National Academy Press, 1990, 27-34.
This paper discusses how milepost referenced data can be spatially managed through a GIS. It is very similar to dynamic segmentation and suggests using TIGER files to save time and money and to link tabular data.

Paredes, Miguel, Emmanuel Fernando, and T. Scullion. *Pavement Management Application of a GIS: A Case Study.* From **Transportation Research Record #1261**. Washington, D.C.: National Academy Press, 1990, 20-26.
This paper describes a TTI project that used PC Arc/INFO to input, process, and display Micro-PES tabular data. The authors report successful digitizing, processing, and displaying. It suggests using TIGER files and tabular data for a faster process.

Pedersen, N.J. and D.R. Samdhal. **Highway Traffic Data for Urbanized Area Project Planning and Design: NCHRP Report #255.** Washington, D.C.: Transportation Research Board, December 1982.
This report details the four-step process and possible error sources.

Petzold, Roger G. and Deborah M. Freund. *Potential for Geographic Information Systems in Transportation Planning and Highway Infrastructure Management.* From **Transportation Research Record #1261**. Washington, D.C.: National Academy Press, 1990, 1-9.
This article summarizes existing data bases and technologies for a GIS-T.

Replogle, Michael. *Computer Transportation Models for Land Use Regulation in Montgomery County, Maryland.* From **Transportation Research Record #1262.** Washington, D.C.: National Academy Press, 1990, 1-9.

This article describes the county's effort to join GIS and their land use model. They now use SPANS and EMME/2 for GIS-T, and report improved calibration. The land use models are slightly more accurate, and they greatly improve data acquisition for both GIS-enhanced models. They use GIS-T + LU models for alternative assessment. The county picked a transit-enhanced strategy to reduce auto peaking problems.

Siegfried, Robert H., et al. *Incident Management Using GIS.* From **1992 Compendium of Technical Papers**. Institute of Transportation Engineers, 1992, 433-436.

This paper describes a TTI/TxDOT project for the Houston Area Automated Incident Management System. It is similar to the University of Texas' MIMS project. This article briefly describes how to put data bases and map layers together.

Simkowitz, Howard J. *Using Geographic Information System Technology to Enhance the Pavement Management Process.* From **Transportation Research Record #1261.** Washington, D.C.: National Academy Press, 1990, 10-19.

This research summarizes a TransCAD-based GIS-T that concentrated on PMS. It describes the strengths of PMS, GIS, and GIS/PMS and uses TIGER files for North Carolina.

Stover, Vergil G., Duk M. Chang, Chun-Soo Chung, and George B. Dresser. *Traffic Forecasting for Project Development.* College Station, TX: Texas Transportation Institute, 1989.

This report demonstrates how to use the Texas Package for windowing and focusing. Due to the software, the process is rather complicated. A GIS link could be used to speed up this process.

Tomlin, Dana C. *Geographic Information Systems and Cartographic Modeling.* Englewood Cliffs, N.J.: Prentice-Hall, 1990.
This is a good general discussion on this subject. It is somewhat dated but may be a good source for definitions and reference. It shows some simple ecological-type models and also addresses how the data bases can be linked.

Transit Geographical Information System. U.S. DOT. Washington, D.C., January 1994.
This sheet outlines the FTA's new policy on GIS-T. The FTA is developing a GIS-T that incorporates user-friendly, personal computer software technology for the following reasons: the U.S. government will establish the data superhighway, BTS is compiling transportation data statistics, and there is a great need for GIS-T.

Vonderohe, A.P., L. Travis, R.L. Smith, and V. Tall. *NCHRP Report 359: Adaptation of Geographic Information Systems for Transportation.* Washington, D.C.: National Academy Press, 1993.
This is a very good general guide, although no specific examples are provided. It is a standard government document: good comprehension, yet lacking in detail. The glossary is also very helpful.

Williams, Tom A. *Adaptation of the Joint NCTCOG/SHDPT/DART Travel Forecasting Model to Arc/INFO GIS.* Paper presented at **The Third National Transportation Planning Methods Application Conference**. Dallas, TX., 1991.
This paper describes the planning, organization, and methodology used to integrate the Dallas/Fort Worth Regional Travel Model system with GIS. Current problems and future expectations are discussed.