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GIS-BASED FREIGHT DENSITY AND CAPACITY MODELING

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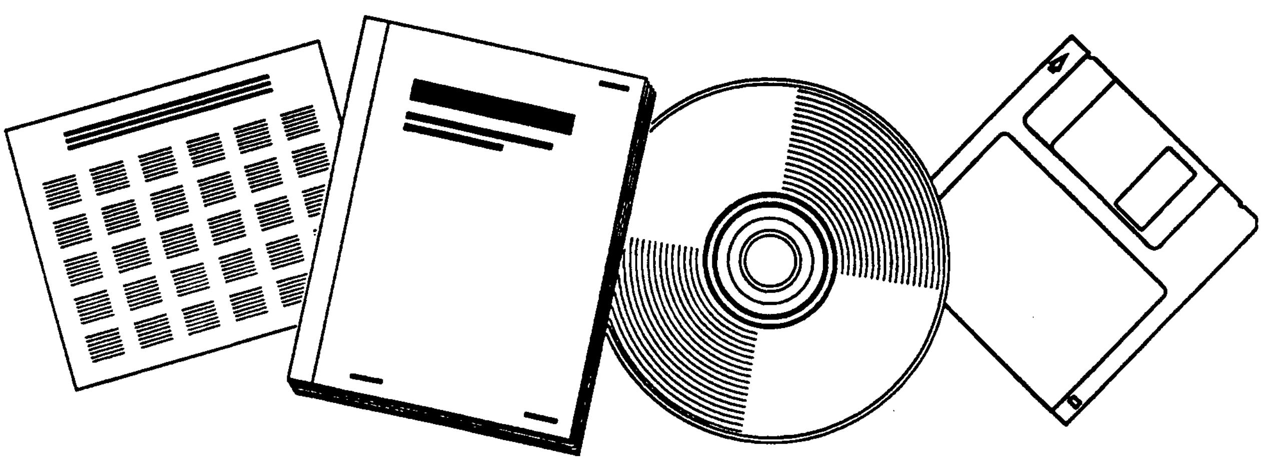

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GIS-BASED FREIGHT DENSITY AND CAPACITY MODELING

MBTC FR-1060

Alex Wong, G. Don Taylor, Hamdy A. Taha, and Jana Wootten

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16. Abstract

This paper discusses the development of Geographical Information Systems (GIS) based tools for use in the trucking industry. The primary goals are to link the GIS with appropriate database information to support both operational and strategic decision making in both truckload (TL) and less-than-truckload (LTL) operations. The GIS-based tools support three primary deliverables. In the LTL industry, we have developed tools to support the determination of near-optimal locations for breakbulk terminals. In the TL industry, we have developed tools to aid in the development of regularly scheduled capacity in the form of driving 'lanes' in an effort to regularize the driving job and to improve service in that industry. For both industries, we have made use of regression analysis to determine the level to which we can make use of demographic information to predict freight density. For all three deliverables, the GIS software system supports the key prerequisite of freight density analysis. Also, the GIS platform provides excellent graphics capabilities for visualizing the various analyses and solutions. The result is an integrated solution platform that enables the trucking industry to better utilize delivery capacity and to proactively seek solutions to problems of strategic importance.

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ABSTRACT

This paper discusses the development of Geographical Information Systems (GIS) based tools for use in the trucking industry. The primary goals are to link the GIS with appropriate database information to support both operational and strategic decision making in both truckload (TL) and less-than-truckload (LTL) operations. Primary inputs into the system include 'typical' freight history files provided by major TL and LTL carriers in the United States, existing and proposed facility or driver domicile locations, information regarding seasonality of freight density by region, and demographic information such as population data. The GIS-based tools support three primary deliverables. In the LTL industry, we have developed tools to support the determination of near-optimal locations for breakbulk terminals. In the TL industry, we have developed tools to aid in the development of regularly scheduled capacity in the form of driving 'lanes' in an effort to regularize the driving job and to improve service in that industry. For both industries, we have made use of regression analysis to determine the level to which we can make use of demographic information to predict freight density. For all three deliverables, the GIS software system supports the key prerequisite of freight density analysis. Also, the GIS platform provides excellent graphics capabilities for visualizing the various analyses and solutions. The

result is an integrated solution platform that enables the trucking industry to better utilize delivery capacity and to proactively seek solutions to problems of strategic importance.

INTRODUCTION

Although GIS tools are commonly used in the transportation industry, it is rare to find published work discussing GIS-related research or practice by TL or LTL carriers. Carrier companies certainly rely on computer based technology for routing/dispatching and for breakbulk terminal location selection and may have developed their own graphical software platforms, but most have not been introduced to the full benefit of commercially available GIS systems.

In the LTL industry, the determination of locations for breakbulks is a key strategic business decision. Some carriers opt for a large number of breakbulk locations in an effort to reduce load circuity and hence reduce driver and fuel costs. The tradeoff is in the number of times that freight may be handled. Other carriers are willing to work with a smaller number of breakbulk terminals to reduce handling cost knowing that this decision will likely add circuitous miles to each load. The authors have been fortunate in having the participation of *ABF Freight System, Inc.* as a valued participant in this research. The company has generously provided supporting freight density data and load profiles and has also contributed engineering expertise to aid in the development of appropriate LTL tools. Herein, the authors describe the resulting GIS tools that help to determine near optimal breakbulk locations. The GIS system makes use of case study data supplied by *ABF* and clearly indicates the transportation and material handling costs associated with various breakbulk location solution options.

In TL trucking, the authors of this paper have been long involved with the industry and with *J.B. Hunt Transport, Inc.* specifically, in an effort to regularize the TL trucking driving job.

The motivation to do so is primarily the high cost associated with high driver turnover rates in the industry which can be more than 85% per year (Mele, 1989). A major contributor to driver turnover is the random dispatching system used for over the road (OTR) drivers in most TL companies. The dispatching system is designed to eliminate the cost of first dispatch empty miles, but the result is usually long tour lengths for OTR drivers. The authors have been involved with several projects seeking to find alternatives to random OTR dispatching methods. The examination of hub and spoke systems has been undertaken with disappointing results (See Taha & Taylor, 1994 or Taylor et al, 1995). More recently, the authors have been working toward the development of regional delivery zones or inter-regional delivery lanes. These results show much more promise as a potential alternative to random dispatching systems (See Taylor et al, 1997). It is in support of these activities that the GIS tool set is developed in the TL industry. Once again, we are fortunate to have the heavy involvement *of J.B. Hunt Transport, Inc.*, the largest publicly owned truckload carrier in the United States (J.B. Hunt, 1997). The GIS-based tools described herein help to locate TL 'lanes' that can be operated efficiently in terms of freight density, freight balance, and driving time. The tools can help to define lane service areas using latitude/longitude regions, circular service regions defined by a hub centroid and radius, zip code locations, or political boundaries such as state or county lines. The software tools developed herein facilitate the selection of desired service regions, calculate density and imbalance statistics, and even calculate the excess circuity encountered by loads that travel through intermediate lane transshipment points.

Either carrier type can benefit from improved freight density analysis or improved visualization of solutions. The GIS platform provides a useful way to achieve both of these desired results. Relative to problem visualization, GIS systems provide a means of viewing database information relative to geographical features with many potential data overlays. For example, carrier data can be visually referenced relative to political boundaries, transportation infrastructure overlays (roads, railways, etc.), geographical overlays (mountain ranges, waterways, lakes, etc.), or demographic data (location of population centers, location of manufacturing, distribution, or mining sites). The ability to use this visual information has obvious implications regarding what is possible in terms of freight density analysis. Furthermore, GIS systems are easily integrated with external routines or programs to further increase their utility for freight density analysis. Herein, we make use of the import/export of data to/from spreadsheet or general programming applications. Upon completion of external routines, data is easily submitted back to GIS systems for additional operations or for state-of-the-art visual presentation.

We now present an outline for the remainder of this paper. Following a brief review of the pertinent literature, we discuss the tools and data used in our solution approach. Following these necessary discussions, we present the solution approaches we have taken for our three primary deliverables. We discuss the development and use of a GIS-based interactive breakbulk location tool for the LTL industry. We discuss the development and use of a tool to aid in lane development for regularization of capacity in the TL industry. Finally, we discuss the use of demographic information and GIS-imbedded regression analysis in both industries. In all cases, we focus on the characteristics of the GIS platform that enhance our solution techniques. Finally, we draw conclusions about the efficacy of the platform.

LITERATURE REVIEW

In general, a Geographic Information System may be defined as a computer-based information system which attempts to capture, store, manipulate, analyze and display spatially referenced and associated tabular attribute data for solving complex research, planning and management problems (Fischer and Nijkamp, 1993). The substantial improvement in computer systems during the last two decades has made it much easier to apply computer technology to the problem of storing, manipulating and analyzing large volumes of spatial data. Today, many organizations make routine use of Geographical Information Systems to undertake diverse tasks such as forecasting potential market areas or analyzing factors contributing to seismic hazard levels. These Geographical Information Systems comprise some quite sophisticated computer software, but they all contain the following major components:

1). A data input subsystem which collects and/or processes spatial data derived from existing maps, remote sensors, etc. (Marble, 1990). This data input subsystem must contain Geographical Information such as latitude and longitude or national grid coordinate, or an implicit reference such as an address, postal code, or road name (ESRI, 1997). There are two different forms for the data to take; the raster model and the vector model (ESRI, 1997). The raster model is made up of a collection of grid cells that come from scanned maps or pictures. The vector model is based on digitized information such as points, lines, and polygons and is usually described by x,y coordinates.

2). A data storage and retrieval subsystem which organizes the spatial data in a form which permits it to be quickly retrieved by the user for subsequent analysis, as well as permitting rapid and accurate updates and corrections to be made to the spatial database (Marble, 1990).

3). A data manipulation and analysis subsystem which performs a variety of tasks such as changing the form of the data through user-defined aggregation rules or producing estimates of parameters and constraints for various space-time optimization or simulation models (Marble, 1990).

4). A data reporting subsystem which is capable of displaying all or part of the original database as well as manipulated data and the output from spatial models in tabular or map form (Marble, 1990).

Geographical Information Systems are capable of acquiring spatially indexed data from a variety of sources, changing the data into useful formats, storing the data, retrieving and manipulating the data for analysis, and then generating the output required by a given user. A great strength of Geographical Information Systems is their ability to handle large, multi-layered databases and to query about the existence, location and properties of a wide range of spatial objects in an interactive way (Fischer and Nijkamp, 1993).

GIS - General Applications

In the past, GIS has been used almost exclusively for map making. However, it has recently been recognized as a viable tool for problem-solving by many different business sectors. GIS has been developed independently for a wide variety of purposes. According to Tomlinson (1990), the growth of GIS in recent years has been led by the developments in a small number of sectors including forestry, property and land parcel management, utilities, civil engineering, agriculture and environmental applications and transport, facility, and distribution planning. Since these developments, GIS has been expanded to include a myriad of other applications. The city of

Chicago uses a GIS to coordinate parking violation information with its parking management system so that the information can be used later for parking management planning. GIS systems are used to manage infrastructure (Dorris, 1990), land records management (Dueker and Delacy, 1990) and even to aid in the cleanup of 10.9 million gallons of oil in Prince William Sound, Alaska (Brooks, 1989). Ranging from sales and marketing to telecommunications and health care, GIS is providing more efficient and effective solutions for a wide spectrum of industries.

GIS - Trucking and Logistics Applications

According to Beard (1989), there are six generic uses for spatial data. These include siting of location, logistics or allocation, routing, navigation, inventory of spatial objects, and monitoring and analysis. Most of these uses are related to the transportation field in some manner. The factor that most GIS applications in the transportation field have in common is that the location component is usually at a national scale and that, usually, only a limited number of location characteristics are taken into account. The fact that the location component in these studies is not as predominant or at as fine a scale as in other application areas, has meant that the use of traditional analytical methods still dominates the field. The potential for integrating GIS within this application area is very promising. Apart from data storage and graphical display, GIS has the ability to make certain specific location concepts and techniques operational: these concepts include the systematic analysis of proximity, accessibility, connectivity and density. In addition GIS can also perform traditional location analysis. The effective integration of all these functions and facilities would be very difficult to achieve, if not impossible, using traditional (i.e. non-GIS) methods (Scholten and van der Vlugt, 1990).

GIS allows the transportation industry to utilize a powerful database while giving consideration to geographical constraints. Currently it is implemented on three distinct transportation markets, transportation infrastructure management, transit management, and fleet and logistics management. In transportation infrastructure management, GIS is used to manage and analyze information based on geographical and spatial components to determine the location of an event or asset and its relationship or proximity to another event or asset (ESRI, 1997). This relationship is often a critical factor to decision making concerning design, construction, or maintenance. An example is using GIS to determine the best place to locate a new facility. In transit management, GIS is used for planning and maintaining traffic and for providing a better understanding of the transit network. For example, GIS provides a visualization of traffic volumes and highway conditions. This allows analysts to determine alternate routes in the event of road closures. In fleet and logistics management, GIS is used primarily to plan routes and select locations for providing a more efficient logistics network. Other applications of GIS related to transportation include evacuation planning, planning for hazardous material release incidents, development of new traffic analysis zones from census tracts, and development of new urban highway networks.

These applications are well documented by O'Neill (1991), Gan (1994), Abkowitz et al. (1990), and Stokes and Marucci (1995). O'Neill and Gan both describe methods for utilizing GIS for urban transportation problems. Gan describes methods for converting census data into a useful form as input data for two Geographical Information Systems, namely ARC/INFO and TransCAD. Stokes and Marucci (1995) present a broad overview of current GIS-Transportation applications and discuss some of the obstacles to large-scale implementation of GIS-Transportation including the high costs of collecting new data, converting existing data, vendor incompatibility, and the lack of basic functionality in most GIS packages to perform network analysis and travel demand modeling. GIS is also used in developing routes for hazardous material transportation. Abkowitz et al. (1990) address the issues involved with utilizing GIS to evaluate the risks of transporting hazardous materials into the general population.

GIS for Truckload and Less-than-Truckload Carriers

Over the years, a great amount of research with different techniques and algorithms has been done in the routing and transportation modeling areas, but very little has been concerned with the carrier business. Most carrier companies depend on non-GIS systems for routing and breakbulk location selection. Efficient algorithms have not yet been developed to address the problems that carrier companies are facing. A potential solution platform for these problems lies in GIS.

Solving a routing problem usually involves many compromises within a set of conflicting goals and constraints (i.e. using the main roads instead of the shortest route, giving a better average service rather than a better service to individual customers). Consequently, the routing solutions are often computed or at least edited by hand. The process of solving a routing problem by hand is quite time-consuming. The first and most tedious task in route planning is the design of algorithms, but other tasks are also necessary; finding the location of the clients, computing the distance between them, evaluating their service time, and managing the fleet of vehicles. When all data is collected and the objectives are well defined, an appropriate algorithm is run. Finally the solutions are evaluated and quite often modified to take into account constraints that could not be modeled in the algorithms. There are many ways in which interactive graphics could help in all the steps involved in the planning and implementation of routes.

Many Geographical Information Systems support analyses in networks, which are systems of connected lines represented in vector data. In the real world, networks consist of road systems, power grids, water supply and the like, all of which transport moveable resources.

Network operations are based on continuous, connected networks, rules for displacement in a network, definitions of units of measure, accumulations of attribute values due to displacements, and rules for manipulating attribute values (Bernhardsen, 1992). As is the case for other GIS analytical tasks, network analyses depend on the existence of topology in the data. The system must, for instance, know which roads can accept traffic flow at intersections. Every link and every node in a network must have a unique identity and the program must contain specifications of where roads begin and end. The analysis includes the simulation of moving resources. The resources, in this case freight trucks, moving along the lines encounter resistance in the form of speed limits, road works, peak traffic, barriers, one-way streets, weight limits, traffic lights, hills sharp curves and so on. Once all the attributes have been allocated, the system can assess movement of resources through the network. In this manner, transport analyses may be conducted to optimize driving time, and minimize travel distance and costs. In practice, analyses usually result in several alternatives which illustrate the consequences of the foregoing simulations (Bernhardsen, 1992).

GIS provides the means by which the trucking industry can easily determine freight density and areas in their transportation network which should be refined. GIS combines information on the transport network with other demographic characteristics to aid in the decision making process for the placement of break bulk locations or driver domiciles. Given the spatial data, GIS also helps determine the best route for a delivery. GIS can also aid in the collection of data. "A major limitation in the use of transportation models is the difficulty of obtaining adequate data for them. Geographical Information Systems are a means of addressing this need" (Lewis, 1990).

The goal of this study is to develop an architecture or a framework for determining breakbulk locations and domicile planning for truckload and less-than-truckload carriers. With this purpose in mind, the use of Geographical Information Systems provides two major advantages. First, GIS allows visualization of the problems using various partition formats or criteria. Second, it allows a visualization of the sequence in which solutions are built. This not only adds an understanding of the logic behind routing network design and related problems, but also provides a way to know more about the data stored in traditional transportation databases that were previously unknown.

For a given segment of road, a GIS knows what routes cross it and whether there is an actual physical intersection. It knows the position of roadside features along the segment and can tell the user which census blocks are to the right and left of the segment or within any specified distance of it. The census block information allows the user to visualize the location of population centers. A GIS with the appropriate routing algorithm and data can easily compute and display the best route for transportation. With the route drawn on the computer screen, the analyst can see immediately the logic behind the model that may have bypassed certain population centers. The analyst has an option to delete any particular path, and then watch the routing algorithm redraw the path on the screen, in contrast to traditional methods in which the modification would require much more manual calculation to account for the change. Most important of all, the analyst is provided a live, interactive experience with this decision support system.

The trucking work perhaps most related to this project appeared in Taylor et al. (1995), in which the authors describe configuration issues and operational concerns associated with the use of hub-and-spoke transportation networks in truckload trucking. Although not built on a GIS platform, their work could have benefited tremendously for GIS features. Also Casavant et al. (1995) discusses the use of GIS-Transportation to model Washington state truck flows. Although not necessarily on GIS platforms, the routing and consolidation problems of TL and LTL shipments have been researched by various authors. Crainic and Roy (1992) describe a load plan of LTL based on a modeling and algorithmic approach. Roy and Delrome (1989) discuss the use of a network optimization model for assisting motor carriers and evaluating various operating strategies and network configurations. List and Turnquist (1995) use GIS, LINDO, and relational database systems (dBASE III+) to view flow patterns, examine the differences between observed and estimated link flows, determine the data "holes" as in the absence of flows in obvious locations or underestimation of flows, store, edit, and review link and node attributes, prepare network flow maps, and validate data sets.

Intermodal Delivery

Truckload and less-than-truckload companies are learning that they can be more competitive through utilization of intermodal delivery networks (Taylor et al, 1995). Companies recognize the potential of an intermodal network as an alternative to traditional shipment methods. They also see the benefits of improving the quality of driver life through regularly scheduled trucking capacity through regularly scheduled routes. One problem that must be looked at is the determination of appropriate rail lanes and terminal locations. GIS can provide a useful platform for this activity as well.

TOOLS AND DATA

The primary component of the GIS framework discussed in this paper is a GIS application called Atlas Select by Strategic Mapping, Inc. This application runs on a Pentium Pro platform in Windows 95 environment. Additionally, Microsoft Excel and Access are used throughout the project for data processing and manipulation. For the LTL deliverables, a comprehensive program calculating the shortest path between two nodes is developed in C++ using Standard Template Libraries (STL) on a UNIX platform. The data structure storing the information (origin, destination, and distance) of the network is an adjacency list. A priority queue implementation is used when examining the shortest path from node *i* to node *i*+1.

ABF Freight System, Inc. is the primary source supplying freight density data for the LTL model. The data set comes in an ASCII format that is converted to dBASE IV format before it is ported to the GIS system. The operational load density data provided by the company is roughly 20 MB in size. Because of the large file size, we divide the file into four segments for easier manipulation. To support TL trucking deliverables, *J.B. Hunt Transport, Inc.* provides data in two formats: ASCII and MS Access. Table 1 contains examples of simplified generic freight history records that contain pickup and dropoff dates as well as zip codes. The zip code centroids are easily converted to lattitude/longitude coordinates using the GIS for further processing.

ID	PICKUPDATE	DESTDATE	PICKUPZIP	DESTZIP
2	3/3/97	3/13/97	72901	89431
3	3/5/97	3/10/97	72901	29379
4	3/5/97	3/11/97	72901	50704
10	3/3/97	3/6/97	72901	60411

Table 1. Typical Freight History Information File.

Data supplied *by J.B. Hunt Transport, Inc.* for use in lane development activities and regression analysis includes comprehensive seasonal data sets. The data cover the months of February, April, July, September and November for both 1995 and 1996. These data sets provide a good representation of low, medium, and high volume of activities in a year. Also included in data needs for this project are metropolitan area population data which we have obtained from the Bureau of Census.

LTL DELIVERABLES

In this section, we present an interactive breakbulk location tool that assists LTL users in developing delivery networks. The tool also helps to evaluate the proposed networks using the standard performance metrics of total miles traveled and total material handling costs accrued.

In LTL trucking, the placement of breakbulk locations or driver domiciles is an important aspect of efficient LTL operation. Breakbulk locations can be based on several factors including circuity and labor costs. Some carriers prefer a large number of breakbulk locations to reduce circuity. Other carriers are willing to work with a smaller number of breakbulk terminals to reduce handling costs. This study makes use of GIS to support the determination of near-optimal locations for breakbulk terminals. Historical freight density data from *ABF Freight System, Inc.* is used to test breakbulk location tools. The supporting data contains pickup and drop-off operational data in the form of zip codes. With the help of GIS, zip codes are geocoded into corresponding latitude and longitude values. The software uses a U.S. ZIP code centroid file to convert ZIP code centroids to table points (x,y). Figure 1 is a screen print showing pickup and dropoff locations for a sample data set. Note that the figure shows freight density only for shipments with a southeast United States pickup or delivery location.

Initial Assignment of Breakbulk Locations

As stated above, the placement of breakbulk locations must be made carefully to ensure efficient LTL operation. For simplicity, all candidate breakbulk locations are assumed to be in a major city or at the intersection of two or more interstate highways. The model introduced herein

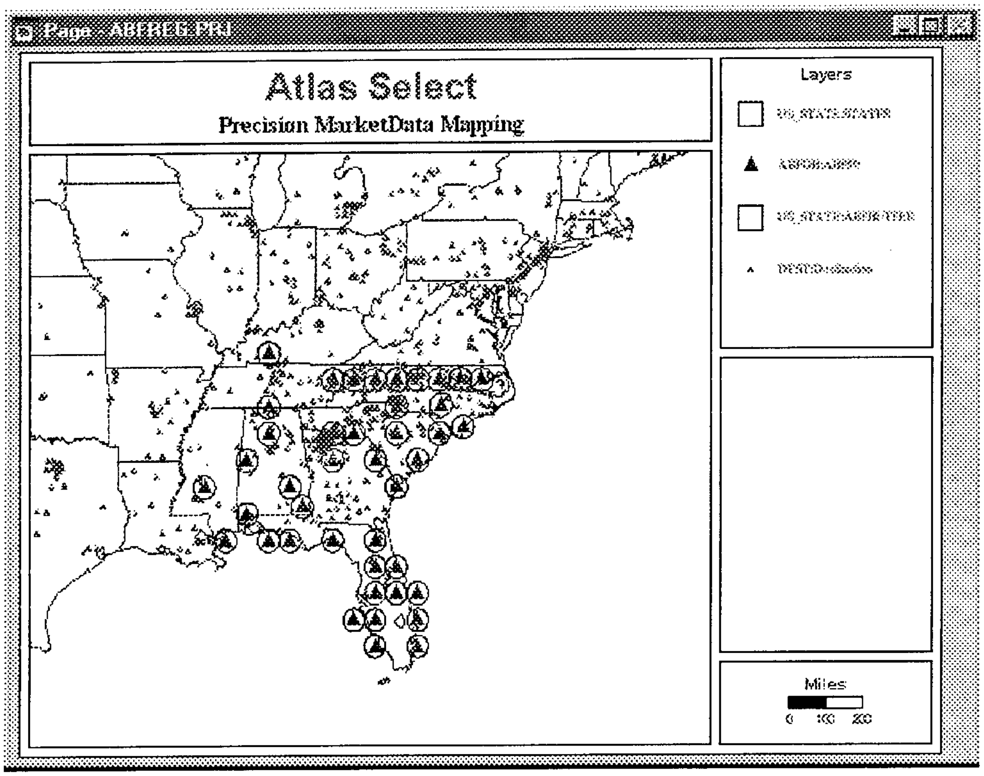

Figure 1. Sample Freight Density File for Southeast United States.

allows one to chose candidate locations from 40 possible breakbulk locations in any combination. These forty potential breakbulk locations have been selected from a pool of 100 locations by experts in the LTL industry. Determination of the latitude/longitude of breakbulk locations is accomplished by constructing two layers in the GIS model. The first layer contains spatial information of 100 major cities including their names, zip codes, and latitude/longitude in the United States while the second layer contains the name of the forty potential breakbulks. The goal is to geocode the breakbulk location layer by matching the breakbulk name with a city name in the first layer. In doing so, the *Geocode by Map Layer* function is used. Table 2 contains the forty potential breakbulk locations and their respective latitudes, longitudes, states, and zip codes.

Breakbulk Location	Latitude (y)	Longitude (x)	State	Zip
Albuquerque	35.13	-106.64	New Mexico	87107
Atlanta	33.76	-84.43	Georgia	30314
Baltimore	39.30	-76.61	Maryland	21233
Boston	42.33	-71.04	Mass	21270
Buffalo	42.88	-78.86	New York	14204
Carlisle	40.20	-77.20	Penn	17013
Chicago	41.85	-87.67	Illinois	60608
Cincinnati	39.13	-84.51	Ohio	45221
Cleveland	41.48	-81.70	Ohio	44193
Columbus	40.00	-83.00	Ohio	43201
Dallas	32.80	-96.77	Texas	75371
Dayton	39.79	-84.16	Ohio	45404
Denver	39.77	-104.90	Colorado	80238
Detroit	42.38	-83.11	Michigan	48206
El Paso	31.85	-106.44	Texas	79904
Houston	29.77	-95.40	Texas	77299
Kansas City	39.12	-94.55	Missouri	64120
Little Rock	34.73	-92.35	Arkansas	72214
Los Angeles	34.09	-118.41	California	90213
Louisville	38.22	-85.74	Kentucky	40217
Memphis	35.10	-89.98	Tennessee	38114
Milwaukee	43.07	-87.97	Wisconsin	53210
Minneapolis	44.96	-93.26	Minnesota	55404
New Orleans	30.05	-89.96	Louisiana	70128
New York	40.67	-73.94	New York	11213
Newark	40.73	-74.18	New Jersey	07188
Oklahoma City	35.47	-97.52	Oklahoma	73102
Philadelphia	40.01	-75.14	Penn	19140
Phoenix	33.56	-112.06	Arizona	85020
Pittsburgh	40.45	-79.98	Penn	15219
Portland	45.54	-122.64	Oregon	97212
Richmond	37.55	-77.46	Virginia	23220
Sacramento	38.57	-121.47	California	94249
Salt Lake City	40.76	-111.88	Utah	84147
San Antonio	29.46	-98.50	Texas	78284
San Francisco	37.77	-122.41	California	94103
Seattle	47.62	-122.34	Washington	98121
St. Louis	38.64	-90.25	Missouri	63156
Tampa	27.96	-82.49	Florida	33650
Winston-Salem	36.11	-80.20	North Carolina	27120

Table 2: Candidate Breakbulk Locations

where x_i = longitude.

y_j = latitude.

69 miles = the approximate number of miles per degree of latitude and the approximate number of miles per degree of longitude at the equator (used as a planar distance approximation).

Phillips and Garcia-Diaz (1981) explain the use of Floyd's algorithm to determine the shortest path from a node (say, node 1) to all other nodes in a network. Floyd's algorithms take as input an $N \times N$ adjacency matrix A and computes an $N \times N$ matrix S, with S_{ij} the length of the shortest path from v to w, or infinity (∞) if there is no direct path between the two nodes. Depicted in the algorithm in Table 3, Floyd's derives the matrix S in N steps, constructing at each step k an intermediate matrix $I(k)$ containing the best-known shortest distance between each pair of nodes. Initially, each pair, $L_{ij}(0)$ is set to the length of the edge (v,w) if the edge exists, and to ∞, otherwise.

```
procedure sequential floyd
begin
  Lij(0) = 0 if i=j
  Lij(0) = length((v,w) if edge exists and i ≠ j
  Lij(0) = infinity otherwise
  for k = 0 to N - i
    for i = 0 to N - i
      for j = 0 to N - i
        Lij(k+1) = min(Iij(k), Iik(k)+Ikj(k))
      endfor
    endfor
  endfor
  S=I(N)
end
```

Table 3. Floyd's All Pairs Shortest Path Algorithm.

When the interactive mode is selected, the user is prompted for a start and end node. The program then computes the shortest path and provides the results shown in the example presented in the screen shot in Table 5. Note that the program not only provides the path itself, it also provides the total travel distance for the shortest path.

```
Enter your start node: LittleRock
Enter your destination Node: Seattle

Shortest Path
==============
LittleRock to SanAntonio to ElPaso to Phoenix to LosAngeles to Sacramento to Portland to
Seattle, Distance: 2982.59
```

Table 5. Shortest Path Between Little Rock, Arkansas and Seattle, Washington.

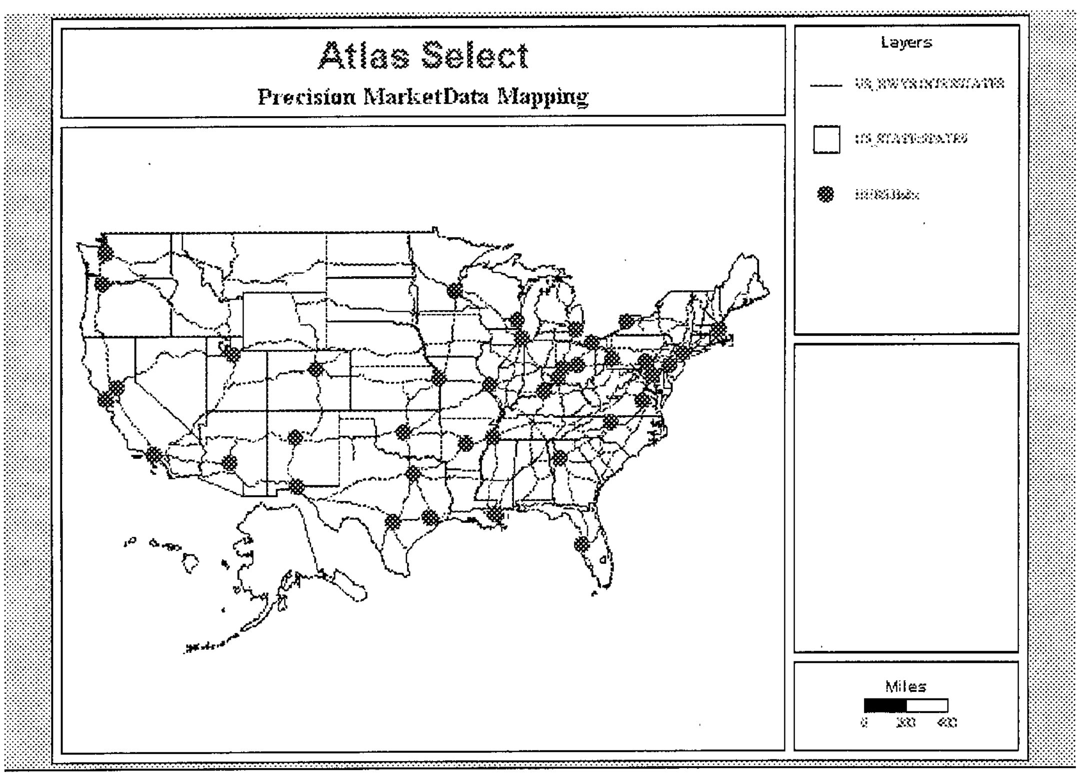

Figure 2. Example LTL Delivery Network.

A very convenient feature of this program is the removal function. It allows the user to remove any hubs in the network. In the screen shot shown in Table 6, El Paso is removed. When performing the shortest path on the same pair of nodes as presented in Table 5, Little Rock and Seattle, you will notice that the path adjusts itself and selects transshipment cities that are entirely different from the previous scenario. Also you will notice that distance increases by approximately 140 miles from 2,983 miles to 3,127 miles. This demonstration reveals the significance of placement of breakbulks in terms of routing decisions and circuity calculations.

System Outputs

Breakbulk terminals are used under three different conditions: EOL pickup, transshipment, and EOL delivery. To account for the throughput density of each breakbulk and also to ensure the loads are categorized appropriately, the LTL model automatically updates counters in each breakbulk based on the results from the Floyd's shortest-path algorithm and the load density data. The results of the model are recorded in a file. Table 7 presents an example of typical generic results for three United States breakbulk locations.

```
Enter your choice: r
Enter hub to be removed: ElPaso
Hub, ElPaso removed.
:
Enter your choice:

Enter your choice: i
Enter your start node: LittleRock
Enter your destination Node: Seattle

Shortest Path
=============
LittleRock to OklahomaCity to Denver to Albuquerque to Phoenix to LosAngeles to
Sacramento to Portland to Seattle, Distance: 3126.94
```

Table 6. Shortest Path Between Little Rock and Seattle with El Paso Terminal Removed.

time with the end purpose of resolving the high driver turnover rates in the industry which can be more than 85% per year (Mele, 1989). The current practice of random OTR dispatching used in most TL companies is designed to eliminate the cost of first dispatch empty miles. The tradeoff is long tour lengths for individual drivers. Recently, the authors have been working toward the development of regional delivery zones or inter-regional delivery lanes. Results indicate that these approaches show tremendous promise as a potential alternative to random OTR dispatching systems (Taylor et al, 1997). It is in support of these activities that a GIS tool set is developed for the TL industry.

In the TL industry, freight density and load analysis plays a key role in the determination of optimal delivery lane locations (Taha and Taylor, 1994). Convenience of original load pick-up and final delivery is important to the selection of lane endpoints, or hubs. The GIS application presented herein helps to define lane service areas using latitude/longitude regions, circular service regions defined by a centroid and radius, zip code locations, or political boundaries such as state or county lines. Figure 3 provides an illustration of one potential delivery lane. In this figure, one service area is defined by a Dallas, TX centroid and a specified radius of 30 miles. The other service area is defined as a zip code region in St. Louis, MO. The connecting driving lane is along US Interstate Highways 30, 40, and 55.

One of the strengths of GIS is its capability of analyzing existing data based on geographic relationships. With functions like 'creating buffer zones' and 'aggregating data', we can determine the tour length and freight density of a delivery lane by merging overlays of existing map layers. The process involving the determination of tour length and freight density between two lane service areas can be done in three simple steps. First we must define the service areas.

column added to the load record. We will use the variable name 'is_inside_buffer' for illustrative purposes. If the load is not within the buffer, a '0' value is assigned. This task is repeated using the same 'assign data by location' query; the first pass involves the pickup point and the second one involves the drop-off data point layer. After the initial assignment is made, the last step is to determine the number of pickup and drop-off data points that meet the delivery criteria, that is the number of loads that are transported between the two service areas in the two cities, Dallas, TX and St. Louis, MO. Note that loads picked up in Dallas, TX may not necessarily go to St. Louis, MO and vice versa. We make the final determination of lane volume through the use of a self-defined query inside the GIS. We count the number of occurrences where the variable 'is_inside_buffer' indicator of both layers contains a value of '1'. The result is written to a new table called 'count'. Lane imbalance can be similarly calculated by counting those loads with a '1' in the pickup layer and comparing with those loads with a '1' in the delivery layer.

There are several ways to calculate the tour length of a delivery lane. The easiest way is to make use of latitude/longitude coordinates of the centroids of the service areas and determine the Euclidean distance between the two zones. This is by far the roughest estimate of the tour length because the actual tour length would be determined by highway routes. The GIS embedded 'calculate distance' function provides an alternative means of distance calculation. To support zone analysis or lanes making use of intermediate transshipment or 'drop & swap' points, distance calculations and flow volumes can be calculated similarly.

In summary, the GIS platform facilitates the selection of desired lane or zone regions, calculates lane density and imbalance statistics, and even calculates the excess circuity mileage encountered by loads that travel through intermediate lane transshipment points. Numerical examples are not presented because of the highly proprietary nature of freight density information.

DEMOGRAPHIC STUDIES

A predictive model using demographic information to predict future freight trends is a possible tool for both TL and LTL industries. Regression analysis and related graphical tools could be easily applied to demographic data or to multiple concurrent types of demographic data to complete a wide array of potential marketing or operational analyses for the industry. Once again, the GIS platform provides an adequate and desirable platform for the analysis. One of the objectives in this project is to determine if there is a strong relationship between demographic properties and freight density. The authors have examined the relationship between the population of fifty major metropolitan areas and freight density within 30-miles of the area centroid. Population data is gathered from 1994 statistics from the Bureau of Census. A simple linear regression is performed on the data provided by *J.B. Hunt Transport, Inc*. The results of this analysis have proven to be very interesting. An r-squared value of 0.25 is obtained, indicating there is a relatively low correlation between freight density and population centers in TL trucking. This can be explained by the fact that many manufacturing plants and major shippers are often located in relatively small cities. This fact helps to support the rural mission of the funding agency, the Mack-Blackwell National Rural Transportation Study Center (MBTC).

Although the r-squared value suggests a low correlation between population and freight density in TL trucking, we have successfully demonstrated the more important issue that the GIS platform is useful for merging demographic and freight density information using valid statistical analysis tools. Furthermore, we have speculated that as we move from TL shipments to smaller shipments approaching parcel or letter size, the r-squared value would increase until it becomes highly correlated with population density. This thesis has been supported by performing an LTL heavily affects a carriers ability to operate profitably. The tool developed in this paper is equally useful as a tool for full network analysis or for perturbation analysis on existing networks. For example, if a company effectively markets their product within a target region or purchases another carrier, the company may want to consider developing new regional breakbulk terminals to support the increased business. The company may further want to consider a network reduction by one or more terminals during periods of declining business. Likely, no other decision with the exception of pricing is more important to the industry than breakbulk location. The tool developed is a convenient, easy to use interactive tool. It allows rapid what-if analysis and presents output in terms of key cost parameters that are pertinent and easily understood. To ensure generality of the tools across a range of carriers, cost information is provided in terms of total travel miles and accrued material handling events. In this way, the carrier can easily multiply these outputs by ($/mile) and ($/handling) costs specific to their company. The drawbacks of the solution technique developed include the fact that the approach is an interactive, non-optimizing approach. Some user skill is required to make initial and subsequent entries in a way that quickly eliminates trivial and poor performing scenarios. The approach is also somewhat 'non-integrated' in that it is a multi-step solution making use of the GIS package and peripheral support. The approach is well documented, but non-integrated from a user's perspective. Also, additional calculation would be required if the user were interested in assigning driving/handling costs that were specific to a particular breakbulk location or driving lane. Finally, the approach in current form does not permit LTL to TL aggregation in a way that would permit some intermediate breakbulks to be bypassed.

The TL trucking tool supporting lane development offers an opportunity to support fundamental operational changes in the industry. The evolution from random over-the-road

In summary, the research presented herein meets all objectives of our research. We have developed useful TL and LTL tools on a GIS platform. We have demonstrated that the tools developed are of a general nature for potential use by almost any carrier, large or small. We have demonstrated the efficacy of the solution approaches using actual industrial data and realistic cases. Finally, we have verified the validity of solutions generated through consultation with industry representatives.

Future research and development could build upon the findings presented herein. Specifically, we are interested in pursuing two ideas. First, we would like to concentrate on the concurrent development of multiple lanes and/or continuous lane moves for use in TL trucking with tools to assist in the selection of well balanced lanes. Also, we would like to develop more user friendly front-end and back-end processors for use with the TL and LTL tools with a GIS solution engine. In this way, we could prompt the user for appropriate input information interactively using Visual Basic or other similar software. Likewise, we could automate the intermediate steps and could present the output in a more optimal format. Furthermore, we could more easily integrate additional databases or demographic information. The GIS platform continues to hold promise for future uses and should have an exiting future in the trucking industry.

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