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Development of a GIS Model for Intermodal Freight

by

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16. Abstract

The purpose of this report is to demonstrate usage of Geographical Information Systems (GIS) for analyzing intermodal freight networks. A complete GIS network, focused on the state of Texas, is developed and used to examine impacts of price, time, location, and policy on shipper routing.

This process begins with an exploration of existing GIS applications, and state of the practice within the intermodal freight industry. This information provides a framework for building a technically feasible and relevant application. Data acquisition and processing techniques for both geographic and attribute data are considered. Relevant processes for creation of a GIS network and data conflation are identified and demonstrated. These techniques are used to create a network modeling the complex interactions and transfer rules amongst modes. Finally, several case studies are developed using the completed network to exhibit the power of GIS applied to intermodal freight. The report concludes with a summary, and observations to assist others attempting to build upon these results.

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EXECUTIVE SUMMARY

The intermodal freight industry is a constantly evolving business. Emerging trends include; usage of Intelligent Transportation Systems applying technology to transportation management and control, a rapid growth in containerization of freight, increasing ship sizes, changing business practices such as just in time delivery, and creation of hub and spoke systems for distribution.

Concurrent with these changes is continued development of enhanced computer analysis capabilities. One such technology is Geographic Information Systems (GIS), which combines database technology with geographic attributes. GIS technology allows integration of multiple data sources based on geography, and offers the capability of graphical representation for solutions. A subset of GIS, Geographic Information Systems for Transportation (GIS-T) is particularly suited to solving the inherently spatial problems associated with the intermodal freight industry.

GIS-T extends basic GIS capabilities into networks and associated transportation problems. Several GIS-T packages are produced, with all including routing capabilities, and some even allowing full travel modeling. Crucial to any application of this technology are the issues of network creation and data conflation. Network creation refers to the proper modeling of decision rules and representation of paths inherent in the actual system. Data conflation is the process of attaching attributes to corresponding network segments in physical space.

This research successfully applies GIS-T to the intermodal freight industry. Specifically, a network capable of usage to analyze containerized freight movements has been developed: integrating rail, ocean, inland waterway, and truck modes with transfer facilities into a single, cohesive whole. The intermodal freight industry, with its multiple modes, complex routing rules, and limited transfer points is a challenging application for network creation.

Crucial issues in creation of this product included: establishment of a theoretical basis, development of project goals, acquisition and application of appropriate data,

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creation of a network representative of the routes available for containerized freight, and development and testing of suitable applications.

The first stage within the project was to examine current research and the state of the art for both intermodal freight and GIS-T. This was done to establish a basis for the project. It was desirable to examine previous work to determine what lessons could be applied, and to ensure that the body of existing work would be expanded through his endeavor. Through his exercise GIS capabilities and limitations were also established. Based upon this analysis, it was determined that usage of GIS as a tool for routing applications was well established, that single mode freight analysis using GIS was common, and that GIS usage for graphical representation was well established. Therefore, a large-scale project demonstrating GIS capabilities applied to the multiple modes would best build upon the existing body of work. ArcView GIS was selected as the project platform as it is widely available, user-friendly, and the necessary tools are available in the Network Analyst extension.

After determining the state of the art, project goals were established. The goals were to demonstrate feasibility of GIS for analysis of intermodal freight shipments, to accurately characterize the freight network relevant to Texas shippers, and to provide a platform for future research and analysis.

To support any research effort, data requirements must first be determined and a methodology developed for acquisition and processing. This stage was a significant part of the effort required to bring this project to fruition. The most important lesson learned within this effort is that determination of data needs and data acquisition should begin early. Much of the geographic data required was readily available, with primary sources being the Texas Department of Transportation (TxDOT), and the National Transportation Atlas Database (NTAD). Gathering attribute data describing these geographic points was a far more difficult task. Both public and private entities were reluctant to divulge data considered proprietary. Some data were available from public sources such as the NTAD. Roadway characteristics were determined using a previously obtained TxDOT file. Rail speeds were inferred from published schedules. The most problematic task was establishing cost and time for rail and ship routes, as these are highly competitive industries with constantly changing service patterns and cost structures. To solve this dilemma, industry averages were applied. Finally, the acquired data was processed for implementation within GIS. This processing converted multiple data sources into a single data structure with consistent geographic, distance, and time units.

The completed data were used to develop a GIS-based network capable of meeting project goals. Each individual modal network was merged, with each class I railroad treated as a separate mode. Several techniques were identified within the review stage, and were applied to model the decision rules inherent within the actual intermodal freight network. These methods included planar separation, turn penalties, and dummy links. Planar separation, creating an artificial elevation such as exists at an overpass, was applied wherever routes intersected and interlining was not permissible. Large transfer facilities were modeled as single points using a turntable within ArcView to set turn prohibitions and turn penalties as proxies for intermodal transfer costs. Dummy links were added to augment the established geographic network and to simulate modal transfers at two mode facilities. The completed network is shown next page, Figure A.

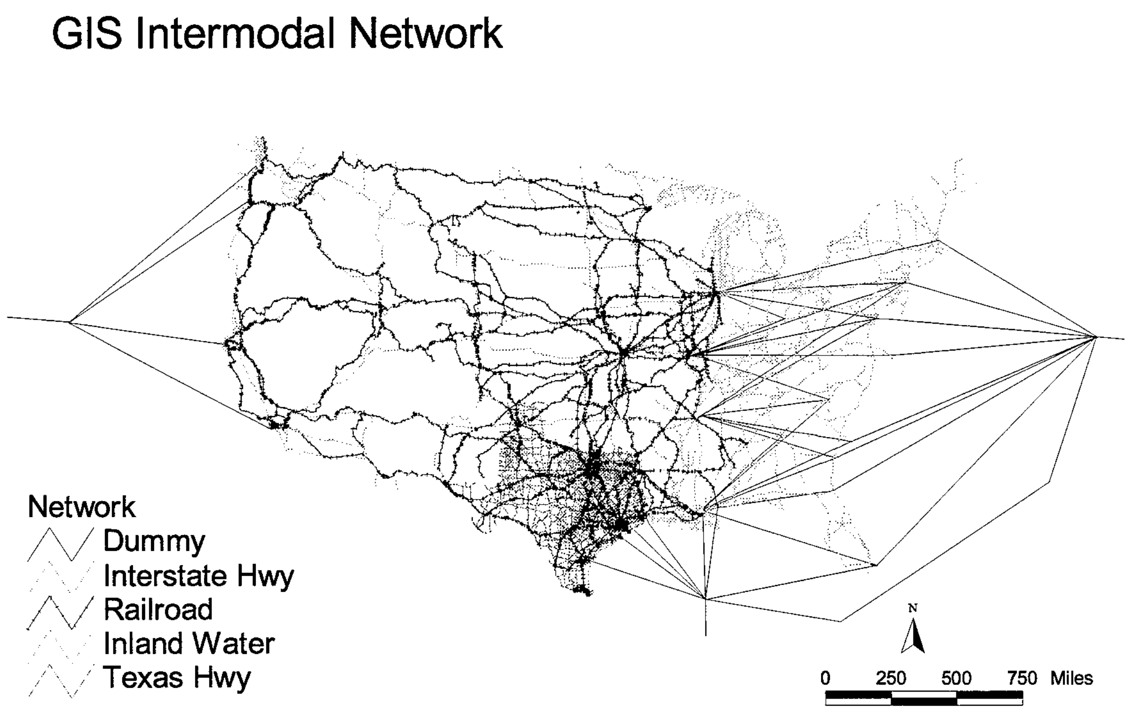

Figure A GIS Intermodal Network

Completion of the intermodal network allowed for several test analyses using ArcView's network analysis capabilities. First, usage of GIS to determine market areas was undertaken, with examination of a potential new rail-truck intermodal facility at Odessa, Tx. Through GIS, areas within three hours of the potential site, and the service areas of competing sites were graphically displayed. In addition, GIS was used as a data integrator, with census data applied to the service area of the Odessa facility to determine enclosed population. A portion of this analysis is displayed in Figure B, next page.

A second analysis was undertaken to determine least cost routing to ports for a shipper in San Angelo. ArcView quickly identified both least cost and least time routes. Least time routes are shown, Figure C, next page. The routes and ports are easily identified, demonstrating the user-friendliness of a GIS representation.

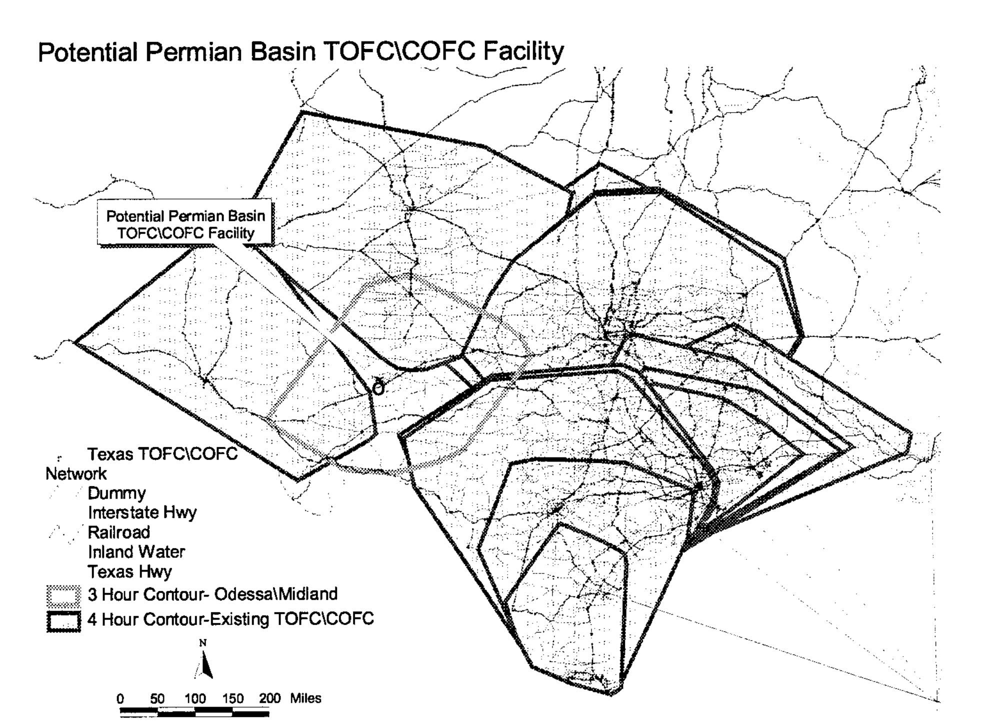

Figure B Potential Permian Basin COFC\TOFC Facility

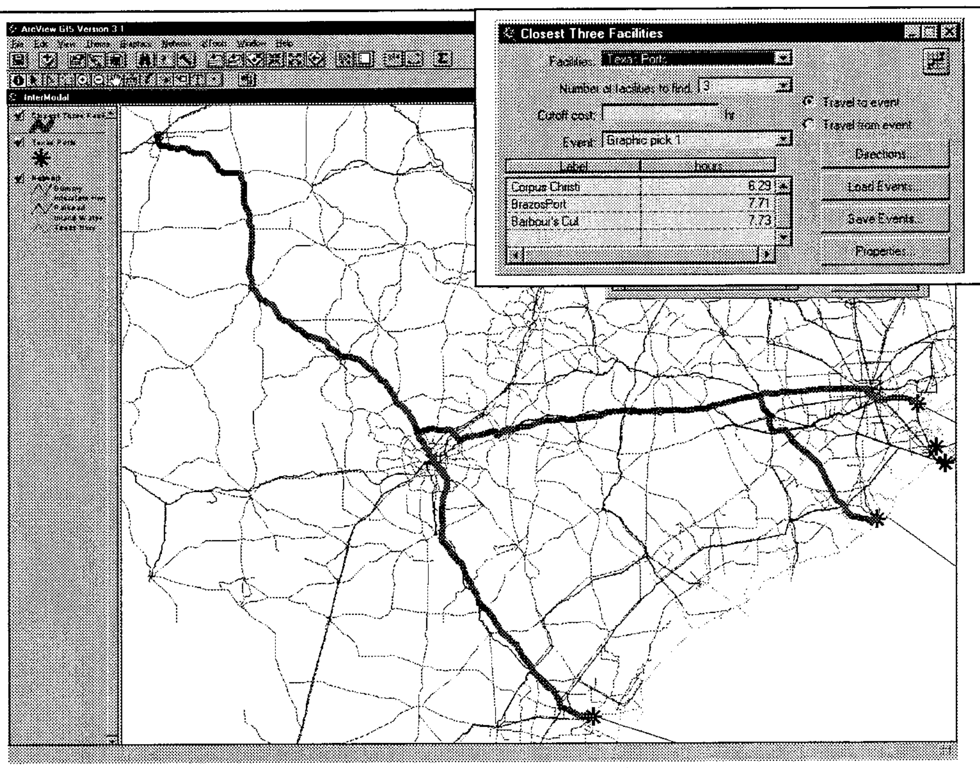

Figure C Closest Facility Analysis For San Angelo

The final analysis undertaken to demonstrate GIS capability for intermodal freight was a series of questions related to construction of a new mega-ship facility at Texas City. This set of analyses fully demonstrates GIS capabilities and the possibilities for this application in particular. First, market areas for East Coast ports were developed and compared with a hypothetical Texas City port. This exercise was repeated with reduced costs associated with terminal improvements, and at two different inventory carrying costs. In addition the probability of shifting land-bridge service, currently utilizing Newark and Los Angeles, was examined. Results showed that a mega-ship terminal in Texas City would have substantial impacts, drawing most freight bound for the Western U.S. and land-bridge services. A sample analysis showing service areas with a Texas City Port and differing inventory carrying costs is shown in Figure D.

Future usage of this research is envisioned in solving problems in routing, market area analysis, and examination of policy impacts. The demonstrated analyses hold to these problem classes. However the basic process can be applied to a wide variety of questions relevant to the intermodal industry.

Results from this research efforts demonstrate feasibility of GIS to model intermodal freight transportation. A comprehensive network accurately depicting movement rules and costs was developed, allowing a rich set of analyses. This network was successfully applied to develop least cost routes, determine market area and market characteristics, test the effects of a new facility, and examine the impact of carrying costs for high value freight on route choice. The final product represents a powerful, easily utilized tool that will provide an excellent platform for industrial users, policy applications, and future research efforts.

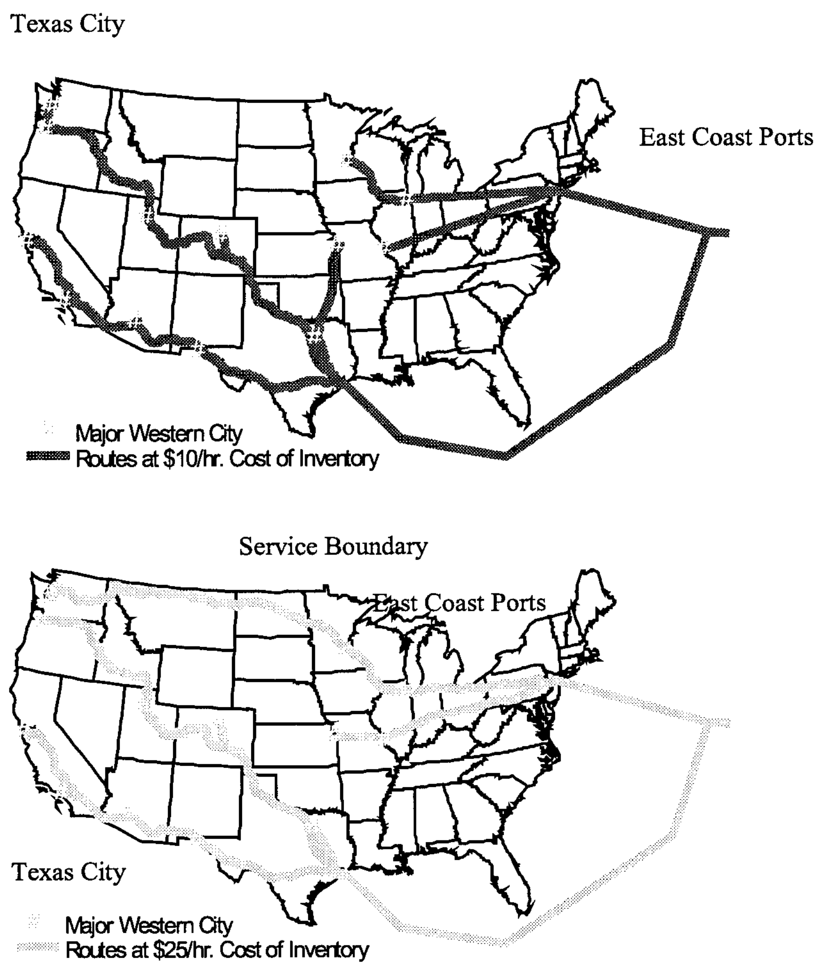

Figure D Service Area for Texas City Mega-Ship Facility

ABSTRACT

The purpose of this report is to demonstrate usage of Geographical Information Systems (GIS) for analyzing intermodal freight networks. A complete GIS network, focused on the state of Texas, is developed and used to examine impacts of price, time, location, and policy on shipper routing.

This process begins with an exploration of existing GIS applications, and state of the practice within the intermodal freight industry. This information provides a framework for building a technically feasible and relevant application. Data acquisition and processing techniques for both geographic and attribute data are considered. Relevant processes for creation of a GIS network and data conflation are identified and demonstrated. These techniques are used to create a network modeling the complex interactions and transfer rules amongst modes. Finally, several case studies are developed using the completed network to exhibit the power of GIS applied to intermodal freight. The report concludes with a summary, and observations to assist others attempting to build upon these results.

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CHAPTER 1: INTRODUCTION AND OVERVIEW

The freight transportation industry has experienced great change in the past two decades, a growing component of this being a shift to intermodal freight transportation. Changing technology, new business practices, reduced regulation, increased roadway congestion, vastly higher international trade levels, and increasing global systems standardization have worked together to make intermodal freight transportation a crucial part of the global economy.

In addition to vast changes in shipping patterns, new operations research and logistics techniques have exploded concurrently with advancing computer technology. One new technology in the planning arena is Geographic Information Systems (GIS), which allows analysis of spatial data. This technology is a natural match for the inherently spatial problems associated with transportation, and is referred to as GIS-T in this application.

This research effort aims to apply GIS-T to the problem of intermodal freight and develop a new tool for freight network analysis. Intermodal in the context of this research refers to containerized freight. The state of Texas is used as a test case. This chapter will define the issues and technologies related to the intermodal industry, and examine the fundamentals of GIS-T as applied to freight transportation, and state project goals and methodology.

1.1 INTERMODAL INDUSTRY OVERVIEW

The intermodal freight industry is represented by a broad range of modes, with vastly different cost structures and performance functions. These services are typically analyzed in terms of cost, time, reliability, and potential damage/theft of goods. By definition, intermodal freight transportation includes at least two of these modes. Intermodalism is the concept of efficiently utilizing multiple modes to optimize product delivery. Intermodal freight is justified when fully allocated savings from switching modes exceed transfer costs. This research examines barges, ocean-going ships, trucks, and rail transportation, focusing on containerized freight.

Growth in intermodal transportation has been stout. Volume via intermodal rail increased from 3.1 million containers and trailers in 1980 to 8.7 million in 1997, with containers gaining a disproportionate amount of this growth in volume[1]. Intermodal shipments account for 18% of U.S. rail revenues[2]. Containerized traffic grew similarly for container ships, rising from 10 million to 18 million containers between 1983 and 1994[3].

Transfer costs, expressed in terms of reliability, time and monetary cost, frequently represent the limiting factor in intermodal utilization. Handling costs at rail intermodal are around $150[4] per container, with port facilities higher. The savings from switching modes must exceed the costs involved in changing modes.

Key to intermodalism and inherent in a transfer between modes is coordination amongst multiple freight transportation providers. A shipment from Asia to the U.S. East coast will likely have 8 different responsible shippers; a truck firm in Asia, a port agency in Asia, a shipping firm for the cross Pacific trip, a port agency on the U.S. West coast, a western U.S. railroad, an Eastern U.S. railroad, and a trucking firm for final delivery. All of these transportation firms must coordinate to insure that connections are made, and that the delivery is properly tracked. In addition each of these transfers incurs additional cost. This process is sufficiently complex that an entire business class, Intermodal Marketing Companies (IMC's), has developed to assist firms using intermodal freight shipments[5]. IMC's account for 42% of intermodal revenue[6]. These firms serve as the shipper representative, tracking deliveries and letting contracts for the multiple modes and transfers required.

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[1] Muller, Gerhardt Intermodal Freight Transportation, 4th Edition, Eno Transportation Foundation Washington, D.C. 1999 pg. 89
[2] Muller 1999 pg. 66
[3] Cambridge Systematics Inc. Intermodal Freight Overview Volume II, FHWA_US DOT Washington , D.C. 1995 pg. 1-7
[4] Cambridge Systematics Inc. Intermodal Freight Overview Volume I, FHWA_US DOT Washington , D.C. 1995 pg. 1-17
[5] Muller,1999, pg. 211
[6] Muller 1999, pg. 213

1.1.1 Regulatory Changes

In the past two decades, the U.S. transportation business has been significantly impacted by reduced regulation. Specifically, the Motor Carrier Act and Staggers Rail Act of 1980[7], and the Shipping Act of 1984[8], affected truck, rail, and water modes, respectively. These acts substantially de-regulated each of these industries. These changes eliminated requirements that arose in the age of rail monopolies and dominance. They allowed for direct negotiation on rates amongst shippers, and removed requirements for fixed rates. This opened up new policy questions, and tended to expedite consolidation of services, and partnerships amongst shippers.

1.1.2 Containerization

The most important trend in the intermodal industry has been a switch to containerization. The progenitor of today's service was SeaLand Corp, founded in 1956 by Malcolm McLean[9] to provide transport of containers via ship. Since this beginning, trailers have been replaced by standardized containers with fixed dimensions and attachment points. Most containers are 8' wide and 8 1/2 feet tall. Lengths vary from 20' to 53', with 20' and 40' containers the most common[10]. The 48' and 53'containers are products of U.S. truck regulations, and are used primarily in domestic transport[11]. The 20 foot container is the basis for the industry standard unit of capacity, the Twenty-foot Equivalent Unit (TEU). One recent change has been a shift to "high-cube" containers with a height of 9.5 feet[12].

Between 1988 and 1993 on U.S. railroads, Trailer On Flatcar(TOFC) volumes were stagnant while containerized traffic grew from 2.3 million to 3.7 million containers. This growth of containerization is a product of reduced handling costs at transfer facilities, reduced theft due to the nature of a container as a sealed box, and the possibility

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[7] Chadwin, Mark Ocean Container Transport: An Operational Perspective, Taylor & Francis New York 1996 Pg. 103
[8] Chadwin, pg. 1
[9] Chadwin, pg. 1
[10] Chadwin, pg. 24
[11] Cambridge Systematics, Volume II pg. 1-3
[12] TRB Policy Options for Intermodal Freight Transportation National Academy Press Washington, D.C. 1998 Pg. 58

of standardized equipment for multiple commodities. A standardized package allows vastly more efficient processes and better equipment utilization.

1.1.3 Business Practices

Changing business practices have radically increased the demand for containerized intermodal shipments.

International trade has increased exponentially, now representing 10% of U.S. GNP[13]. This traffic often requires a combination of air, water, truck, and rail modes.

Inventory techniques have also changed dramatically, with a shift to just in time (JIT) delivery, and now exactly on time delivery. This has created a demand for high reliability and frequent small deliveries. These new practices have spawned a new field, Materials Resource Planning (MRP)[14], devoted to optimizing inventory and delivery schedules.. The transportation industry is now a moving warehouse, with goods delivery often delayed by unavailability of storage space, and minimal slack inventory in case of delays.

An important consideration for freight travel, and intermodal travel in particular is the concept of backhauls. The possibility of a return load (backhaul) greatly increases the profitability and cost structure of a given shipment. One example of backhauls affecting rate is higher rates to the U.S. from Asia compared with the reverse move due to the trade imbalance along this route. Rates in 1997 were over $150 less per TEU when travelling from the U.S. to Asia. As business patterns change, this variable is affected. The directionality in U.S.-Asia rates was much higher in late 1995 at almost $300, representing a 30% higher rate in the primary direction.

1.1.4 Rail Technology and Practice

Rail transportation of containerized goods has evolved to handle the increased demand for this service. There are three primary means of intermodal rail transportation. First is Container on Flatcar (COFC), directly attaching a container onto a rail flatcar. An important variant of this service is double-stack COFC, which places containers two high

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[13] TRB 1998. pg. 39

[14] Eno Transportation Foundation Intermodal Freight Transport in Europe and the United States, Eno Transportation Foundation, Lansdowne, Va. 1998 pg. 47

on lowered flatcars. This technique requires approximately twenty feet of clearance form the top of the rail. This reduces friction from both aerodynamic resistance and, by reducing the number of bogies, rolling resistance. It also allows for more containers given a fixed train length, reducing average labor costs, and increasing the net to tare ratio[15]. This is important as train lengths are often constrained by siding length and grade crossing delay. Most western railroads can accommodate these trains, but eastern railroads frequently require costly bridge re-building and alteration to the vertical profile of the tracks. Costs by double-stack are estimated to average between 25% (Mercer Management estimate)[16] and 35% (US DOT)[17] lower than for single stack service. An addition technology is spine cars[18]; lightweight, articulated, single stack cars for containers that reduce weight and jarring of contents. Second, for truck to rail shipments, TOFC, Trailer on flatcar technology can be used. A slightly modified truck trailer is attached to a flatcar, allowing fast, efficient transfer between these modes. A final alternative for road and rail intermodal transport is use of Road-Railer, wherein a trailer has both rail bogies and road-going axles, allowing minimal terminal facilities.

Rail industry practices have also changed with the increase in intermodal traffic and de-regulation. In 1990, intermodal market share in the U.S. for non-bulk goods and distances greater than 500 miles was 21.4%. Service in the U.S. has become concentrated in key markets, as the number of ramps dropped from over 1500 in 1975 to 230 in 1992[19]. Carriers have responded to demand with frequent intermodal trains from ports and between key domestic markets. Products such as port to port cross-continental "land-bridge" rail transport serving shipments between Europe and Asia, and daily, fixed schedule, double stack trains have been introduced. Intermodal trains have become "hot loads" given priority over other shipments, with track improved to allow higher speeds.

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[15] USDOT Double Stack Container Systems: Implications for U.S. Railroads and Ports, USDOT Washington D.C. 1990 pg. 11
[16] Carini and Figliozzi, Application of Technology in Intermodal Rail, University of Austin at Texas, 1997 pg. 16
[17] Cambridge Systematics Volume I pg. 1-17
[18] US DOT 1990, pg. 1
[19] Cambridge Systematics Volume II pg. 1-8

Railroads and government have spent large sums raising clearances to provide double-stack service.

It is generally acknowledged that minimum practical distances exist for intermodal shipments. Authors varied in their assessments of the minimal practical distance, with estimates for truck-rail-truck intermodal shipments ranging from 540[20] to 800 miles[21]. It should be noted that this distance is less for ship-rail-truck intermodal delivery, as it only adds one additional transfer. Some shippers have taken advantage of this reality by having inland terminals, where containers are off-loaded onto unit trains from container ships. These trains proceed to a location more central than the port of call where they are then processed for distribution.

1.1.5 Shipping Technology and Practice

Shipping technology has been driven by size. Larger ships require less labor, cost less to build, and provide greater fuel economy on a per TEU basis. In the last two decades, container ships have evolved from Panamax ships optimized to fit into the Panama canal, carrying 4000 TEU's, to new megaships requiring 45 to 50 feet of draft and holding over 6,000 TEU's. Table 1.1 demonstrates this evolution. With increased size, the required investment in terminal equipment and creation and maintenance of sufficient draft has also grown. Costs for a single crane capable of serving Post-Panamax vessels are $5-8 million[22], a substantial investment. In addition, as of 1996, only 7 U.S. ports have drafts over 45 feet[23], indicating that most U.S. ports will require additional dredging to accommodate mega-ships.

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[20] US DOT 1990 pg. i
[21] Eno pg. 51
[22] Muller 1999 pg. 231
[23] American Association of Port Authorities, Seaports of the America's Alexandria, Va. 1996

Table 1.1 Containership Generations

Generation	Type	Capacity	Length	Draft
1st	Converted Dry Cargo Vessel	1000 TEU	630 ft	variable
2nd	Converted Oil Tanker	2000 TEU	700 ft	variable
3rd	Cellular (Panamax)	4000 TEU	950 ft	42 ft
4th	Post-Panamax	5000 TEU	1,000 ft	45 ft
5th	Megaship	6000 TEU	1,100 ft	50 ft

Source: Vickerman Zachary Miller

In addition to larger vessels, faster vessels are being developed. FastShip Atlantic, Inc. is preparing to launch a new service from Philadelphia to Bordeaux using ships capable of 45 knots, versus 25 knots for a conventional vessel[24]. This service will bridge the gap between existing ship and air services.

Finally, Roll On, Roll Off (RO-RO) systems provide another alternative for intermodal transport, with containers capable of being rolled off of vessels. FastShip, Inc. is planning a variant of this service[25], with several containers packed on a movable platform to facilitate off-loading. This is predicted to allow the ships to have a four hour turnaround time.

A second water mode is barges. This is one component of the U.S. intermodal system generally considered underutilized given its potential[26]. Current usage is limited by a paucity of facilities and routes operated. However, barge service has great potential as it is most cost effective. A hypothetical shipment from Philadelphia to Jacksonville might cost $3800 by truck, $2000 by intermodal rail, and only $1,000 by barge[27].

1.1.6 Truck Technology and Practice

The basic physical technology involved in transport by truck has experienced little change in the past 20 years. However, ITS and changing business practices have changed how the trucking industry operates.

[24] Eno pg. 53
[25] Eno pg. 53
[26] TRB 1998 pg. 63
[27] Baldwin, Tom Journal of Commerce 3/26/98

First, a new class of firm, less-than-load (LTL) shippers has emerged in the trucking industry[28], with firms such as UPS, Yellow Freight, Consolidated Freightways, and Roadway Express providing this service. These firms have established break-bulk terminals, operating as hubs in a manner similar to overnight air transportation. These firms are a substantial source of intermodal traffic. UPS alone accounts for 10% of intermodal rail revenues[29].

Additionally, since the 1990's a shortage of drivers has developed[30]. This has raised labor costs and given drivers greater leverage in negotiating work rules. The result has been higher costs, partially offset by greater fuel economy. Also, driver preference for fewer days away from home has resulted in a desire to reduce the length of hauls; a boon for intermodalism.

1.1.7 Terminal Technology and Practice

Concurrent with changes in ship, rail, and truck technology, transfer facility design has also evolved dramatically to meet current demands. The basic structure of both ports and rail/truck transfer locations are similar. In both cases, large cranes, or similar equipment is used to offload containers from the incoming train or ship. Containers are then transferred onto a chassis and either placed directly on a waiting outbound truck or moved to storage. Containers are usually stacked, with most facilities stacking loaded containers three high, with empties often stacked to five containers height[31]. The container remains in the storage facility until it is picked up. This process is reversed for outbound shipments. Trucks arrive at the gate to the terminal facility and are instructed on proper procedure. Documentation is checked at the gate to the yard for both entering and exiting loads. Depending on facility, the truck may pick up or drop off its own container or a yard vehicle may make movements within the yard. This time until pick-up is highly variable, with a mean value of 2.3 days, and a standard deviation of 1.8

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[28] Muller 1999 pg. 103
[29] Norris, Bahar Intermodal Freight: An Industry Overview FHWA Washington D.C. 1994 pg. 20
[30] Frazier, Clark and Aeppli, Andreas Analysis of Intermodal Terminal Highway Access to Economic Activity Centers Transportation Research Circular 459 TRB Washington, D.C. 1996 pgs. 42-43.
[31] Muller 1999 pg 234-236

days[32]. A firm using JIT delivery may have limited on-site storage capacity, therefore if a shipment arrives before it is needed the terminal facility may function as a warehouse.

Rail-truck intermodal facilities typically use either side lifts or overhead cranes to load and off-load containers or trailers. Higher volume facilities tend to use overhead cranes rather than side lifts, saving approximately forty seconds per container[33]. One exception to this are new technologies such as Road-Railer which can be coupled, uncoupled, and moved with a normal tractor. The number and type of cranes determines throughput when a train arrives and is off-loaded. This is an important point as time-sensitive deliveries can be delayed if equipment is insufficient. The time required for a truck to pick up a container is also crucial. Current estimates of overall truck operating costs are on the order of $40 per hour and typical times in terminal range from 30 to 45 minutes [34]. However, 90 minute access times are not uncommon.

Port facilities are similar to rail in concept. However, the concept of time as money pervades even more than for rail. The enormous capital outlays for current intermodal vessels necessitate high utilization. A ship in port is not earning money. A typical container vessel calls at a fixed circuit of ports. By reducing time at each port, faster, more frequent service can be provided, additional ports can be added, or fewer vessels can be used to service the same demand. Each of these options represents the possibility of additional profit.

Throughput at ports is typically determined by speed, number of cranes, and hours of operation. The cranes must also be sufficient to span the vessel. Clearly, the tendency towards larger ships drives crane types. In 1997, 77% of cranes were capable of serving Panamax vessels, while 83% of crane orders for 1998 delivery were for post-Panamax capable cranes[35]. Typical throughput is 60 lifts per hour[36]. Post-Panamax cranes, at 100' height and 156' reach cost $5-8 million[37], representing a substantial investment.

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[32] Nierat, Patrick Market Area Of Rail-Truck Terminals: Pertinence Of The Spatial Theory Transportation Research Part A Vol: 31 No: 2 TRB Washington, D.C. pg. 99
[33] Anderson, Kevin Evaluating Intermodal Freight Terminals: A Framework For Government Participation University of Texas at Austin, Austin Tx. 1998 pg. 33
[34] Kelley, Ken Equipment Location Systems: Providing Intermodal Terminals with Accurate Information Transportation Research Circular 459 TRB Washington, D.C. 1996 pg. 212
[35] Eno, pg. 63

When a ship calls at port, the top priority is efficient loading/off-loading of the vessel. Dock space is often limited, necessitating swift removal of containers from the dock to remote storage areas. This process must be carefully weighed against landside costs, estimated at 60% of an ocean carriers total cost[38].

A crucial component of terminal design is physical location, and access. In 1996, Sea-land and Maher alone generated 6,000 truck trips per day at the Port of Elizabeth[39]. To be competitive terminals must offer easy access to markets and be geographically situated to minimize costs amongst all modes. Classical micro-economics provides a suitable analogy in the Weber Diagram which considers shipping costs of raw goods, costs to deliver finished goods, and relative flows to determine an optimal location. As an example, a food company requiring wheat from the Midwest, fruit from the Caribbean, and desiring proximity to a major metropolitan area might choose to locate in Houston. This would minimize total transportation costs of moving raw goods to the factory and finished goods from factory to market.

Mega-ships create a new challenge. Given the large investment and relatively deep water required to serve these new ships, only a handful of ports can be developed. Therefore, location of these facilities must be carefully planned.

1.1.8 ITS Advances

Intelligent Transportation Systems, ITS, represents the fusion of technology into business processes. Within intermodal transportation, ITS is an established entity. Specifically, Automatic Vehicle Identification (AVI)and Electronic Data Interchange(EDI) have become industry norms[40]. The American Association of Railroads (AAR) manages a system used by U.S. Class I railroads implemented with ITS derived electronic tags, representing an investment of over $300 million dollars and over 1.5 million railcars.[41]. These tags are also used to monitor cars, track containers in terminals

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[36] Eno, pg. 63
[37] Muller 1999 pg.231
[38] Norris pg. 38
[39] Aylward, Anne. Intelligent Transportation Systems and Intermodal Freight US DOT Washington, D.C. 1996 pg. 33
[40] Eno, pg. 51
[41] Muller 1999 pg. 296

and en route, and plan unloading schedules. Ships often send data on their contents, including location, weight, size and destination of all containers, before arriving at port so that a suitable unloading plan can be developed[42]. Global Position Systems (GPS) is an additional ITS technology being applied to intermodal freight. In large freight yards, tracking location of containers is often a difficult task, GPS allows entry of an exact location as containers are placed.

1.2 GIS TECHNOLOGY

Geographic Information Systems (GIS) are a product of increased computing power, improved database technology, and strengthened Computer Aided Design (CAD) capabilities. GIS represents the fusion of these technologies into one product designed to display, query, and manage, and manipulate spatial data. Popular products include ARC/INFO, ArcView, Intergraph, MGE MDS, TransCAD, Atlas, and MapInfo. It should be noted that of these programs, both TransCAD and ARC/INFO allow gravity models, with TransCAD having full four-step UTPS modeling capability. As with most software, GIS programs vary greatly, with most researchers noting a trade-off between functionality and user-friendliness[43].

1.2.1 GIS Building Blocks

GIS Technology, as with most computer software, has advanced dramatically. Their are four basic building blocks within GIS. Data is associated with one of these blocks. First is points, single locations that describe locations such as stations. Second is arcs: lines which describe spatial paths. Third is polygons: collections of lines enclosing an area in space. The final building block is raster GIS, which creates a matrix corresponding to a user defined spatial grid. Each cell represents a square in geographic space and is given a single value, such as height in a digital elevation model.

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[42] Muller 1999 pg 289

[43] Sutton, John The Role of GIS in Regional Transportation Planning Transportation Research Record #1518 TRB Washington, D.C. 1996 pgs. 25-31

1.2.2 Application of GIS

In approaching GIS, two decisions must be made: how to use GIS technology, and suitability of analysis via GIS. Traditionally, GIS has been applied to two-dimensional analysis on strictly spatial data. Such applications include traditional urban planning and mapping, particularly demographic data, marketing, and real estate analysis. In addition, usage in natural sciences and water and environmental engineering has become the norm. Examples of such activities include a GIS representation of point and non-point source pollution in the Chesapeake bay area by the EPA. Also being modeled are geological systems to improve mining operations, forestry management, and industrial contamination.

One common link in the above problems is that they all involve systems where decisions and conditions can be treated as static. The current condition of a system is recorded using spatial data and then used for analysis. This represents an ideal GIS application.

1.2.3 Application of GIS-T

Compared to traditional GIS applications, GIS for Transportation (GIS-T) tends to be more complex, with network linkages the key to creating a powerful analysis tool. Thus, network analysis and network development are at the leading edge of current GIS-T technology.

Most GIS programs allow user defined impedance as an input to a routing algorithm. A network topography, with rules as allowed by the underlying software is established using these impedance measures, forming the basis for analysis

1.2.4 GIS-T Network Development

Traditionally, three methods have been used to build a network for GIS analysis[44]. First is hard coding, requiring the user to manually input all links and impedance values within the system to be modeled. This method is as accurate as the user input, but requires much tedious data entry. Second is "warm linkage" which uses a geocoded network as its basis. This is generally acceptable, except where multiple independent

[44] Sutton

processes exist in the same space. Specifically, this might occur where two bus routes and cars share the same geographic space in a multi-modal network. Since there is no geographic distinction between these modes, GIS would be unable to consider them independently if modeled using a "warm linkage". Both of the above methodologies use arcs and nodes as basic units. A third method is "hot linkage" whereby the user codes a connection between the GIS, an external database, and external network analysis software. In this model the GIS only contributes the network geography. "Hot linkage" often uses dynamic segmentation to break links into multiple user defined segments. Examples of programs used to create a "hot linkage" include TP>ARC and M2ARC which link TranPlan and EMME/2 with ARC/INFO.

Dynamic segmentation is an important feature recently implemented within several GIS packages. Traditionally, data within a GIS system has been referenced by Euclidean geometry, i.e. a defined latitude and longitude. However, "dynamic segmentation uses GIS-defined routes or virtual networks that overlay the underlying street network and allow the attribute data to be defined more precisely than they are by the static link-node model.[45]" The underlying arcs are used to form routes, and units of measure and a beginning datum are specified for each route. Known data points are specified and used to properly calibrate distance within the GIS to actual measured distance. This calibration is required to account for the two-dimensionality and simplification inherent in GIS representation of physical features. Attribute data is attached based on calibrated distance and the user defined offset or beginning distance.

Dynamic segmentation is particularly useful for transportation data, as mileposts are the traditional means to enter location along transportation routes such as railroads and highways. In addition dynamic segmentation allows multiple routes on a single arc, freeing users from strict arc-node topography. Rather than assigning data to links, data is attached to routes. Dynamic segmentation allows for easier network maintenance, as attributes are often static over several links, allowing on entry for multiple links.

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[45] Sutton

1.2.5 Network Analysis

After completion of a suitable network, analysis can commence. This is an area where GIS-T is still developing as a tool. Transportation planning yields a wide variety of opportunities and challenges. There have been many solutions developed within GIS-T, such as four-step modeling (network loading and allocation), optimal routing algorithms, travel time contours, and closest facility analysis. However, transportation planners still must create custom applications for many problems, using either a GIS scripting language or a linked external application.

1.3 CURRENT RESEARCH AND STATE OF THE ART

This research effort attempts to combine aspects of GIS-T with intermodal analysis. Section 1.3, examining these efforts is divided into four parts (1.3.1-1.3.4). The first section delves into pertinent freight transportation research, focusing on data acquisition and modeling (1.3.1). Second, efforts combining these two fields are introduced and discussed (1.3.2 and 1.3.3). Finally, based on the preceding sections, the benefits to GIS based freight analysis are outlined (1.3.4).

1.3.1 Intermodal Freight Research

Intermodal freight transportation is a complex problem. Multiple modes and commodities must be considered. Each of these modes has a different, constantly shifting, cost structure. From an operations research viewpoint, each commodity and each shipper have different objective functions. Shippers base route and modal decisions on multiple criterion such as cost, time, reliability, and damage/theft of contents. Basic data is often difficult to obtain, further complicating calibration and formulation of applicable models.

Modeling of freight movement as it currently exists began in the 1960's[46]. One such early model was the Harvard-Brookings Model, developed in1966. This model used simple economic and spatial factors as the basis for assignment. A second early model was by Guelat, using cost functions based on commodity and traditional link based analysis. Both of these models were hindered by massive data needs and high model complexity.

The traditional method of modeling personal transportation, the Urban Transportation Planning System (UTPS), often provides a basis for freight analysis. This model consists of four steps, calculation of trip frequency (trip generation), assignment of origins and destinations (trip distribution), determination of mode choice (modal split), and routing within the model network (trip assignment). The primary distinctions when applying this model to freight analysis is the greater complexity in mode choice, a decreased number of possible routes relative to passenger travel, and the need to apply differing cost functions. Several examples of such applications are presented in section 1.3.2.

Pertinent current research efforts involve modeling of goods movement, data acquisition, and spatial analysis. The models usually combine some form of UTPS and commodity based analysis. Typically, the UTPS system is applied with commodity specific modal split, attractiveness and origination equations. These separate models are then layered to produce a complete model[47]. The interconnecting problems associated with a freight model are frequently solved by steps, without benefit of an iterative process[48]. This method has been widely used, recurring multiple times in examined literature. It should be noted that most efforts at modeling truck movements ignore the marginal costs of additional truck travel on travel times[49]due to the relatively slight impact of additional truck travel above existing utilization.

Reginald Souleyrette in A Freight Planning Typology, provides an excellent case study on successful implementation of a freight model[50], including use of GIS as a visualization tool. This work established a framework for creation of an appropriate

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[46] Souleyrette, Reginald, et. al. A Freight Planning Typology Transportation Research Record #1613 TRB Washington D.C. 1998
[47] Nierat, pg. 92
[48] Nierat, pg. 94
[49] Prim, Clyde and Yu, Ping Applying Urban Transportation Modeling Techniques to Model Regional Freight Movement Transportation Research Record #1518 TRB Washington, D.C. 1996 pgs. 22-24
[50] Soulyrette

methodology. The case study examines the meat and farm machinery industries in Iowa. Five steps are identified as crucial to model formulation, summarized below,.

1 - Identify Issues. Determination problem sets to be addressed by the freight model. In the case study, analysis of economic development and flow forecasts were primary goals.
2 - Identify Modes. Establish which modes are relevant in solving model problem set. In the case study, only trucks were considered as they provided the bulk of relevant movement.
3 - Identify Commodity Layers. Examine freight data and determine primary commodities being transported. In Iowa, grain, meat and farm machinery were dominant. Soulyrette chose to focus on the latter two goods.
4 - Identify Analytical Tools and Assess Data Needs. Determine network and GIS tools, and necessary inputs. In the case study O-D data and economic attributes were identified as necessary data. TranPlan and MapInfo were used for analysis.
5 - Identify Data and Develop model. Decide on data sources and perform necessary modeling work. The case study used data from Reebie and Associates. This data was also augmented using population and employment measures. The network was established as state owned roadways. After establishment of the network and appropriate data, TranPlan was used to model the relevant flows.
In preparing this research effort, methods for data collection were also examined.

One of the most comprehensive efforts was undertaken by Nigel Rockliffe analyzing commodity flows in Australia[51]. As in the U.S., data on commodity flows within Australia is severely limited, primarily as much of this information is proprietary. Rockliffe gathered data on tonnage, commodity by Standard Industrial Code (SIC), origin and destination, and mode. The final product is marketed as FreightInfo.

FreightInfo focuses on determining the impact of production processes to estimate commodity flows. He posits that if the ratio of inputs to final product is known, one needs only one of these measures to determine the quantities of both. Therefore, by gathering data on production centers, business to business freight flows can be estimated. Movement of finished goods, usually less proprietary in nature, must then be estimated to complete the process.

Three methods are used for data acquisition. First, shipping firms and producers were interviewed to obtain volumes at various points in the production process. Second, published data where available was gathered. Third, decision rules were used to assign freight flows. Lastly, known flows were used as a basis for movement of finished goods. These efforts demonstrate the complexity associated with modeling multiple modes and commodities. The first step, data acquisition, is often extremely difficult, particularly given budget constraints.

A final problem class is spatial analysis. This approach is exemplified by a recent paper entitled Market Area of Rail-Truck Terminals: Pertinence of the Spatial Theory, authored by Patrick Nierat[52]. This research used explicit cost functions to examine port operations, hauling costs, and spatial density of freight originations and destinations. These functions were defined over geographic space (France) and examined by mode. The goal was to define spatially where intermodal or truck is most competitive. The relevance to this research is as one example of techniques to define market areas and model intermodal costs.

1.3.2 Freight Research using GIS

Use of GIS for analysis of freight flows is a fairly new application. Applications range from data display to full models of freight activity.

The simplest usage of GIS for freight analysis is data display and manipulation. Typically, such programs use "hot linkage" to map answers derived from an external analysis program. One recent example of such an applications is a Commodity

[51] Rockliffe, Nigel et. al. Developing Database Of Nationwide Freight Flows For Australia Transportation Research Record No: 1625 TRB Washington, D.C. 1998
[52] Nierat

Information Management System (CIMS) developed for Wisconsin DOT[53]. TranPlan was used as analysis software, with MSAccess used for data manipulation, and ArcView as a display tool. Data from Reebie and Associates was obtained, and used as the primary basis for analysis. The authors identified three goals; the ability to edit scenarios, scenario modeling capability, and generation of maps and reports. Each of these goals is a strength of GIS usage, and is also applicable to this research effort. This work is one of many establishing GIS as a platform for data integration.

A number of efforts have used applied TransCAD to freight traffic as a GIS modeling solution. Specifically, TransCAD was used for analysis of geographic resolution, and as an assignment tool.

The first case modeled truck travel in Centre County, Pennsylvania[54]. Data on employment and associated SIC code, obtained form the US Census was used as a basis for development of attractions and productions. This was further analyzed in TransCAD to distribute and assign trips. The author noted results within a reasonable margin of error, and that higher resolution had little impact on errors for all but the least significant roads. This is an important result in that it first validates use of GIS as an analysis tool, and second establishes that smaller roads need not be included to ensure accuracy on more important links.

Two cases of usage of TransCAD for assignment are an investigation of freight flows in the I-90/I-94 corridor[55] and assignment of travel in Massachusetts[56]. Both of these research projects focused on truck travel. Both projects focused on truck flows. The Massachusetts research used commodity flows to estimate truck travel. The likelihood of a backhaul and tonnage of supplies in a given truck shipment were factored to produce truck trips. The National Transportation Atlas Database was used as a base

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[53] Yarborough, et. al. Creating a System to Analyze Commodity Flows in Wisconsin Proceedings, GIS-T Symposium March 24-26 AASHTO Washington, D.C. 1997

[54] Marker, John Truck Traffic Prediction Using Quick Response Freight Model Under Different Degrees Of Geographic Resolution: Geographic Information System Application In Pennsylvania Transportation Research Record No: 1625 TRB Washington, D.C. 1998

[55] Elam, Mohammed and Fepke, Edward Application of GIS-T in Freight Data Analysis; A Case Study of I-90/I-94 Corridor Analysis Transportation Research Record No: 1625 TRB Washington, D.C. 1998

[56] Krishnan, V. Highway Freight Flow Assignment In Massachusetts Using Geographic Information Systems Transportation Research Record No: 1625 TRB Washington, D.C. 1998

for the network. Results were generally good with the authors claiming an "average accuracy" of 81%. The second TransCAD analysis, modeling flows in the I-90/I-94 corridor from Washington State to Wisconsin, used TransCAD to determine effects of changing truck size and weight regulations on freight flows. There was some multi-modal analysis, primarily formation of desire lines for rail analysis. Both of these cases demonstrate that GIS is feasible as a full analysis tool. They also point to the complexity of a truly intermodal approach, as neither effort attempted a comprehensive multi-modal model.

1.3.3 GIS Benefits

In the field of intermodal freight transportation, GIS offers several benefits. GIS represents a comprehensive, integrated data storage and analysis tool. Section 1.3.2 outlines multiple research efforts using GIS in this capacity.

GIS offers the possibility of easy analysis by end users. This is done in two ways, creation of custom graphical user interfaces (GUI's) specially suited to any custom application, and custom scripts. Most GIS programs allow customization of their windows toolbar and menus, creating a new GUI. Scripts, such as Avenue in ArcView or GISDK in TransCAD, allow a programmer to define new analysis routines, and create macros from existing program functions. Combined, these tools allow one to automate analysis procedures, allowing a quick learning curve for the end user. The Wisconsin CIMS is an excellent example of this usage as a custom interface was developed for this program.

The possibility of creating visual answers to spatial problems is a powerful benefit of using GIS. Several researchers chose to add GIS as a layer over TranPlan to gain this capability. Decisions are rarely made based on a single factor, and GIS allows users to overlay data from different sources. As an example, a shipper might be interested in both the cost to ship and the local labor market when deciding where to locate a new facility. GIS allows both of these data types to be displayed simultaneously. Visual results are easily understood, and easily compared.

1.4 SUMMARY

This research begins by describing existing conditions, capabilities, and implementation. The industry was examined, with recent technological advances, movement trends, and new business techniques noted. The most relevant changes to note are the increase in containerization, the movement towards larger vessels, changed inventory management such as JIT systems, and the growth in international trade. The capabilities of GIS are examined in concert with recent research in both GIS and freight modeling. Examples of GIS-T (GIS for Transportation) usage are identified, and appropriate techniques are derived from these studies. Understanding the available body of research is necessary to develop goals relevant to the intermodal industry and to ensure technical feasibility within GIS.

Conclusions cannot be derived without an understanding the actual processes. Therefore, an understanding of both the state of GIS software and the state of the freight industry provides a framework for developing project goals and methodology. Chapter 2 builds upon this base and provides a means to harness the power of GIS to analyze intermodal freight.

CHAPTER 2: PROJECT GOALS AND METHODOLOGY

Development of project goals and methodology is a key step in any research effort. This chapter builds upon the established industry state of the art, GIS capabilities analysis, and current research outlined in chapter 1 to produce an appropriate framework for analysis.

2.1 PROJECT GOALS

The development of a GIS-based intermodal analysis tool was driven by three primary goals: to demonstrate feasibility of GIS for analysis of intermodal freight shipments, to accurately characterize the freight network relevant to Texas shippers, and to provide a platform for future research and analysis.

The first goal, demonstration of GIS usage, is an attempt to build upon work such as had been conducted by Southworth[57], et. al. at Oak Ridge National Laboratory (ORNL) in building a framework for intermodal analysis within GIS. It is also intended to build upon single mode commodity flow models and traditional data mapping uses. Given the body of existing work, anything short of a fully operational demonstration would duplicate existing work.

For maximum impact in demonstrating new technology and/or techniques one must solve "real world" problems applicable to end users. This task is best accomplished by considering end users and their needs. For this research effort, possible end users were identified as shippers, logistics managers, planning agencies and researchers. Each of these classes has differing needs that must be considered. Logistics managers and shippers are most interested in information on time, cost and reliability. Planners and researchers desire to perform macroscopic evaluation of system changes and attributes. They require robust analysis capabilities and good data organization, applicable for a wide variety of uses.

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[57] Southworth, Frank Development of Analytical Intermodal Freight Networks For Use Within GIS Oak Ridge National Laboratory Oak Ridge, Tn. 1997

The second goal, to characterize the freight network relevant to Texas shippers is an extension of the first goal. In order to solve actual problems, one must develop a good representation of the appropriate system and its constraints.

In developing a model of the Texas freight network, four criteria were used; accuracy, sufficiency, relevancy, and organization. The following will define these criteria and how they relate to the creation of a GIS application. Following chapters will demonstrate how they shaped this research effort.

Accuracy refers to the extent of correlation between data as entered into the GIS model and actual conditions. In the case of a GIS system, both geographic data and attribute data must be considered. Obviously, it is highly desirable to be as accurate as possible, however this desire must be weighed against both the acquisition costs for better data and the sensitivity to errors within the model. The issue of sensitivity is important in that one must understand the likely impact of erroneous data in order to focus resources on acquiring this data.

Characterizing the system has additional benefits outside of the thrust of this work. The creation of a GIS map and an underlying freight database allows use of GIS mapping; an excellent graphical representation of the existing Texas freight system. Decision-makers can quickly grasp current conditions, an invaluable asset.

Finally, this is an endeavor to create a platform for future research. The intermodal network represents a tool for future policy and business analysis. It is also a pre-requisite to creation of GUI's and custom applications. Specifically, this research allows analysis of location for new facilities, and provides a means to test impacts of changed cost structures. However, future additions are by no means limited to these applications.

2.2 RESEARCH METHODOLOGY

The project started with a literature review and project definition. This was followed by data acquisition, data processing, application development, application testing, and application utilization. Finally, results were summarized and disseminated.

Souleyrette provides a useful methodology for analysis[58], outlined in section 1.3.1. The results of his methodology as applied to this research are summarized below.

1- Identify Issues. An extensive literature review was conducted to identify relevant issues. GIS limitations were noted, and project scope pared accordingly. Based upon this analysis, project goals and criteria were established (Section 1.5). The primary focus of this research was identified as spatial cost allocation and realistic network movement across multiple modes.
2- Identify Modes. Modes selected for analysis include rail, truck, ship, and barge. These represent the normal modes used for containerized freight.
3- Identify Commodity Layers. This research is applicable to all containerized commodities. The nature of containers as a ubiquitous package greatly reduces the importance of the commodity being shipped, especially when only considering assignment as in this work.
4- Identify Analytical Tools and Assess Data Needs. ArcView GIS is the primary analytical tool. Arc/INFO was a secondary tool used to build appropriate networks. The selection of ArcView is a function of the availability of a network analysis extension, and the prevalence of ArcView within multiple institutions. Given likely distribution of the final product, ArcView represented a good compromise of availability, cost, and capabilities. The project goals led to formulation of data needs. Chapter 3 discusses data needs in detail. They consisted of geographic data and performance functions across the various included modes.
5- Identify Data and Develop model. Data is identified in Chapters 3. Chapter 4 further defines this data and demonstrates the processing of this information required to build a working intermodal model. Model development, based upon the data derived in Chapter 4, is examined in Chapter 5. Upon

[58] Souleyrette

establishment of a satisfactory prototype, the application was tested and utilized to solve problems of interest for intermodal freight, Chapter 6.

6-

In addition to the above methodology, an additional step is information dissemination. Any academic research effort should produce documentation of errors, results and processes in order to guide future researchers and further the general body of work in a field.

2.3 SUMMARY

To sum, project goals are to demonstrate feasibility of GIS for analysis of intermodal freight, characterization of the transportation network relevant to Texas-based shippers, and to provide a platform for future research. The methodology to accomplish these goals will involve examination of the existing body of work, analysis of available tools and data, and model development. This is followed by dissemination of results for the benefit of future researchers.

CHAPTER 3: GEOGRAPHIC AND ATTRIBUTE DATA

Central to any Geographic Information Systems (GIS) based system is the underlying geographic and attribute data. GIS ties data together based on location, and these points represent the base map both geographically and structurally with respect to attribute data. Chapter 3 examines acquisition of data to describe an intermodal network both geographically and in terms of attached attributes. Appropriate sources of such information are identified and analyzed for suitability to the purposes of this work.

3.1 DATA NEEDS

Data requirements are vastly different for geographic data versus the associated attributes of geographic features. Geographic features are defined solely by inclusion and spatial bounds, whereas necessary descriptors of these features vary widely according to analysis purpose.

3.1.1 Geographic Data Needs

When assessing geographic data for use within a GIS several criteria must be considered. First is ease of acquisition, particularly cost but also the time involved in negotiating bureaucratic processes. A geographic data set is only useful if it can be obtained. Second, the need for geographic accuracy and completeness must be considered. Third, one must determine compatibility with other, non-geographic, data. Finally, geographic extents must be determined.

An additional concern is the geographic projection of spatial data. Any flat map necessarily distorts the round earth, and GIS systems are no exception. Fortunately, most software easily converts from one projection to another. Therefore, in creating a GIS system, one must choose a projection that minimizes distortion in those areas of greatest interest, and convert all data into this projection. This research used the Texas Department of Transportation (TxDOT), standard projection, shown Table 3.1.

Table 3.1 TxDOT Geographic Projection

TSMS (Texas Statewide Mapping System)	
Projection:	Lambert Conformal Conic
Ellipsoid:	Clarke 1866
Datum:	North American 1927
Central Meridian:	100 degrees west (-100)
Latitude of Origin:	31 degrees & 10 minutes (31.16666667)
Standard Parallel 1:	27 degrees & 25 minutes (27.41666667)
Standard Parallel 2:	34 degrees & 55 minutes (34.91666667)
False Easting:	3,000,000 feet
False Northing:	3,000,000 feet
Unit of Measure:	international foot

Within this research effort, geographic data needs included transportation features and jurisdictional boundaries. In order to build a multi-modal network, the geography of each mode and transfer point was required. Also, jurisdictional features were deemed crucial for both checking errors and providing reference points.

3.1.2 Attribute Data Needs

The first step towards identification of attribute data needs is determination of appropriate performance functions for each mode and for transfer facilities. The goal is to include the primary variables used by shippers when making routing decisions. Two fundamental properties were established as the primary decision variables: cost and time. Two additional components typically considered are reliability and accessibility. Reliability was not included in the final product as it is fairly subjective, and as a product of random processes such as theft, damage, and equipment failure is difficult to calculate. Accessibility, the availability of a mode choice at a particular location, is inherent in the model by use of GIS, and therefore not considered explicitly within model performance functions.

The first mode considered was the truck mode, and associated road network. In order to describe the system, three primary performance measures were desired; distance, off-peak travel time, and peak travel time. From these three items, travel time and travel distance can be estimated. Additionally, truck volumes are useful to describe current utilization for goods movement.

Inclusion of peak and off-peak travel times rather than an average is crucial to accurately describe today's often congested road network. This is especially important in light of the principle of random incidence, as an individual is statistically more likely to travel on roads with high volumes and congestion.

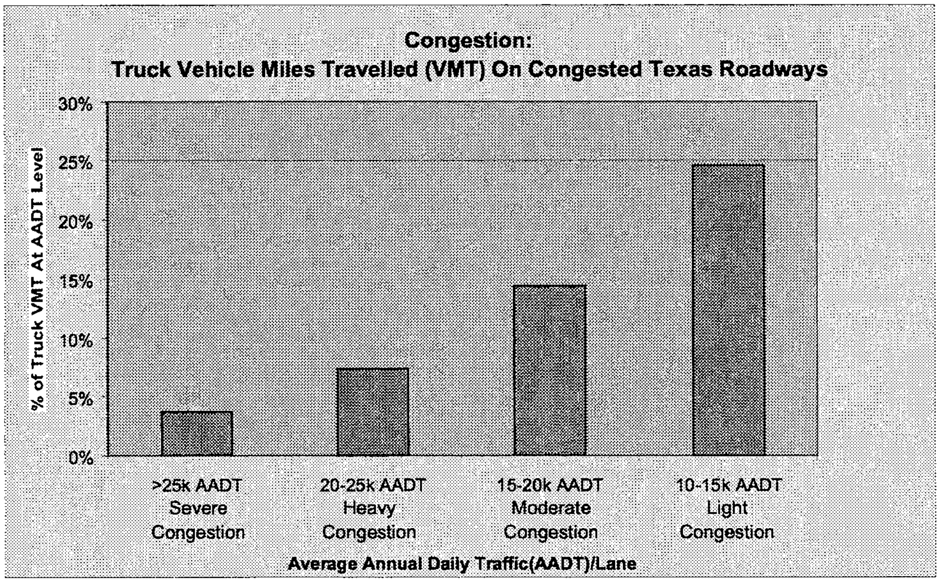
Additionally, firms using extreme Just-in-Time delivery processes have a fairly low tolerance for the variability in travel time associated with congested, chaotic flow conditions. Figure 3.1 demonstrates the extent to which congestion effects truck travel on the Texas road network.

While distance is simple to calculate, direct observation of speed is not possible for each link in a large network. Therefore, to estimate time, performance indicators for speed are needed. Specifically, data on speed limits, Average Annual Daily Traffic (AADT), peaking factors, number of lanes and functional class are required to estimate speed.

Data requirements for the rail network differ substantially from roads due to the very different structure of railroads as private entities, the existence of single track sections, and speed restrictions that vary substantially by train type and location.

Desired data for rail movements include siding lengths, siding intervals, trackage rights, speed limits or average speed, trackage rights, and costs. Further, speed restriction and cost data should be directly applicable to intermodal freight, especially containerized goods.

Water transportation has the fewest data needs for line haul portions. Excluding charges for canal usage, operating costs and time are primarily functions of distance and vessel type . Therefore, per-mile costs and distances are the only required data for this mode.



Source Data: Texas Department of Transportation, 1996

Figure 3.1 Congestion on Texas Roadways

Finally, data needs for transfer facilities must be considered. Specifically, transfer costs and transfer times must be estimated. Cost is relatively straightforward but time is difficult to capture. The first problem arises when one considers the value of shipment reliability. Individual shipments vary greatly in time sensitivity. Second, with the emergence of transportation as warehouse, shipments are often not picked up when first available but are left at the port or yard until needed. The amount to which this occurs is largely dependent on the fee structure for "late pickups" at a given facility. Obviously, this has a large bearing on average time from train arrival to pick-up, and means that average dwell time of a container is not an effective proxy for time required to process a container. A more accurate number for transfer time can be obtained by taking mean time from train arrival to container availability plus truck access time inside the terminal. Therefore, an estimate of this value is desirable to model rail-truck intermodal and port facilities.

While rail-truck intermodal yards operate based on scheduled service, activity at port facilities tends to be random. Therefore, while performance of a rail-truck terminal is relatively uniform, the performance of a port is in large part a function of the number of calls by vessels. This is fairly difficult to simulate in a deterministic model. Modeling the processes involved in this time variation is outside the scope of this work, and therefore no data was required. A second item is data on facility characteristics, as ports vary greatly in the size of ship that can be serviced.

The process of assessing data needs revealed the following requirements. Data is needed for each mode and transfer facility, including two time periods for the truck mode. Within each mode, performance functions to determine time and cost are required. Once this assessment is complete, identification of possible sources and acquisition of data can commence.

3.2 POTENTIAL DATA SOURCES

Three basic data sources were considered; public domain, proprietary, and privately collected information. Each of these types will be examined in the context of accuracy, ease of acquisition and compatibility with other sources.

The first data type, public data, is easiest to obtain. Examples in transportation include data from all types of government involvement, such as traffic volumes, facilities mapping and characterization, land use and demographic data. Often this data is freely disseminated. Unfortunately public data is often limited by privacy requirements. Witness the frequent omission of data in the Census Bureau's County Business Patterns series because only a few firms in a particular county contribute to a particular industry, a classic example of this deficiency. However, public geographic data and data pertaining to individual travel and public facilities such as ports and roads is often excellent.

The second data type, proprietary data, is crucial in describing private facilities. Acquisition of this data is often quite difficult, requiring political savvy and acumen. Private entities such as railroads, private ports and trucking firms are often reluctant to share operational data as they feel it will unnecessarily reveal competitive positions, and might lead to legal difficulties. This data can often be difficult to collect. Requests for assistance are often referred to upper management, as lower ranking employees have little incentive to further research efforts, but bear substantial risks of misuse of disclosed data.

To obtain proprietary data, one must convince entities that fulfillment of one's request will be mutually beneficial. Second, the data holders must be convinced that release of the data will not compromise their competitive position, or that the benefits of cooperation outweigh such risks. Therefore one must carefully prepare an outline of benefits and rebuttals to questions of risk, before approaching data sources.

The third data type, private data, is exemplified by companies such as Reebie & Associates[59], and Nigel Rockliffe's Freightinfo[60] that prepare industry specific data for a substantial fee. This data is frequently used by industry participants and consulting firms, with limits on its distribution. Given budget constraints, and intended public nature of the completed work, this data source was not pursued for this project.

3.3 DATA ACQUISITION

After examination of data requirements and potential sources, the process of data acquisition could occur. Appropriate sources were gathered for both geographic and attribute data. These efforts are described below.

3.3.1 Geographic Data Acquisition

Geographic data was obtained from multiple, independent sources. Some of this data was public, and the remainder is proprietary Texas Department of Transportation (TxDOT) data. Rail, port, and TOFC/COFC (Trailer on Flatcar/ Container on Flatcar) facilities were modeled using the National Transportation Atlas Database 1997 (NTAD) produced by the Bureau of Transportation Statistics (BTS). Data on Texas roads was acquired from a proprietary TxDOT basemap. The national roadway system is based on a data set included with ESRI's ArcView GIS package. Additional supporting data such as census boundaries was obtained from the department of Community and Regional

[59] Rockliffe

Planning at the University of Texas at Austin. The wide variety of source for geographic data demonstrates the integration capabilities of GIS.

The base map from TxDOT was crucial for this research effort. It was fortuitous that TxDOT was developing this map concurrently with the early stages of this research effort, and allowed full access and technical support. Thus, a geographic definition of Texas roads was quite easy to obtain. Acquiring a base map of this quality was critical

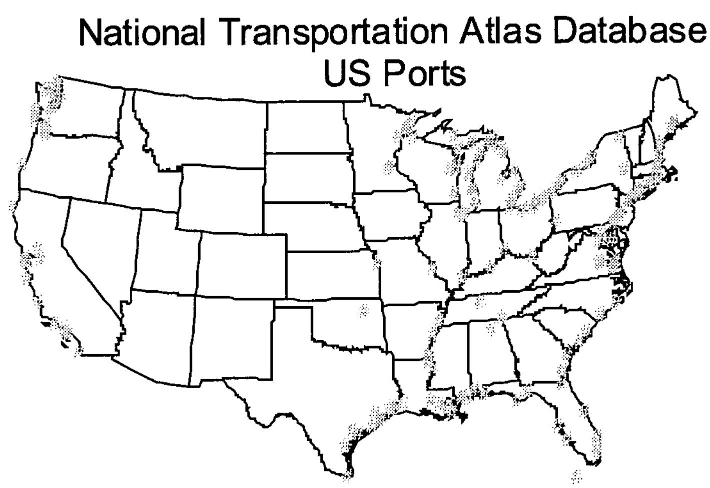


Figure 3.2 US Ports in 1997 NTAD

for this project. The TxDOT base map was highly accurate at +- 50ft. For the purposes of this research this was more than sufficient. In addition, there was a high degree of compatibility with the attribute data sets for Texas roads. Most of the difficulties arose due to differing levels of jurisdiction, counties and districts, being used as the basis for assigning mileage (See chapters 4 and 5). Unfortunately, this data set's extent was only Texas, limiting its usage.

[60] Rockliffe

The second important source for geographic base maps is the National Transportation Atlas Database (NTAD). This was also relatively easy to obtain, as the Bureau of Transportation Statistics (BTS) sells this data on compact disc for a nominal fee. Railroad data was included in this package, ensuring that attribute and geographic data were compatible. One area of concern is the accuracy of this data. It is national in scope, with a choice of 1:100,000 or 1:2,000,000 scale. The lesser scale, 1:2m, has a fair amount of geographic error, but was compatible with the included rail data and was therefore used. Additionally, inland waterways were included in this package, with the same concerns present. Given the long distances involved in intermodal transportation, errors should be minimal.

The NTAD also provided point data for intermodal facilities such as ports (Figure 3.2), waterways and TOFC/COFC transfer yards (Figure 3.3). Again, the scope was national, but accuracy was of less importance as the point data served only as a reference location for introduction of dummy links. Given point data and a limited number of locations, compatibility was not an issue. This data could be "hand coded".

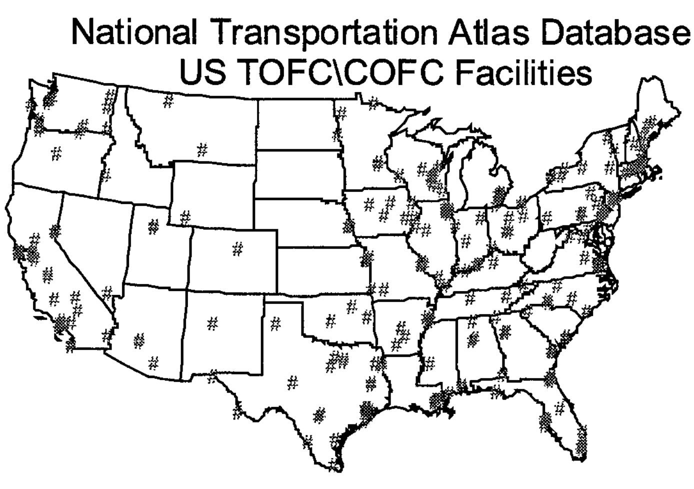


Figure 3.3 U.S. TOFC/COFC in 1997 NTAD

Data from the Community and Regional Planning Program at the University of Texas at Austin is also used. Specifically, background data such as Texas counties is included

The last data set is the interstate network provided by ESRI for use with ArcView. This was chosen primarily for the ease of acquisition. Pinpoint accuracy was not needed for areas outside of Texas, allowing use of a less accurate base map. The extent was national, expanding on the TxDOT data. Again, jurisdictions were important to make this data compatible.

Geographic source data is summarized in Figure 3.4. Clearly a rich variety of sources were combined in creation of this project. This highlights the power of GIS as a data integrator.

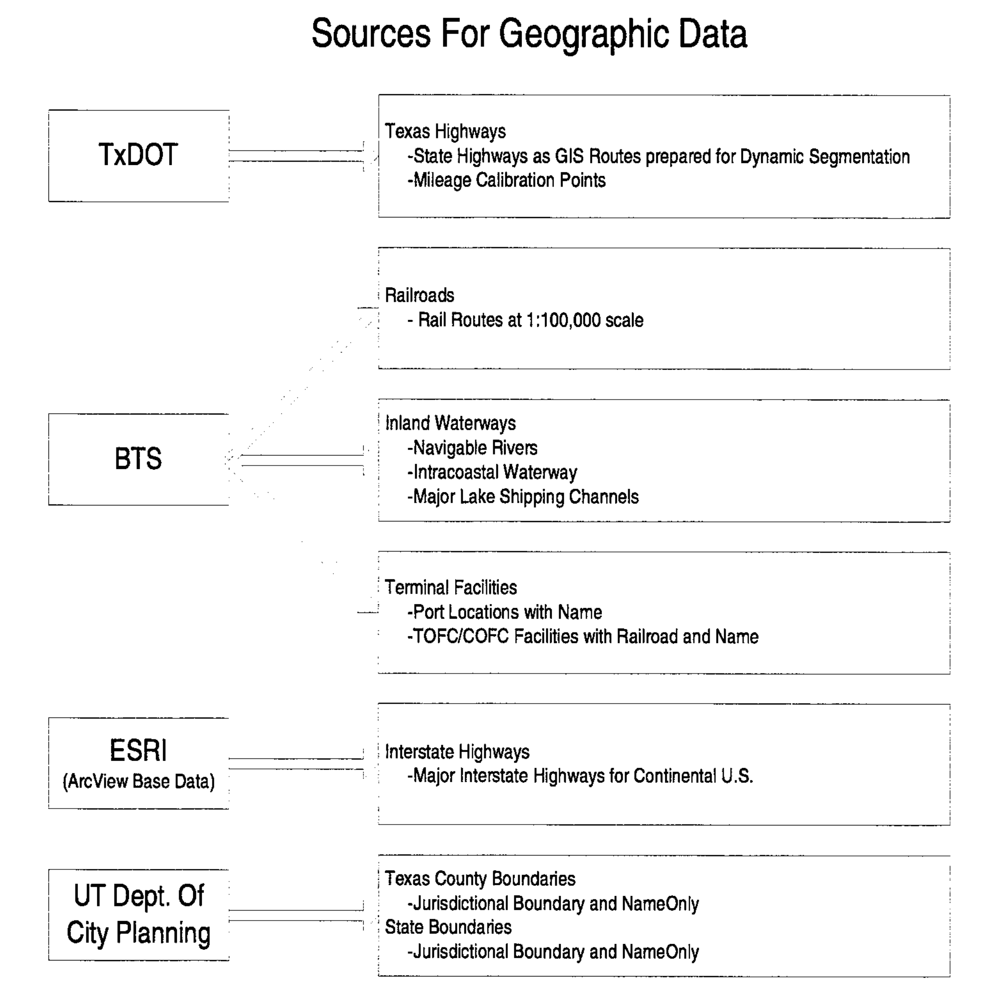


Figure 3.4 GIS Data

3.3.2 Acquisition of Attribute Data

This section addresses how, and from whom, attribute information was acquired. This project draws from a wide variety of sources, demonstrating the data integration capabilities of GIS.

The most important attribute data sources were public; the Texas Department of Transportation (TxDOT), and the Bureau of Transportation Statistics (BTS). These organizations provided the GIS basemaps and associated attribute data. The National Transportation Atlas Database(NTAD) provided data for waterways, ports, TOFC/COFC facilities, some roads outside Texas, and the rail network.

Detailed attribute data was somewhat difficult to obtain. Given the current litigious environment, and TxDOT's role in maintaining and planning roadways, TxDOT is generally reluctant to share detailed road characteristics with the public. Therefore, a readily available TxDOT database from a 1996 study was used.

Public rail data was readily available via the NTAD, and included all relevant variables except speed. The NTAD contains data on trackage rights, signal types, and freight flows. However, speed is perhaps the most important variable, and this is difficult to obtain. Several methods were tried to obtain speed data from the railroads. Railroads (Burlington Northern-Santa Fe and Union Pacific) were contacted via phone and a series of letters. Second, the American Association of Railroads and the Federal Railroad Administration were contacted. FRA permitted track speeds are in the public domain and could potentially be used as a proxy for intermodal speed. However, track speed changes quite frequently and in the absence of a centralized data system, current data is unavailable. Therefore, published scheduled were obtained and used as a basis for average speed.

Transfer facilities, as highly competitive entities, are reluctant to share specific data regarding performance and cost. However, several industry participants were able to provide approximate data for transfer facility performance.

Finally, for each mode approximate cost functions were gathered from available literature and discussion with industry participants. This process assured that gathered performance indicators were introduced into appropriate performance functions to determine utility of each mode.

A summary of sources for attribute data is provided Figure 3.5. These sources serve as descriptors of the intermodal network, tied together by geography within GIS.

3.4 SUMMARY

Chapter 3 demonstrates the assessment, identification, and acquisition of data necessary for a GIS-based intermodal model. The assembled combination of geographic and attribute data demonstrates the power of GIS to integrate data sets. Combined, these pieces are an excellent description of the Texas freight network and associated external links. The geography and attribute data together provide the basis for a successful model of intermodal freight movement.

With completion of assessment of data needs and data identification for both attributes and geography, an important milestone is reached wherein questions of data requirements are settled. This milestone allows one to focus on the process of developing a model. Completion of this GIS based model requires three additional stages, data processing (Chapter 4), network development (Chapter 5), and model implementation and application (Chapter 6).

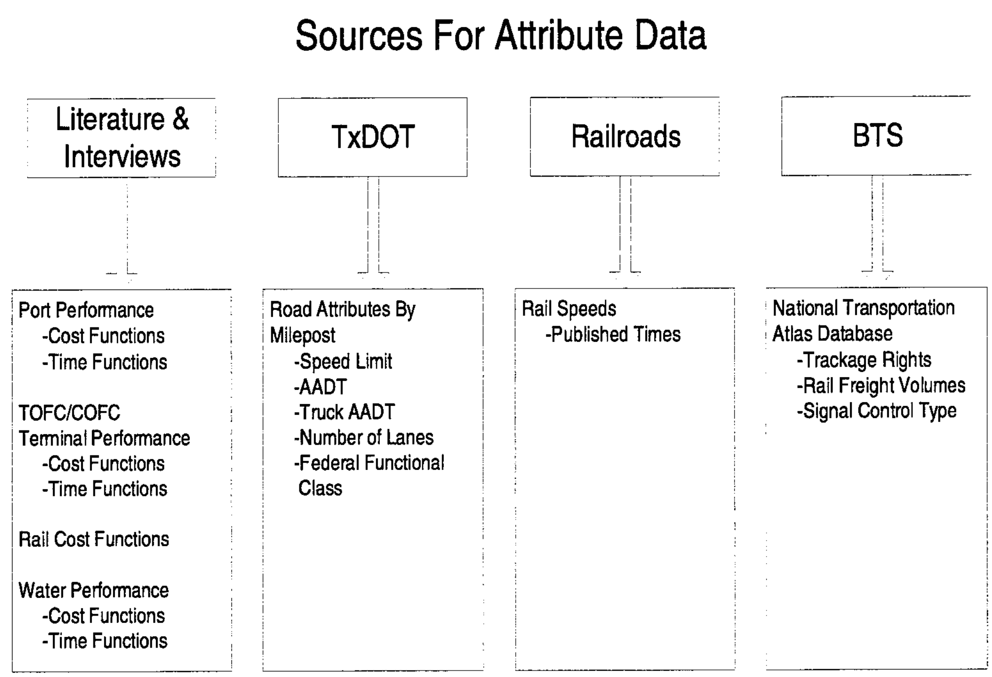


Figure 3.5 Attribute Data

CHAPTER 4: ATTRIBUTE DATA AND DATA CONFLATION

Chapter four aims to describe the data used for this research project, and the methodology for data conflation. The chapter builds upon the identified data, and demonstrates how these references were prepared to build an effective model.

Four issues are addressed in describing data for each mode; Sufficiency- whether sufficient information exists to properly model the real intermodal network., Relevancy- the importance of data vis-à-vis stated goals., Accuracy- the extent to which the data in the GIS model represents actual conditions., Organization- the ability to quickly use and understand database structures. Solutions to problems related to these four criteria will be discussed, with technical details in the appendix.

Data conflation, the attachment of data to geographic points, is discussed in relation to the road network and dynamic segmentation. All other networks use conventional arc-node structures for conflation.

4.1 PROCESSING AND CONFLATION OF ROAD DATA

First, the road network will be addressed. As previously noted, the road data used in this research is from the Texas Department of Transportation (TxDOT) and is based on the most recent entries prior to 1996. This data is derived from the Texas Reference Marker (TRM) system. Each record in the TRM database included a "from" and "to" milepost value, the route designation, and attribute data for that segment. Mileposts were based on county divisions, starting at zero at the boundary line of each county. Table 4.1 shows the data structure for the road system.

Table 4.1 Road Attribute Data

Basemap Attributes	
F_ELEV	From elevation for planar separation
T_ELEV	To elevation for planar separation
Geographic Data	Various
Unique	Linkage to Attribute Data

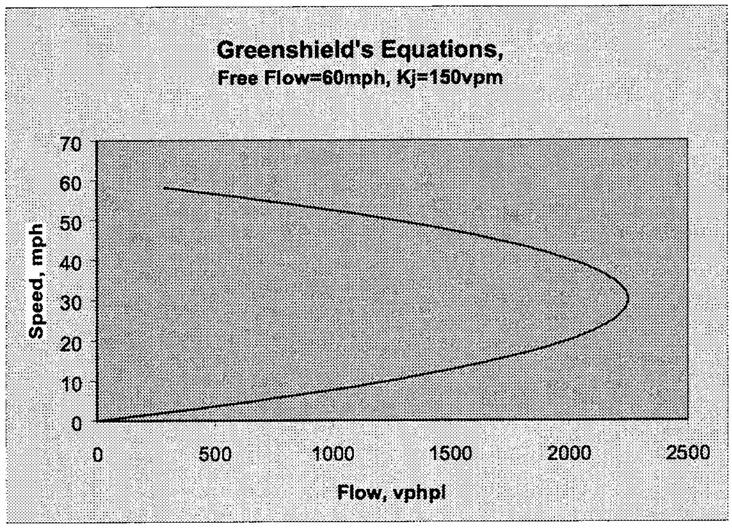
COUNTY	Number(A-Z) of county containing link
ROUTE	TxDOT route designation
FROM	Starting milepost
TO	Ending milepost
AADT	Average Annual Daily Traffic
TAADT	Truck Average Annual Daily Traffic
SPEED	Speed limit
FUNCLASS	Functional Class
LANES	Number of lanes
CORRFACTOR	Correction factor for geographic error
DISTRICT	TxDOT district
UNIQUE	Linkage to geographic data

Establishing sufficiency and relevance on for the road network was a fairly easy process. The project goals were to be capable of estimating speed and cost for all roads relevant to the Texas freight network.

First, relevancy was determined somewhat arbitrarily, by setting a condition that all included routes have a maximum value of 200 truck AADT or higher to be included in the study. This represents approximately the 10^{th} percentile for all links, and eliminated many irrelevant minor state routes from consideration. In addition, it was considered important to include interstate routes and selected roads near Texas as relevant to Texas based shippers.

4.1.1 Estimation of Road Speeds

The road attribute data is more than sufficient to predict speeds and represent the Texas network. Specifically, data on functional class, speed limits, AADT, and number of lanes allow estimation of speed. Two candidate functions were considered to estimate speeds. First, Greenshield's equations, Figure 4.1, relating jam density, free flow speed and flow rate to operating conditions were applied to approximate peak period speeds were examined. This curve is well supported by traffic flow theory, but can be difficult



$S=S_f*(1-(K/K_j))$

$Q=K*S$

Where,

S= Speed, mph

S_f=Free flow speed, mph

Q=Flow, vph

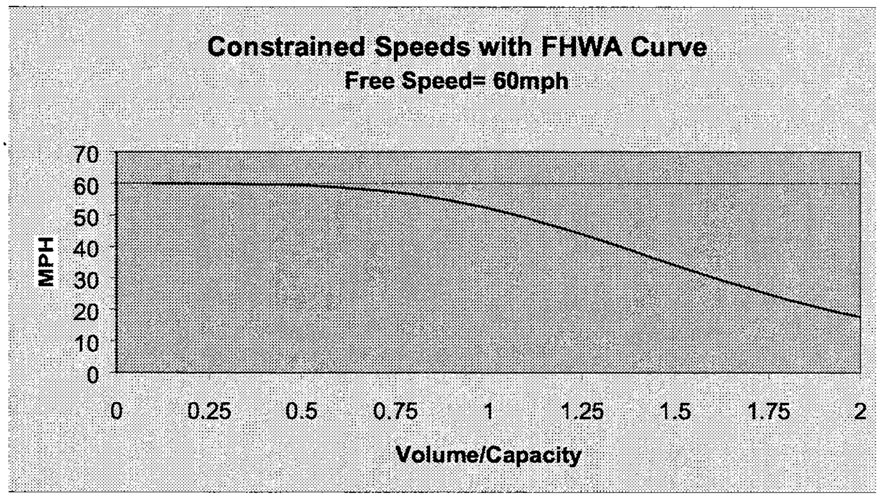
K=density, vehicles per mile

K_j= Jam density, vehicles per mile

Figure 4.1 Greenshield's Equations

to apply. Due to its parabolic nature, two roots exist for a given volume. The upper root represents non-chaotic flow conditions. The lower root, indicating chaotic, congested flow conditions is often displayed as a dashed line, indicating uncertainty in the result. In most instances it is appropriate to assume that the upper root representing uncongested flow is correct. However, in cases of high volumes, the correct root cannot be easily determined, and no solution exists where volume exceeds theoretical capacity.

Second, an FHWA curve[61] derived from empirical observation, and often used for travel simulation purposes was examined. This function, Figure 4.2, takes on an exponential form with speed rapidly decreasing as volume approaches and exceeds capacity. This method for estimation of speed was chosen due to its easily tractable nature and its ability to estimate speeds beyond theoretical capacity.



FHWA Curve
Speed= Sf/(1+0.15*(V/C)^4)
Where:
  Sf= Free Flow Speed
  V/C= Volume over Capacity

Figure 4.2 FHWA Speed to Volume Curve

To use the FHWA function to estimate peak hour speed, estimates of capacity and peak hour volumes are required. Peak hour volume is assumed to be one tenth of daily AADT in the peak hour. Capacities are based on Delaware Valley Regional Planning Commission's modeling guidelines[62] and federal functional class. Off-peak speeds were estimated using speed limits and an additional correction to reduce speeds on

[61] 1990 Validation of DVRPC Travel Simulation Models Delaware Valley Regional Planning Commission Philadelphia, Pa. 1997
[62] DVRPC

roads with lower functional classes. These values were in turn used as the basis for free flow speed in the congested scenario. Note that modeling of directionality, while technically feasible within the GIS software, was not attempted due to the difficulties of data collection and conflation. Table 4.2 shows the assumptions underlying the calculation of roadway travel speed.

Table 4.2 Capacity per Lane by Federal Functional Class

Functional Class	Description	Hourly Capacity	Daily Capacity	Speed Correction Factor
1	Rural Interstate	2100	21000	1.00
2	Rural Principal Arterial	2100	21000	1.00
6	Rural Minor Arterial	1100	11000	0.90
7	Rural Major Collector	800	8000	0.90
8	Rural Minor Collector	750	7500	0.80
9	Rural Local	680	6800	0.80
11	Urban Interstate	1950	19500	1.00
12	Urban Freeway, Other	1950	19500	1.00
14	Urban Principal Arterial	820	8200	0.75
16	Urban Minor Arterial	570	5700	0.60
17	Urban Minor Collector	500	5000	0.60
19	Urban Local	500	5000	0.50

Data on roads outside Texas is limited to the geography of the interstate system. This is a function of the Texas scope of the project. A full analysis of all U.S. interstate highways would unnecessarily expand project scope. Given that most long distance shipments occur on uncongested rural interstate highways, the Texas research focus, and the difficulties in gathering and conflating roadway speeds, approximate values are deemed sufficient to describe the characteristics of these links.

4.1.2 Accuracy of Data for Texas Roads

Maintaining accuracy of road data in the state of Texas was a difficult problem. Mileposts from the TxDOT GIS division did not always match the distances in the TRM based road attribute data. In addition, there were errors in producing a database referenced by milepost from the TRM system, especially duplicate and/or overlapping data points.

The first question to be addressed in ensuring accuracy was establishing a basis for judgement of accuracy. In this instance, given a claimed accuracy of +- 50ft., it was assumed that the TxDOT GIS basemap was geographically accurate. This data set is inherently geographic in nature and therefore was more thoroughly checked for accuracy vis-a-vis milepost location. Data from the TRM system was adjusted accordingly. Links in the TxDOT basemap were coded with both county and district. Therefore, Microsoft Access was used to compute the sum of arc lengths in the TxDOT basemap for each route in each county. This value was compared to the maximum milepost recorded for that county in the road data to find an appropriate adjustment factor. For example, if the sum of arc lengths in County A on Route Z was 25 miles and the maximum milepost was 20, the value of each milepost on Route Z in County A would be multiplied by a factor of 25/20, or 1.25. This value was recorded under the field "Corrfactor" in the final product.

One important benefit to correcting road attributes by route and county is the ability to isolate error to a specific county. Errors in data conflation are not carried across county lines. This prevents the error from propagating throughout a route.

4.1.3 Data Conflation for Texas Roads

Organization of road data is fairly straightforward, with each segment having its own unique ID in the final product, and associated data stored in a separate, flat, data file. This allows users to quickly access the road database.

A final section related to building the road network is the twin issues of data conflation and application of dynamic segmentation. Data conflation refers to the attachment of data to geographic features. In this research, dynamic segmentation was used for data conflation in the road network. The process was rather involved, and the complication primarily related to error minimization.

The first step towards preparing the road attributes was maintaining accuracy by establishing proper lengths. Second, mileposts on each route were adjusted to be cumulative through counties. While this is a simple task for a few roads, 1,119 routes were included. Therefore, custom code was written in the C language (Appendix A) to adjust mileage. This code required a starting county and route. TXDOT sets zero mileposts at either the northernmost or westernmost points, with the exception of interstate highways, which begin at the southernmost point. The code queried for nodes on the selected route, the original county on one adjacent link, and a link in a second county opposite the first link. If one such node was founded, the code increased all mileposts in the second county by the maximum mileage in the previous county, and placed the associated data in a file. An exception to this was cases where routes entered a county multiple times, where the code generated an error indicating the need for hand processing the selected route using a spreadsheet.

In addition, further processing was undertaken to remove duplicate data. More customized 'C' code was written (Appendix B) to examine adjacent road segments. If no attribute data change linearly along the route, multiple segments are combined so that the attributes of geographically adjacent records are unique.

Upon establishing a statewide measurement system, road data was converted into dBase format and conflated using the "Add Event Theme" function in ArcView GIS. Several problems were apparent. First, both ArcView and Arc/Info required continuous routes to accomplish dynamic segmentation. However, the statewide data as configured did not account for route concurrency, where the same road is signed as two different highways. Therefore mileage along a route as calculated by GIS would continue to increase while concurrent with another route but the attribute data did not account for this difference. Figure 4.3 shows U.S. 290 in the Austin, Tx. Area as an example. Note that U.S. 290 is concurrent with Interstate 35 for 7.68 miles. Upon identification of this problem, TxDOT was very helpful by providing all instances of such concurrencies, and the beginning and ending mileposts. More 'C' coding (Appendix C) was used to adjust milepost data by adding the difference between beginning and end of each concurrency for each route to the milepost fields on all records with milepost values greater than the beginning of the concurrency. This was done starting at zero mileage and working up so that previous concurrent routes would be accurately reflected in later mileposts.

Finally, data was not being placed onto the ends of routes. ArcView only places data based on the "From" value when conflating continuously along a route. A correction was undertaken to ensure that the minimum milepost for all routes was zero

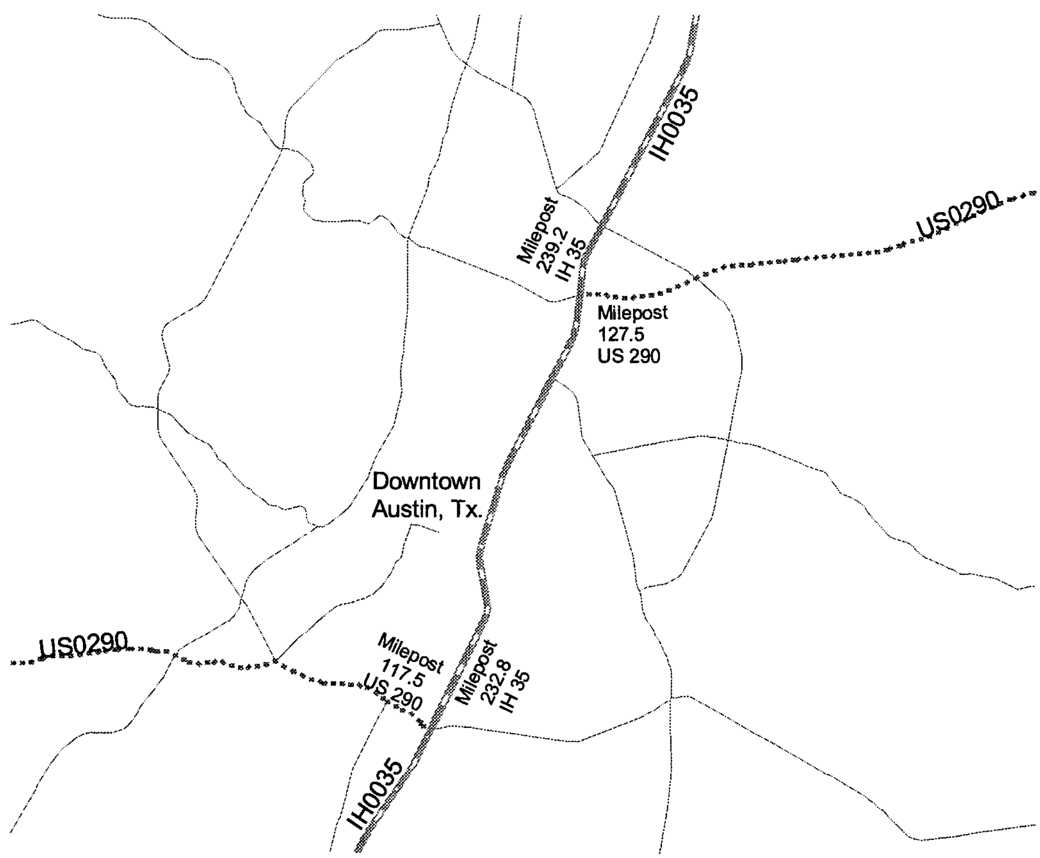


Figure 4.3 Concurrency, Mileposts on US290 & IH35 in Austin, Tx.

('C' code, Appendix D). Additionally to smooth the ends of routes a dummy record was added with the same data as that of the highest mileage record, a "From" value equal to the highest recorded milepost value, and a "To" value equal to the TxDOT provided maximum mileage for the specified route.

4.1.4 Final Processing of Texas Highway Network

After processing the data records through all of the above steps, conflation was again attempted. This was largely successful. However, two problems emerged. First, some routes still were not complete, with a small distance near the end (highest milepost) improperly processed, leaving a slight gap. Second, some of the final records added to bridge this gap in fact spanned the entire route. After much examination, it was determined that the results could not be improved via changes in underlying data or use of Arc/Info for conflation. Therefore, the road network was converted into a coverage and processed to remove spatial errors using Arc/Info. The first step in this process was to us the "clean" command in Arc/INFO, which moved nodes in close proximity to a common node, and eliminated overlap caused by data records associated with entire routes. Second, all dangling arcs were selected. These are segments that do not have nodes with multiple arcs at each end. They are "dead ends". Invoking the Arc/Info "snap" command, using a roughly half mile tolerance, relocated the unattached nodes to the nearest node within a half mile. Arc/Info was set so that if no node was found, the nearest vertex was used as the basis for the snap command. This corrected error associated with undershoots, except in two cases. First, if no route existing within a half mile, the dangling arc was unchanged. Frequently, this was actually correct, such as at the Texas border. Second, if the dangling arc was short, the closest node was often the other end of the affected link. Snap then deleted the link by moving both end nodes to the same location. The second error was corrected only where network connectivity was drastically effected, and can be corrected as needed in the final product.

The results from Arc/Info were converted back into an ArcView shapefile, providing the Texas road network as used. This network can be seen in the following figures. Figures 4.4 and 4.5 show AADT and truck AADT, respectively, on included Texas Highways.

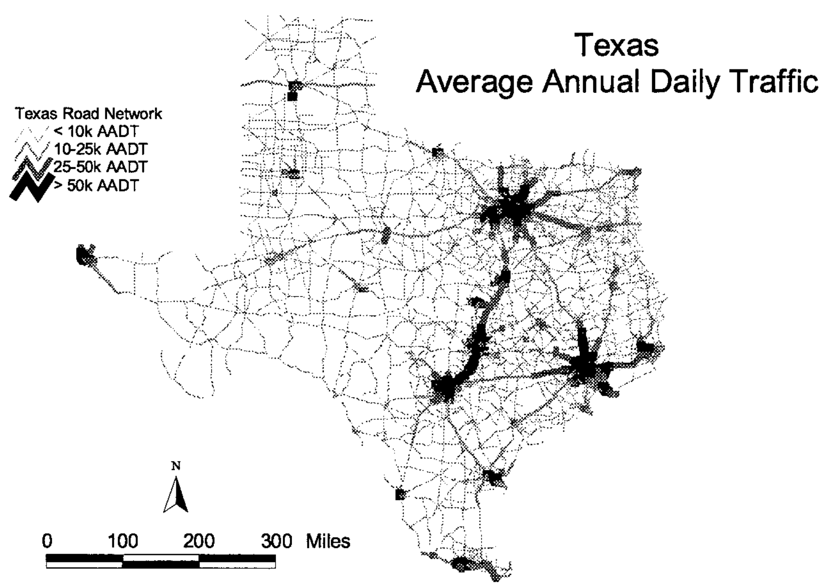


Figure 4.4 Texas AADT, 1996

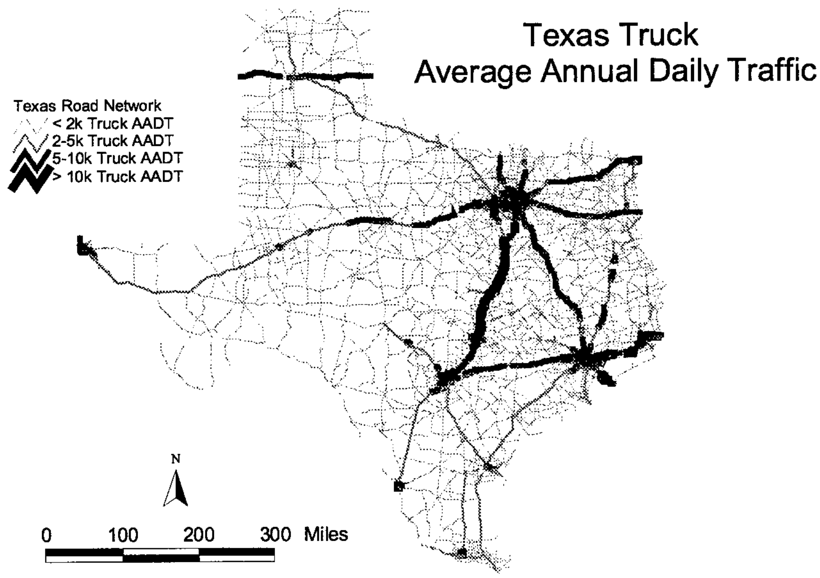


Figure 4.5 Texas Truck AADT, 1997

4.1.5 Truck Cost Assumptions

Estimates of truck rates ranged from $1 to $1.50 per mile. Muller establishes operating costs for the truck mode at $0.89 to $1.03 plus profits. The AAR estimates marginal cost at $0.35/mile[63]. This combined with a separate cost of idling at $60 per hour[64], yields a result of $1.44 per mile at 55mph. Industry sources estimated that costs were on the order of $1 to $1.50 per mile. For the purposes of this study truck costs were estimated at $1.25 per mile. However, performance functions including time as a cost variable are easily used within the final GIS model.

[63] Carini

[64] Kelley, pg. 212

4.2 PROCESSING OF RAIL NETWORK

The second set of attribute data is for the rail network. This data is from the National Transportation Atlas Database (NTAD). The NTAD one to two million scale geographic data set includes a variety of data, providing a good basis for analysis.

The NTAD rail data is fairly accurate, providing a good description of each link. Of particular interest to this project are traffic density and trackage rights. Unfortunately, speed is not included in the data set due to its highly variable nature. As a proxy for actual speed limits, scheduled speeds were obtained from the railroads. Route speeds were then extrapolated from this data.

With a national scope, the NTAD was more than sufficient geographically to model the freight network. The data on trackage rights is also crucial as a necessary piece of data to sufficiently describe a rail freight network.

4.2.1 Organization of Rail Data

Rail data was organized relationally, with each link having associated data. The raw structure is shown Table 4.3. However, as discussed in Chapter 4, trackage rights are handled explicitly by geographic differentiation, so this data is not included in the final attribute tables. Data is structured in a manner similar to the highway network, with the "UNIQUE" field linking the geographic links with the underlying data.

4.2.2 Relevance of Included Rail Links

Relevancy was established vis-à-vis included links by selecting all trackage in the state of Texas, and links carrying more than 20 million tons of freight annually where a Class I operating in the state of Texas has trackage rights. These railroads include the Union Pacific (UP), Burlington Northern- Santa Fe (BNSF), and Kansas City Southern (KCS). These rail routes are shown Figure 4.6.

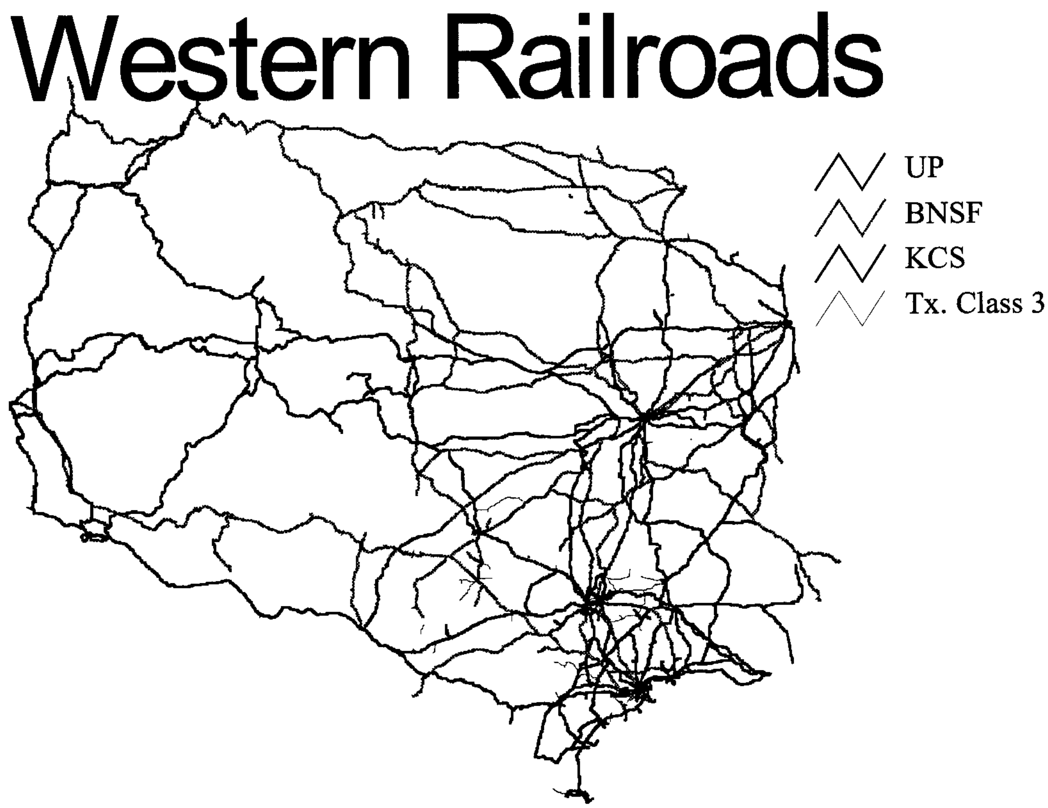


Figure 4.6 Major Western Rail Lines, 1997 NTAD

Table 4.3 Rail Attribute Data

Basemap Attributes	
F_ELEV	From elevation for planar separation
T_ELEV	To elevation for planar separation
Geographic Data	Various
UNIQUE	Linkage to Attribute Data

NTAD Rail Data	
UNIQUE	Linkage to Attribute Data
Link ID	NTAD identifier
Ownership	Owner of rail
Freight Volume	0.0 - unknown, abandoned, or dummy 1.0 - 0.1 to 4.9 MGTM/Mi. 2.0 - 5.0 to 9.9 MGTM/Mi. 3.0 - 10.0 to 19.9 MGTM/Mi. 4.0 - 20.0 to 39.9 MGTM/Mi. 5.0 - 40.0 to 59.9 MGMT/Mi. 6.0 - 60.0 to 99.9 MGMT/Mi. 7.0 - 100.0 and greater MGMT/Mi.
Signalization	- unknown CTC - Centralized Traffic Control ABS - Automatic Block Sign ACS - Automatic Cab Sign ATS - Automatic Train Stop ATC - Automatic Train Control MAN - Manual, including dark (none) TTO - Time Table/Train Order

NTAD Rail Data	
Link ID	NTAD identifier
Trackage Rights	Railroad Abbreviation

4.2.3 Estimation of Rail Speeds

The last piece of rail data is to determine an appropriate value for average intermodal train speeds. To perform this analysis, rail schedules were obtained from the web sites of relevant railroads in February of 2000. A representative sample, T70 able 4.4, showing the first trains in a given week is shown below.

Table 4.4 Rail Intermodal Speeds[65]

Railroad	From	Day	Time	To	Day	Time	Miles	Hours	MPH
UP	Houston	Mon	5:00pm	Chicago	Thur	6:00am	1102	61	20.8
UP	Houston	Tue	2:00pm	New Orleans	Wed	2:30pm	341	12.5	75.8
UP	Barbour's Cut	Mon	3:30pm	Los Angeles	Thur	6:00pm	1628	74.5	24.5
UP	Barbour's Cut	Mon	3:30pm	Portland	Mon	6:30am	2456	159	16.3
UP	Barbour's Cut	Tue	3:30pm	El Paso	Thu	12:00pm	814	44.5	22.3
UP	Dallas (Miller)	Mon	9:00pm	Los Angeles	Fri	8:00pm	1457	95	16.7
UP	Dallas (Miller)	Mon	9:00pm	Seattle	Sun	3:00am	2340	126	19.8
UP	Laredo	Mon	7:00pm	Chicago	Thu	6:00am	1363	59	26.7
UP	Laredo	Mon	7:00pm	St. Louis	Wed	3:00pm	1096	44	30.4
UP	El Paso	Mon	6:00pm	Chicago	Thu	1:00pm	1633	67	27.7
BNSF	Fort Worth	Tue	2:00am	Chicago	Wed	12:00pm	964	34	37.1
BNSF	Fort Worth	Mon	8:00pm	Oakland	Fri	3:00pm	1829	91	22.0
BNSF	Fort Worth	Mon	8:00pm	Los Angeles	Thu	12:00pm	1540	68	25.7
BNSF	Fort Worth	Tue	2:00am	Seattle	Mon	4:00am	2549	146	18.5
BNSF	Houston	Mon	6:00pm	Los Angeles	Fri	12:00pm	1750	90	21.3
BNSF	Houston	Mon	6:00pm	Chicago	Thu	12:00pm	1248	66	21.5
KCS	Laredo	Mon	8:00pm	Chicago	Sun	12:00pm	1724	136	13.5
KCS	Laredo	Mon	8:00pm	Kansas City	Fri	2:15pm	1264	90.25	15.4
KCS	Laredo	Mon	8:00pm	Dallas	Thu	12:00pm	916	64	16.4
KCS	Dallas	Mon	4:00pm	Kansas City	Wed	11:45am	512	43.75	14.3
KCS	Dallas	Mon	11:00am	New Orleans	Wed	7:00am	739	44	20.5

Examining this data it is clear that distance traveled plays little role in average speed and that an appropriate assumption for rail intermodal times might be a fixed terminal time plus a fixed running speed. The above data on rail speeds was first analyzed using linear regression to find an equation for time of the form $y = m * x + b$. This classical equation assumes a certain fixed time, "b", and a time per distance, "m". Using this form yielded an equation for rail intermodal speed of

[65] www.kcsi.com, www.uprr.com, www.bnsf.com

$time(hours) = .0507 * miles - 3.91 hours$. Clearly this was not an acceptable equation as the y-intercept was negative, implying negative terminal time. A second attempt at estimating rail intermodal speed using an assumption of a four-hour time to availability, or eight hours of terminal time, was undertaken. This yielded a slope of .0507 hours per mile, or a speed of 19.71 miles per hour. A chart showing this basic relationship and the corresponding r-squared value is shown Fig 4.7.

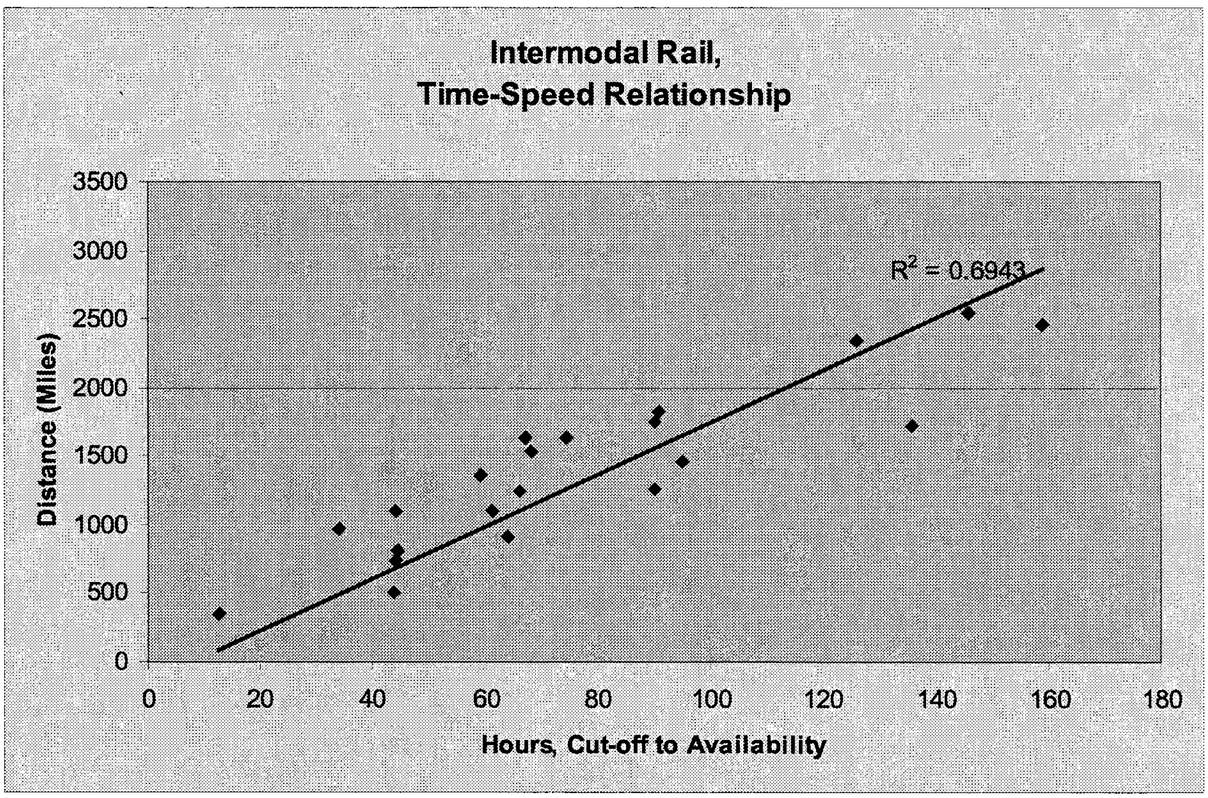


Figure 4.7 Rail Intermodal Speeds

4.3 ATTRIBUTE DATA FOR WATER MODES

Performance of water modes, operating in a ubiquitous environment, is governed by vessel performance. Distance is a straight line, with speeds ranging from barges at 12 knots[66] to large containerships at 18 knots[67]. Costs vary substantially for both barge and

[66] Muller 1999 pg 147

ocean vessels, depending on directionality of flow and market competition. Table 4.5 shows ocean rates for major markets. These rates were used as a basis to assign costs of 12.5 cents per TEU mile in the Atlantic Ocean and Gulf of Mexico markets, and 10 cents in the Pacific Ocean market. Barge costs were assumed at 20 cents per TEU mile.

Table 4.5 Average Container Rates via Ocean Vessel, 1997[68]

From	To	Rate
Europe	U.S.	$1302
U.S.	Europe	$1459
Asia	U.S.	$1473
U.S.	Asia	$1280

4.4 PORT AND TOFC/COFC ATTRIBUTE DATA

Port and TOFC/COFC attribute data is derived from both the NTAD and previous research undertaken at the University of Texas[69]. The NTAD provided data on modes serviced and accurate locations for intermodal facilities. This prior work served to provide a basis for inclusion of facilities. Performance data for port facilities is highly variable, with both temporal changes and random arrivals serving to make performance estimation difficult. Given that this research is focused on GIS application, an effort to model port performance is considered to be beyond the scope of this effort.

Performance at intermodal transfer facilities is an important component to model intermodal freight movements. Variability in performance is a crucial determining factor in facility usage. Modeling each individual facility is outside of the scope of this study, but would make a useful addition to complement this work. Based upon discussions with industry participants, the performance assumption shown in Table 4.6 were applied to the intermodal network.

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[67] Muller 1999 pg. 131
[68] Muller 1999 pg. 332
[69] Anderson

Table 4.6 Performance Assumptions

Facility Type	Cost Assumption	Time Assumption
Ocean Port	$250	12 hours
Rail-Truck Intermodal	$150	4 hours
Barge-Rail, Barge-Road	$200	4 hours

4.5 SUMMARY

Completion of data preparation is a crucial to the process of creating a valid network. First, it ensures that results will be valid, as errors have been minimized and appropriate performance statistics obtained. In the case of this research; rail, ship, and truck modes were all prepared for analysis, and analyzed for possible error. Second, the process of data conflation is the basis for network development (Chapter 5), the next logical step towards a final product. Inherent in GIS is the need for geographic placement, as properties occupy physical space that must be accurately represented. Proper data preparation ensures that spatially represented data will be correct within the completed network.

CHAPTER 5: NETWORK AND MODEL DEVELOPMENT

Chapter five focuses on model development: the mechanics of creating a GIS-based network. Specifically, available techniques will be addressed, followed by a discussion of movement rules and actual implementation. While the nature of the final network is known, one must carefully consider available tools and formulate a plan for implementation.

5.1 GIS NETWORK CODING PRACTICES

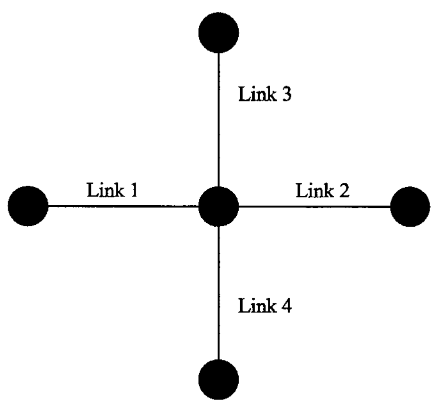
GIS networks follow standard practice, requiring development of a node-link structure. This data structure does not inherently exist but must be built in conjunction with network production. When developing a GIS network, it is crucial to be aware that several builds may be necessary, disturbing the link-node number assignments. Also, all points where lines cross in geographic space are nodes in a GIS network. Each link and each node are numbered sequentially, and these internal numbers are used for analysis.

Most GIS software contains several built-in tools for network building. ArcView allows users to define network typology in three ways: planar differentiation, artificial (or "dummy") links, and turn penalties (turntables). Each of these techniques allows for coding of movement rules and assessment of penalties into the final product.

The first of these techniques is planar differentiation. ArcView allows each link to have an elevation setting at nodes. Relative node values must be known, as one value, typically F_ELEV or a similar variable name, is used for elevation at the lesser node, and T_ELEV at the greater node. Figure 5.1 gives a graphical description of this method. The typical use for this feature is to allow representation of overpasses. However, it can be used to set other movement rules. Elevations can be arbitrarily set, as most GIS packages, including ArcView, only recognize elevation difference as a binary Yes/No vis-à-vis allowable movement. An important distinction for this technique is that elevation can be set based on underlying attribute data, allowing fast coding of large networking.

The second primary technique for creating a GIS network is artificial links, usually referred to as "dummy" links. These links have no physical counterpart, and are therefore "dumb" as there is no associate data from the actual system being modeled. They exist solely to allow movements that would otherwise be prohibited or to assess costs. When combined with planar differentiation, movement can be allowed between different elevations by setting each node of the dummy link to the planar elevation of its intersecting links. An example is shown, building on the previous figure, in Figure 5.2.

Finally, GIS programs such as ArcView usually include a feature such as turntable, allowing hard coding of impedance values between nodes. Table 5.1 shows such a table being to achieve the results of Fig 5.1.



Development of an overpass		
Link	F_ELEV	T_ELEV
1	0	0
2	0	0
3	1	1
4	1	1

Figure 5.1 Planar Differentiation

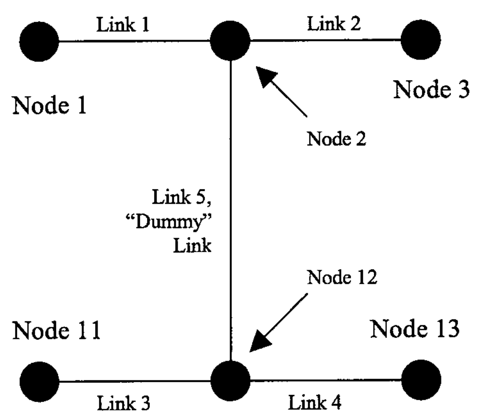


Figure 5.2 Dummy Links

Development of a Dummy Link				
Link #	From Node	To Node	From Elev.	To Elev.
1	1	2	1	1
2	2	3	1	1
3	11	12	10	10
4	12	13	10	10
5	2	12	1	10

Table 5.1 Turntable to Prevent Movement

Node	From Link	To Link	IMPEDANCE
3	1	3	999,999,999
3	1	4	999,999,999
3	2	3	999,999,999
3	2	4	999,999,999
3	3	1	999,999,999
3	3	2	999,999,999
3	4	1	999,999,999
3	4	2	999,999,999

As can be seen in figure 5.3 establishing a turntable can be a cumbersome process requiring a record for each possible turning movement and direction. This process does not lend itself to usage en-masse based on attribute data, an important consideration for a large data set. Typical uses for this feature include coding of one-way streets, and prohibited or slow left turns. By setting a large impedance value movement can be effectively prohibited.

5.2 DECISION RULES FOR INTERMODAL FREIGHT

The second step in establishing a network is to determine the desired decision rules. Development of an accurate model for intermodal freight was complicated by the required movement restrictions. First, is trackage rights on the rail network, and second, transfer facilities serving three or more modes.

Within this project, one goal was to accurately portray the effect of railroads as separate corporations on rail movements. To achieve this goal within the state of Texas, four sub-networks needed to be defined; one for each class 1 railroad and a fourth for minor railroads. Movement needed to be limited such that travel between these rail sub-networks did not occur. One exception is the intersection of small, class 3 railroads with class 1's where interlining is a necessity.

Second, rules for transfer facilities must be established. For rail to road transfers, this is relatively simple, as all movements are permissible. However, at ports, six movements can occur: rail-truck, truck-ship, truck-barge, rail-ship, rail-barge, and ship-barge. Each of these movements must be coded in some fashion, and not all modal pairs may be permitted.

5.3 NETWORK CREATION

Creation of the actual model network required use of all the tools described above. Several software limitations governed the mechanics of the process. First, given ArcView, and the Network Analyst extension as a platform, the shapefile (*.shp) file format is required. Second, ArcView has only limited tools for network topography and en masse error correction. To overcome this obstacle requires use of Arc/INFO or similarly powerful GIS software as an additional editing tool.

The first step towards network creation was to project all data into the same coordinate system. Given the Texas orientation of the research, the Texas Department of Transportation's statewide coordinate system was used. Thus, the geographic data is most accurate within the state of Texas, and the projection tends to distort at the geographic margins. These data sets included Texas roads, Interstate highways, inland waterways, and railroads.

The next challenge was to accurately represent the separate railroad networks. The largest dilemma was how to control routing. The first inclination is to use a turntable to prevent link to link turns that are not possible in the actual rail network. Unfortunately this does not prevent routing onto a link with single trackage rights from a link in use by multiple railroads. The final solution, shown in Figure 5.3, highlighting the Galveston area, was to create individual networks for each railroad. These sub-networks were then projected at five hundred foot offsets, given unique elevations, and then merged. This effectively treated each of the class one railroads in Texas as a separate modal choice.

The last issue was to create appropriate decision rules for intersections of class three railroads with links having more than one class one railroad. The challenge is to prevent movement between class one railroads at such intersections. The use of turntables is ideal for this application, preventing undesirable movements.

After all data was both geographically consistent and properly coded, the themes

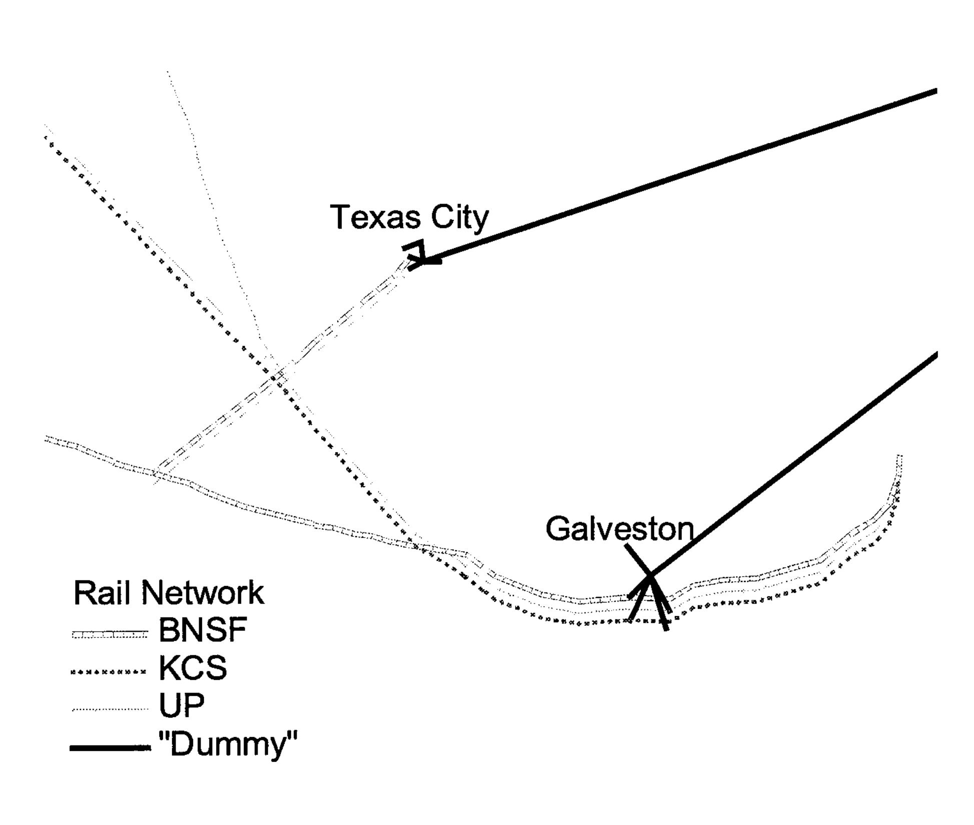


Figure 5.3 Trackage Rights in Galveston Area

needed to be merged. This was accomplished using a set of tools developed by the Oregon Department of Forestry called XTools. These features have since been added to ArcView in version 3.1.

Simply combining themes in ArcView was not sufficient to create a true network, as node and polygon data cannot be created within ArcView. Therefore, the combined themes were converted into an Arc/Info coverage. These themes were then processed using the clean command with a tolerance of 10^{-14}. The clean command corrects slight geographic errors using proximity as a guideline, however the very low tolerance value limited alteration of geographic data. A through examination of likely least cost paths revealed several locations where lines were roughly parallel and clean maintained only one of the paths. These errors were corrected as discovered by manually editing the rail geography.

When invoking the clean command, links are split if they cross other links and the attribute data is assigned to each new link. Given that multiple overlapping data sets were present, this created a dilemma. Multiple links would have identical associated data, ballooning the size of the underlying database and making data management very difficult. In addition, each link type has unique fields used to define member attributes. Combining all data into one large table would produce a sparse, unnecessarily wasteful matrix. To combat these problems, a unique numbers was assigned to each link prior to merging and cleaning the data sets. The unique number was retained in the main attribute table, allowing the original data to be relationally joined as needed. The ranges assigned are shown Table 5.2.

Table 5.2 Correspondence of "Unique" Field to Mode

Link Mode	Range
Dummy Link	0 to 999
Inland Waterway	1,000-9,999
Interstate Highway	10,000-49,999
Western Railroad	50,000-99,999
Texas Road	100,000-199,999
Texas Class IV Railroad	200,000+

Upon completion of the geographically referenced data sets, addition of dummy links was undertaken. Several classes of dummy links were required. Specifically, links were needed to preserve network movement rules, provide for cost assignment, for representation of routes not geographically referenced, and for error correction. The first two classes of dummy links, to preserve movement rules and enable cost assignment were created at all interchange points. These links allow explicit cost allocation and assignment of permissible routes. Figure 5.4 shows the area surrounding New Orleans. There are a variety of purposes for "dummy" links in this region. The spokes at the bottom of the map are used to model modal interactions at the port of New Orleans. By focusing "dummy" links representing each mode to a single node, a turntable can be

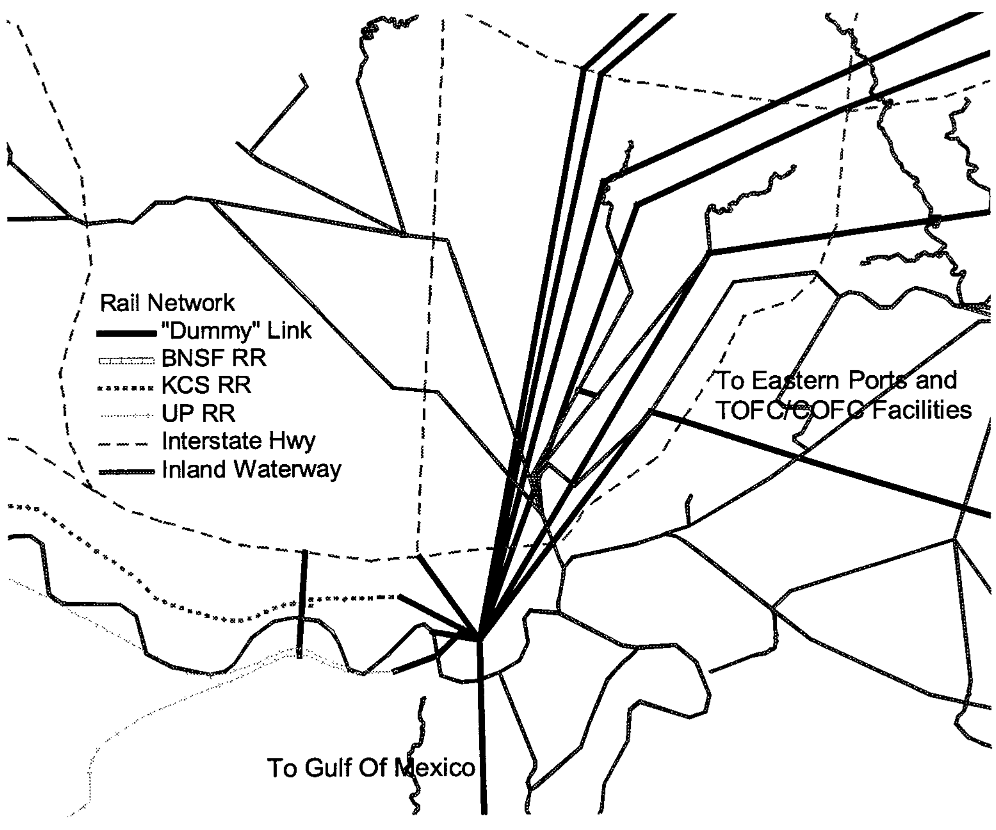


Figure 5.4 Dummy Links in New Orleans Area

established to specifically set transfer penalties for any modal combination at the port. Additionally, an infinite cost can be assigned to prohibit movement between modes.

Second, a "dummy" link connecting the Union Pacific Railroad to Interstate Highway 10 exists west of the port of New Orleans. This serves two purposes. First, it allows Union Pacific TOFC/COFC traffic to enter IH 10 at a more geographically accurate point. Second, ArcView Network Analyst is currently limited to 10 links per node at turntables, see Appendix E. The node representing the port of New Orleans is connected to 11 distinct destinations, however the railroads are combined to reduce the number of links at that node to 10 and allow analysis. Therefore to mathematically segregate UP and KCS TOFC/COFC traffic, a separate link for UP traffic was desirable. The final two classes of dummy links completed the network. In many cases, links did not exist in any of the geographic data sets used. Figure 5.5 shows eastern railroad routes and ocean routes modeled as dummy links. In other instances, small errors in the underlying data needed correction. This was especially true for railroad data where trackage rights were crucial.

5.4 COST ALLOCATION

The final task to complete the network is assignment of costs. Performance functions for each mode are required, and a methodology for placing these costs into a format readable by ArcView must be developed. Figure 5.5, next page, shows the process to develop a cost allocation structure.

Two methods were used to assign costs. The first method was to place the cost in the link attribute database. This allows for use of geographic attributes such as length, and exactly defines the segment associated with a specific cost. Costs and Time were assigned on links for rail, truck, and barge movements, and for two mode intermodal facilities. The second method was to use a turntable, assigning costs at a given node. Therefore, the entire cost of movement over a link or series of links is assigned at a single node. To preserve an accurate display, total costs for line haul segments represented as dummy links were assessed when traveling from a non-dummy line haul segment to a

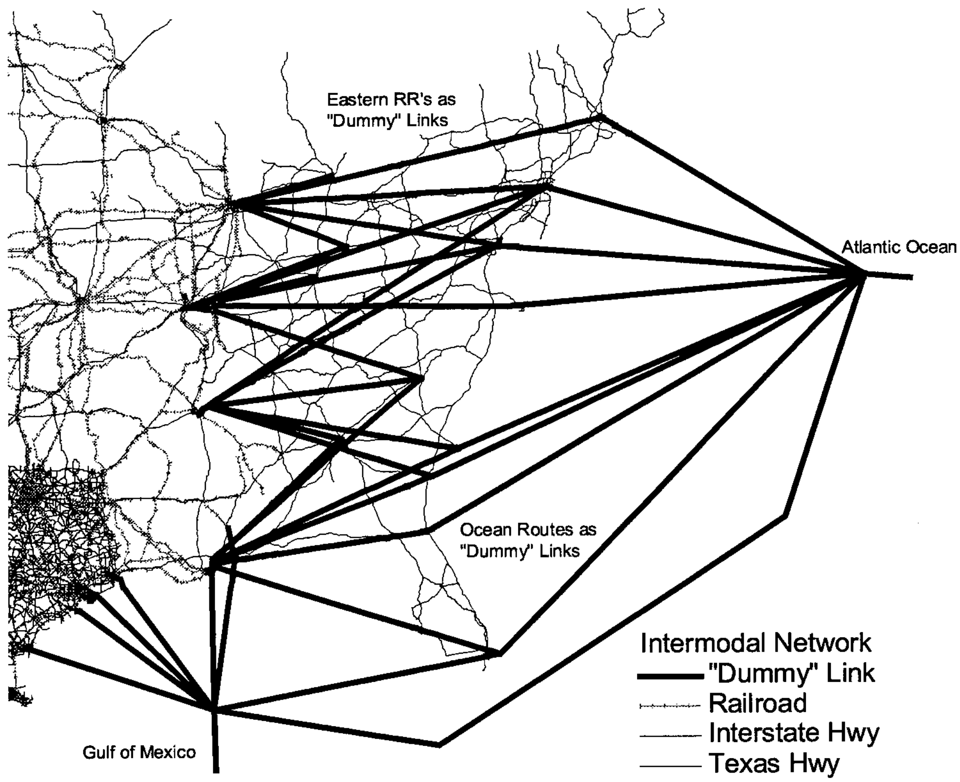


Figure 5.5 Eastern Railroad and Ocean Routes as "Dummy" Links

dummy link used to represent a line haul route. For example, intermodal rail movements between New Orleans to Atlanta would incur the rail linehaul impedance at Atlanta when travelling to New Orleans and at New Orleans when travelling to Atlanta. The costs and times associated with the respective transfer facilities would be included at those nodes. This method was used for all line hauls represented as dummy links, such as ocean routes and eastern railroads. Turntables were also used to assign costs at transfer facilities with more than two modes.

The procedure to assign costs is as follows. First, performance was calculated on links using ArcView as a database editor. Links for each mode are isolated and the appropriate performance function applied. Second, two files were developed for use in formulating the final turntable. A file of default intermodal transfer penalties was created. Each mode received an ID number, Table 5.3, and these ID numbers were combined by multiplying the from mode by 100 and adding the to node. Thus, a move from Open Ocean(6), representing Europe, Asia, or South America to Dummy Ocean(5), representing the approach to US ports, is identified as 605. The purpose in this step is to be able to quickly change basic assumptions for an entire class of modal transfers. This file is saved as default.dbf. A second file was created, saved as linehaul.dbf, to assign the costs associated with line hauls modeled as

Table 5.3 Modal Identifiers

ID number	Type	Description
1	Union Pacific	Union Pacific Railroad
2	BNSF	Burlington Northern Santa Fe Railroad
3	Union Pacific	Kansas City Southern Railroad
4	Barge	Barge
5	Ocean	Ocean Approach to U.S. Ports
6	Open Ocean	Common Route to Final International Port
7	Eastern RR	Eastern Railroads
8	Roads	Roadways

dummy links. This file uses the "To_Rec" field within the turntable to assign an additional cost and time above the default transfer penalty. Since each link within the GIS network must have a unique record number, and all routes being modeled are a composite of at least two links, each record number emanating from a node represents a unique route. This property allows for one data entry per route, and use of the record number as an identifier for the real route being modeled. To complete the assignment of costs via turntable, line haul performance and default transfer penalties are joined to the base turntable and the respective costs and times combined.

With completion of a proper turntable and assignment of costs onto links as per Figure 5.6, costs are allocated onto the network. From this data, cost can be used as a primary routing decision variable. Additionally, cost and time can be combined to perform analysis using a time value of money.

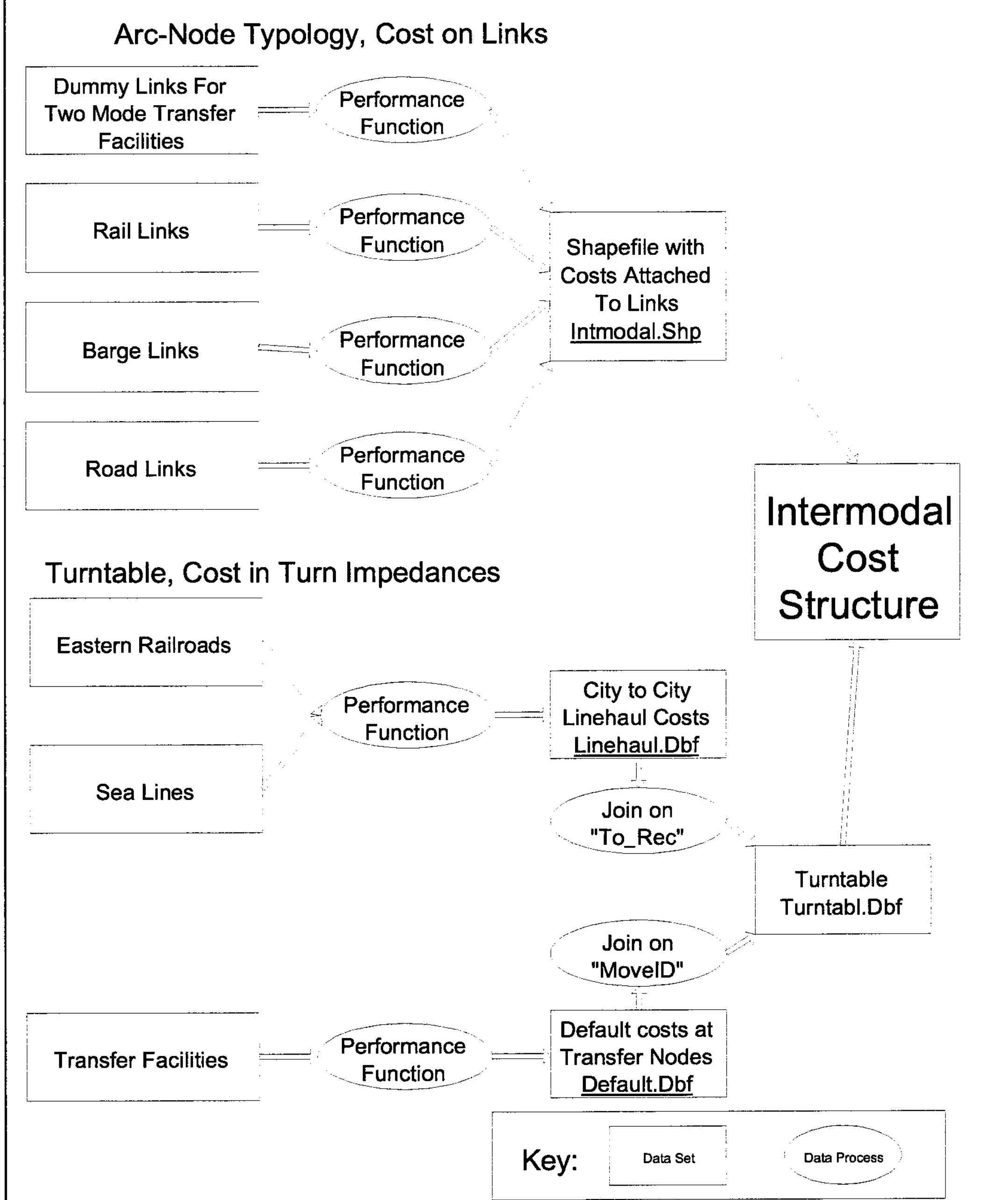


Figure 5.6 Cost Allocation Process

5.5 SUMMARY

The net result of this process is creation of a network capable of use in solving routing problems. By careful consideration of detail and process, movement rules and costs could be controlled and assigned via conventional GIS-based network coding techniques. Figure 5.7 sums the network development process. Via this process, attribute data is conflated onto geographic points for each mode, individual networks are prepared and merged, dummy links are created, and finally cost and performance functions are applied to the underlying GIS network to produce a realistic model of intermodal freight travel. The next step, detailed in Chapter 6 is to apply this network to real world problems.

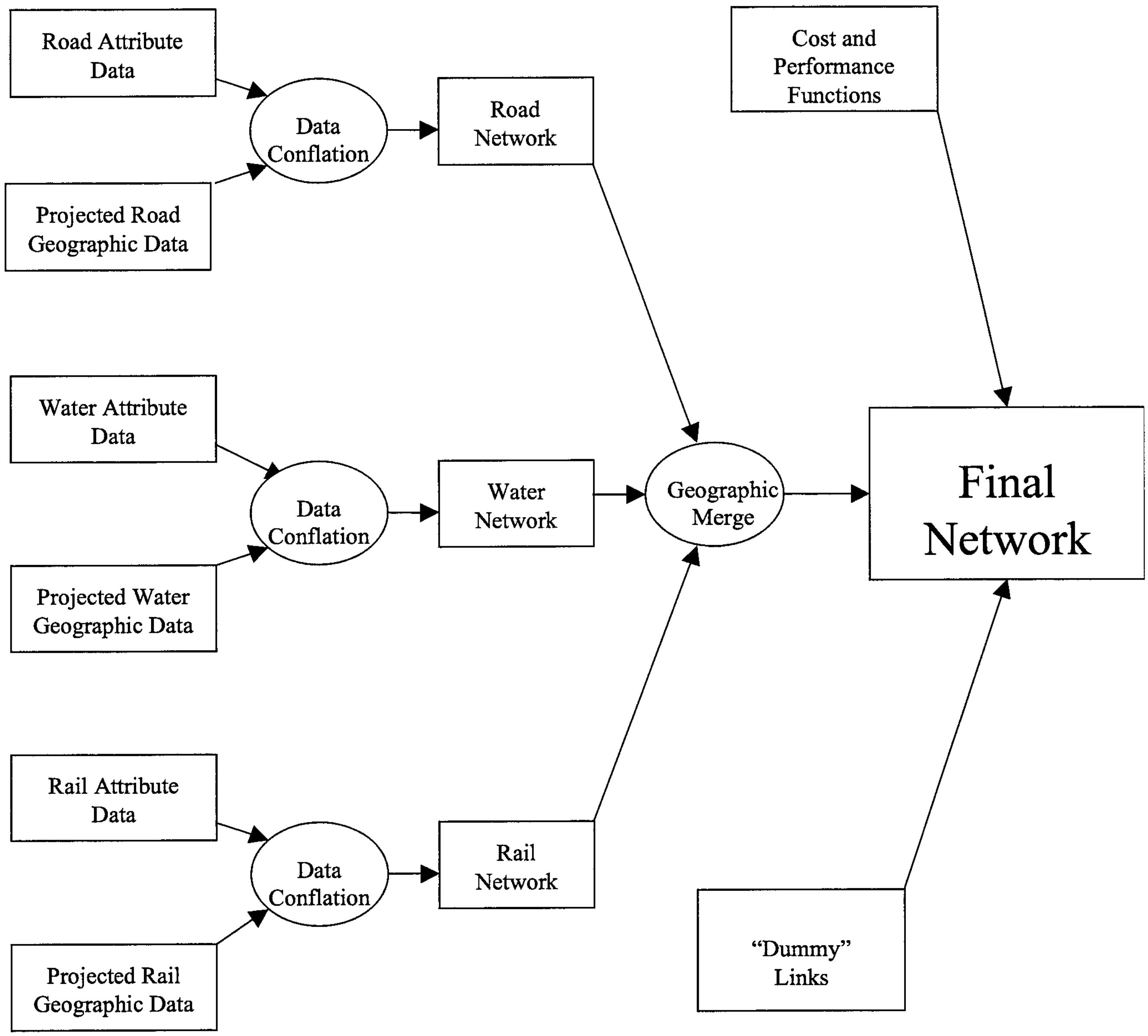


Figure 5.7 Network Development Process

CHAPTER 6: MODEL APPLICATION

Chapter six aims to demonstrate usage of the developed intermodal network. Four basic analysis' will be examined; market area analysis, shipper routing, effect of terminal improvements, and the impact of time sensitivity on modal choice. These problems will be analyzed in the context of three case studies, locating a new rail-truck terminal, routing to the nearest port, and creation of a new port with mega-ship capabilities. Within each of these case studies the benefits of GIS will be determined, and results demonstrated.

6.1 CASE STUDY: LOCATION OF TEXAS COFC/TOFC FACILITIES

One potential application of this research is to analyze the spatial distribution of TOFC/COFC facilities and make recommendations for further study. This study generates accessibility contours for Texas TOFC/COFC based on travel time, demonstrates policy and planning implications of this data, and illustrates usage of GIS to generate market size data for a proposed facility.

The ability to examine travel time contours from intermodal facilities is an important output of interest to policy makers and freight planners. Federal regulation limiting driving time to ten hours[70]. One result of this decree has been that LTL shippers have placed load transfer facilities approximately eight hours apart. This allows a two hour margin for loading/unloading and unusual congestion en route. A second result is that in the intermodal freight industry, half of this value, four hours, is a key number as it represents a maximum reliable distance for a trucker to return home, thereby not requiring full over-the-road compensation and other associated costs..

The mechanics of displaying travel times within the ArcView environment is straightforward. An appropriate network, a map of sites placed over existing roads, and a time value are sufficient to generate a Service Network and Service Area, representing the links within the given travel time, and the interpolated accessible area respectively.

[70] Downs, Jerry Rules for Truckers Take Aim at Safety Philadelphia Inquirer 4/26/200

This process was applied to the Texas freight network, using a four hour travel time. Figure 6.1 demonstrates the results of this analysis assuming peak conditions.

Examining Figure 6.1, it becomes clear that the coverage of intermodal facilities within Texas is fairly comprehensive. However, the Permian Basin region and the Big Bend area are not within four hours of an existing facility. These areas are sparsely populated, limiting the appeal of a new facility at this region and the Big Bend area are not within four hours of an existing facility. However, since this is the only undeserved Texas region, this case study will analyze the potential for a new facility. For the purpose of this study, a location at FM 1788 and US 80, adjacent to Union Pacific trackage is proposed. To develop a usage shed, a 3-hour travel time contour, representing those area closest to a proposed Midland/Odessa Facility was created using the Service Area

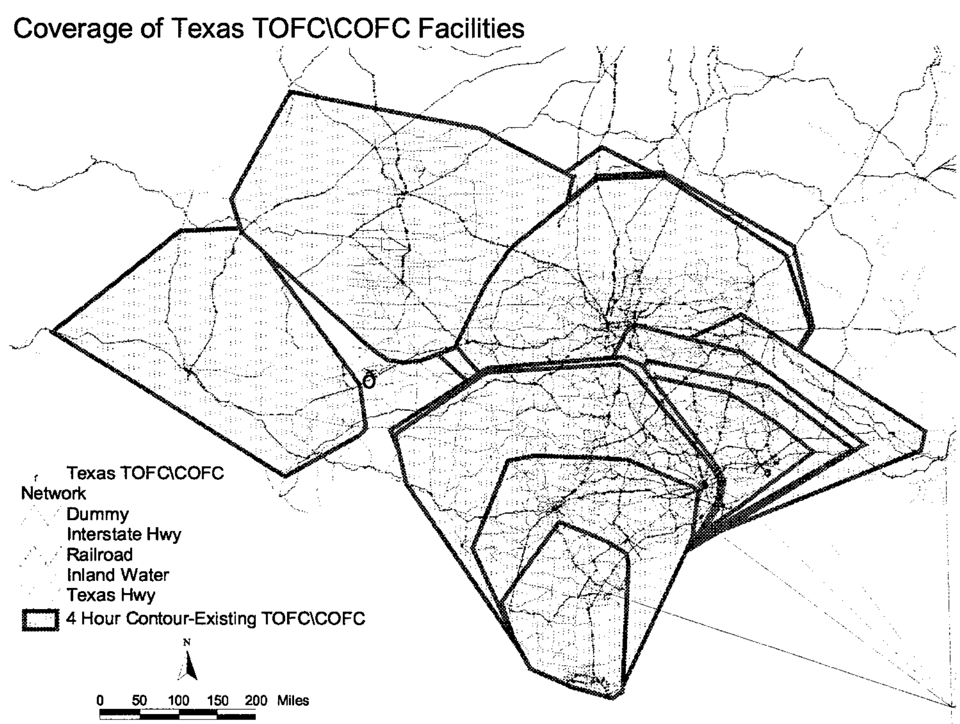


Figure 6.1 Coverage of Texas Intermodal Facilities

command within ArcView, shown as thick lines on Figure 6.2.

Once a service area is defined, the power of GIS can be applied to sum demographic data within this region. Several pieces of data are of interest to this case study. First is total population, serving as a proxy for consumer demand. Second is total employment, and finally, one might have an interest in a particular economic sector. Two analysis techniques were used for tabulation. First, a counties file can be overlaid over the travel time contour, allowing one to quickly determine those counties within the catchment area. This is most useful for aggregated data such as employment by sector where finer detail is not available. Second, is a geographic join, shown using 1990 Census data provided by ESRI. This file contains population by Census block, where

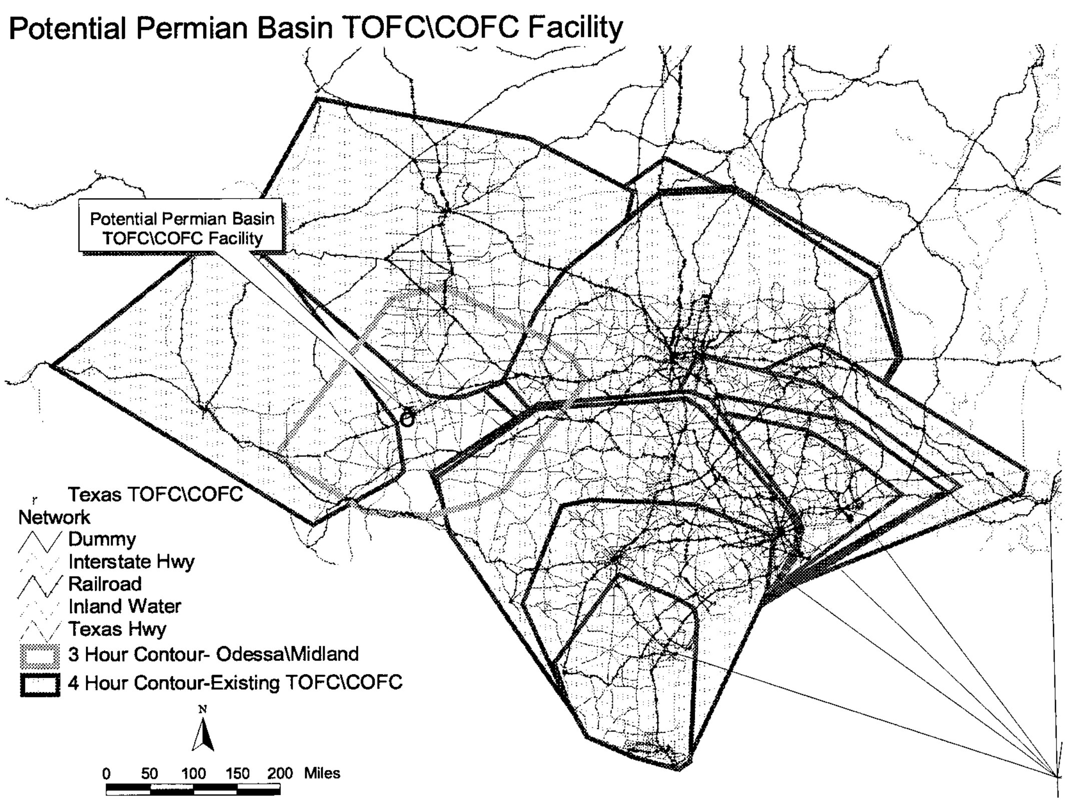


Figure 6.2 Potential Permian Basin COFC\TOFC Facility

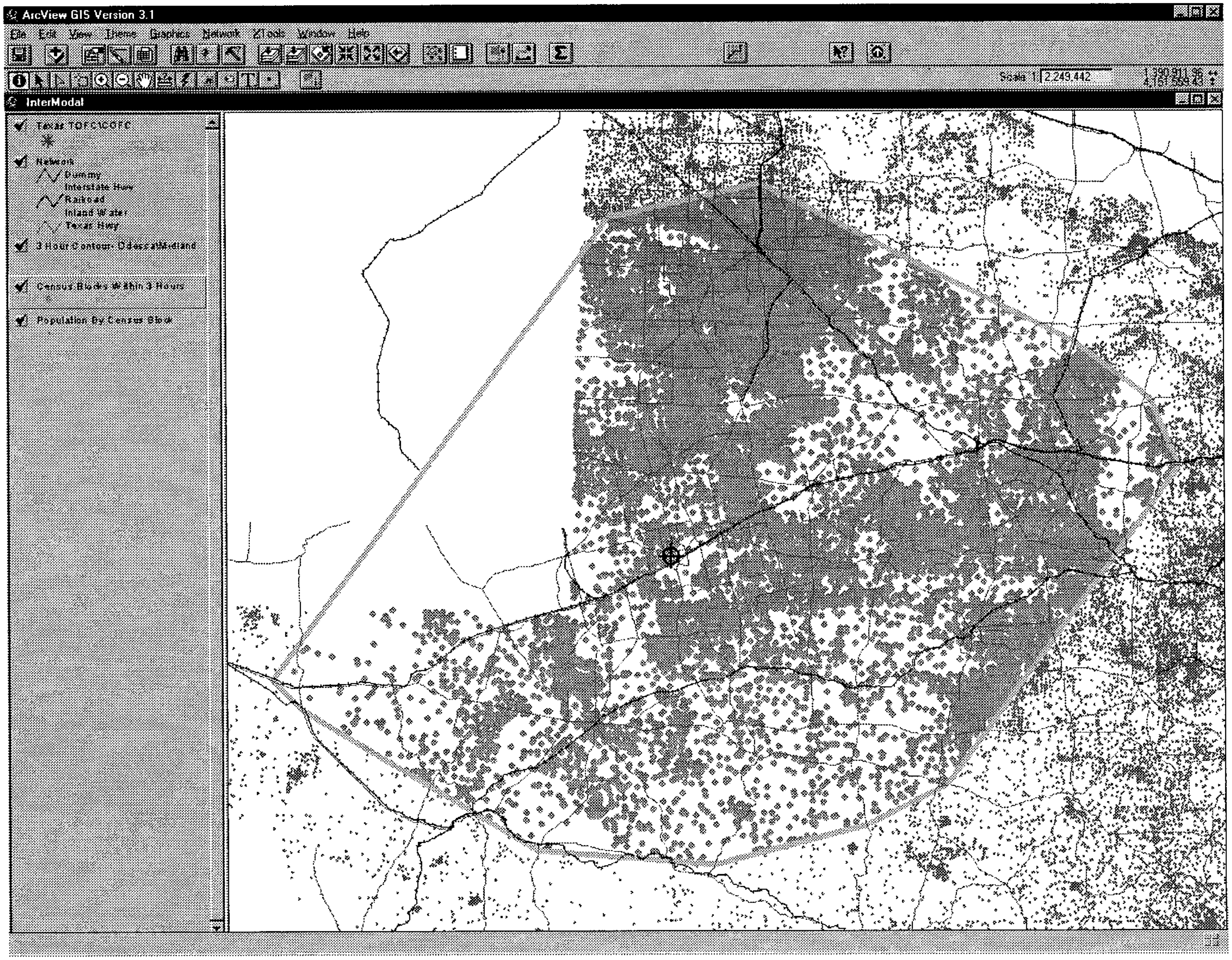
blocks are point data represented at the areal centroid of the block. This process identifies those block centroids within the specified travel contour. These records can then be isolated and summed, quickly yielding a total population within 3 hours of one million persons. This process is shown Figure 6.3.

Results from this case study indicate that just over one million individuals live within three hours of the proposed site. The power of both visual and geographic referencing within GIS to integrate data sets was shown. Usage of GIS allowed for a quick, accurate answer to assist planners in determining viability of a particular location for an intermodal freight terminal

6.2 CASE STUDY: CLOSEST FACILITY ANALYSIS FOR SAN ANGELO

One potential usage for an intermodal GIS application is closest facility analysis. This case study offers a demonstration of ArcView Network Analyst's Closest Facility tool, applied to a hypothetical shipper in San Angelo. The following information is required: a list of facilities, the location of the shipper, and the roadway network with travel times. Figure 6.4, next page, shows the results of a search for the three closest ports for a San Angelo shipper using peak times.

Clearly, there is great value in being able to readily make this analysis. Figure 6.4 shows that the GIS system is able to produce an exact routing in a visual manner that is easily understood. The ability to quickly quantify impact of location on shipper costs is quite valuable as an analysis tool. Also, from a policy perspective, the ability to quickly display relative costs and times to potential shippers has great potential to generate modal shift.



Sum of 1990 Texas Census Population By Block: 1,054,417 persons

Figure 6.3 Census Block Groups Within 3 Hours of Proposed Permian Basin TOFC\COFC Facility

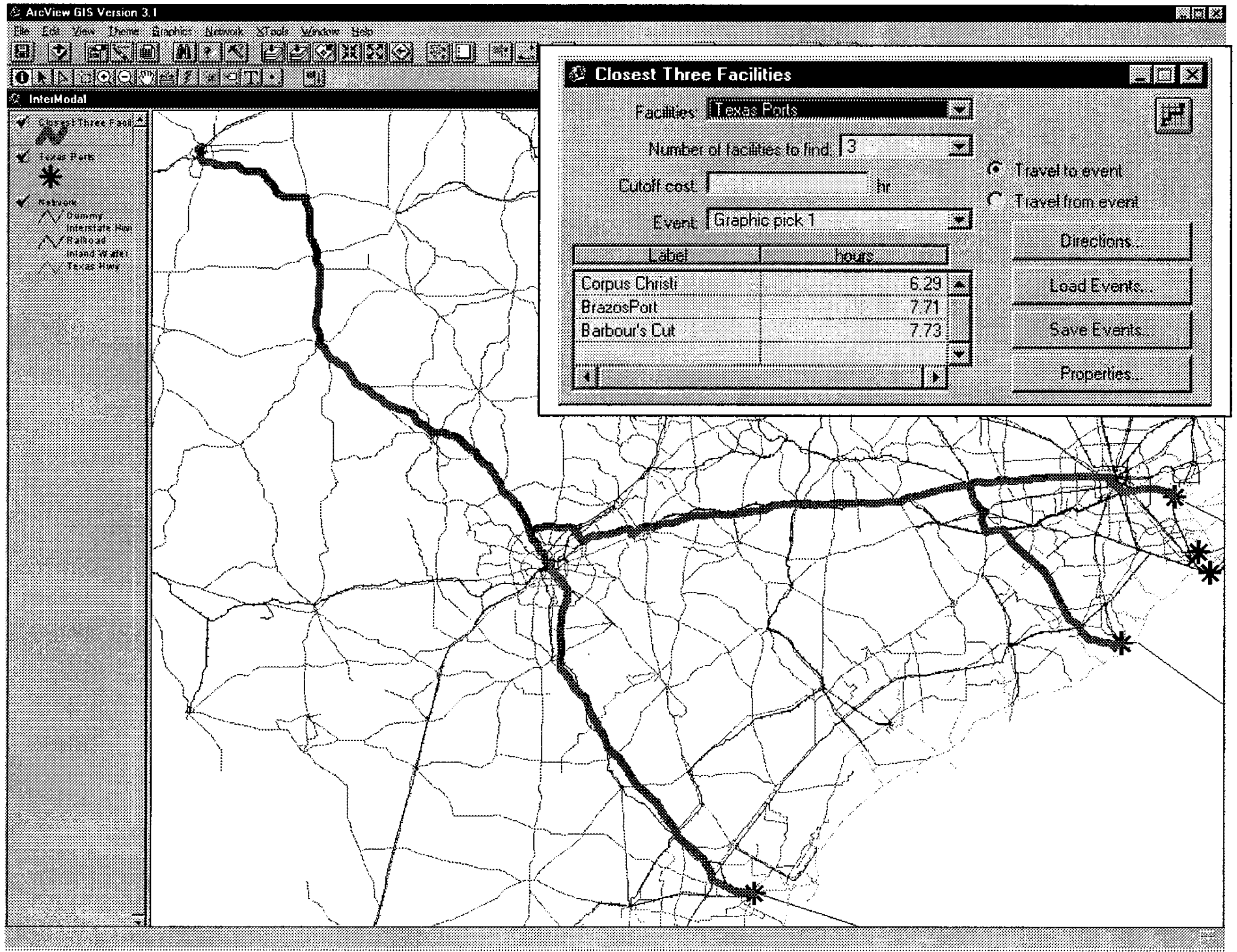


Figure 6.4, Closest Facility Analysis For San Angelo

6.3 CASE STUDY: TEXAS CITY MEGA-SHIP FACILITY

One important application for this research is determining the impact of changes to cost structures on route choice. The Port of Texas City has examined the possibility of expanding to serve mega-ships, the current largest class of container vessels. This case study will examine the geographic impacts of such a facility. Both least cost routes and service area will be developed to show the influence that construction of this project might have.

The following assumptions were made to model a mega-ship facility. First, cost was reduced by 25% from 12.5 cents to 9.375 cents per TEU mile. Second speed was increased from 20mph (17.5 knots) to 25mph (22 knots). This reflects the increased performance of these vessels over Panamax vessels.

6.3.1 Current Service Areas

The first portion of this case study examines usage of a new Texas City mega-ship terminal versus the combination of Newark, New Jersey and land services for service to Europe. The goal is to demonstrate how traffic might shift from East Coast ports to Texas City. Newark was chosen as it is the pre-imminent East Coast port, handling almost 2.5 million TEU's in 1997[71]. Figure 6.5 shows those roadways accessible within a $4500 limit, with inventory carrying costs at $10 per hour. Note that only accessible roadways are shown, with rail reaching farther inland but short of an intermodal terminal for both ports. This figure demonstrates that given current costs, Gulf Coast ports are minimally competitive with Eastern ports. Houston is the least cost port for the Houston metropolitan area, a relatively small area for a major port. Additionally, any vessel calling at this port will most likely be travelling partially laden from an east cost port. Therefore, significant economies must exist before such a service becomes feasible.

6.3.2 Service Area with Texas City Mega-Ship Terminal

A second analysis was undertaken, Figure 6.6, to determine a $4500 accessibility contour with a mega-ship facility at Texas City. Several important observations can be obtained from this figure relative to Figure 6.5. First, port expansion at Texas City would

[71] Muller 1999 pg. 357

offer a sufficiently large service area to be economical. One can clearly see that shippers in the Southwest and the Mississippi Delta regions would benefit from a Texas City terminal. These savings would continue into Missouri, where both contours overlap, indicating that individual shippers in this region will vary in their usage of Texas City instead of current patterns.

A second analysis is to examine impact in major markets and the impact of inventory carrying costs on route choice given a new Texas City facility. Figure 6.8 shows preferred routing to major western cities at $10 and $25 per hour inventory carrying costs.

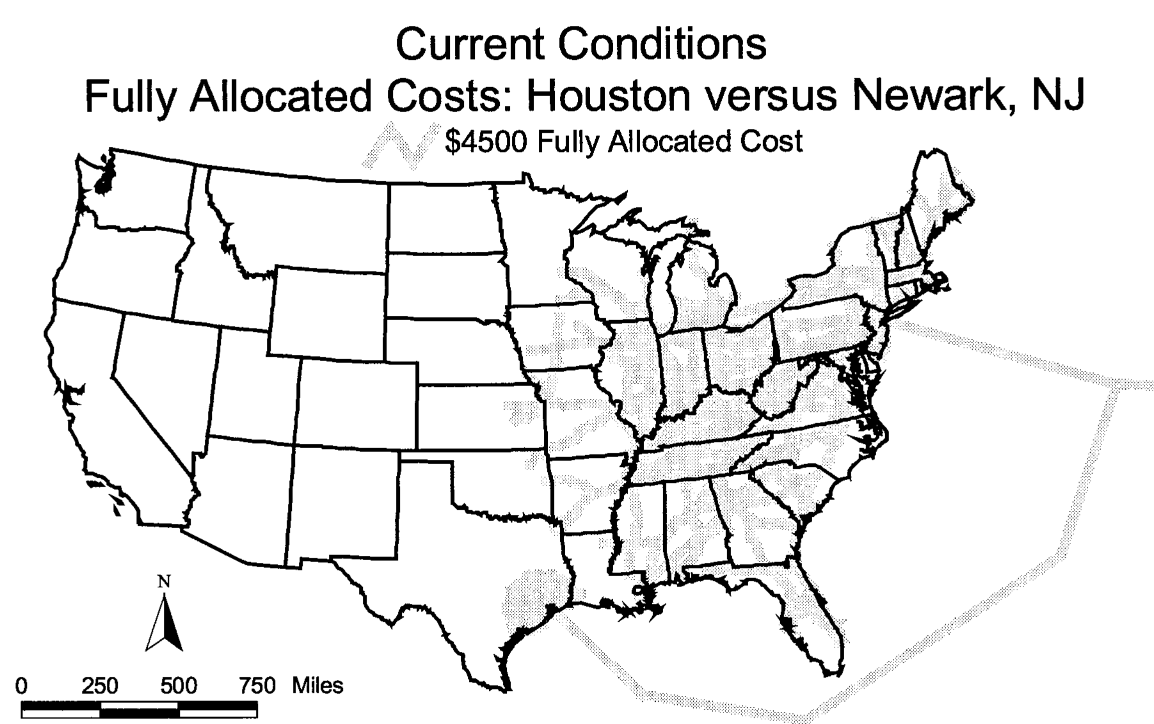


Figure 6.5 Fully Allocated Cost Contour for Houston and Newark
* $10/hr. inventory carrying cost

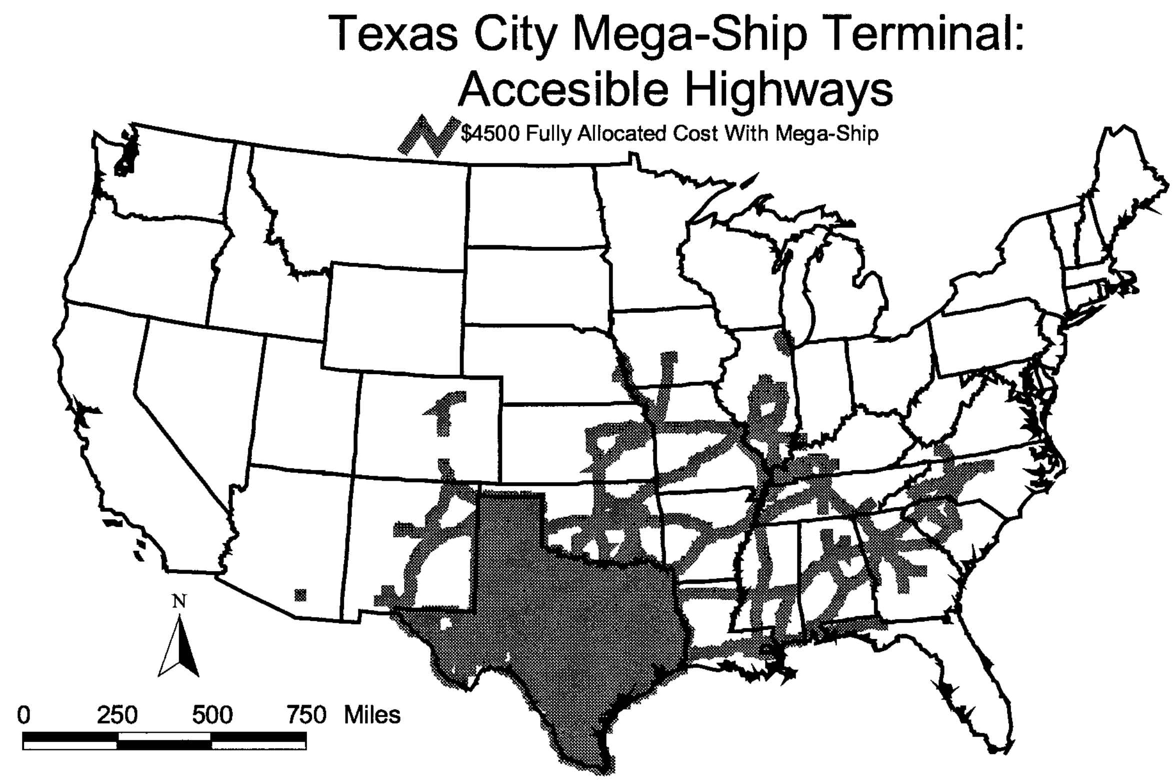


Figure 6.6 Texas City Mega-Ship Terminal Accessibility

Figure 6.7 shows that for all West Coast ports except Seattle, a routing through Texas City has the lowest fully allocated costs at $25 per hour inventory costs. This suggests that creation of a mega-ship capable port on the Gulf Coast is likely to radically alter the nature of land-bridge services, perhaps altering the flow of a significant amount of freight from East Coast ports to the new facility.

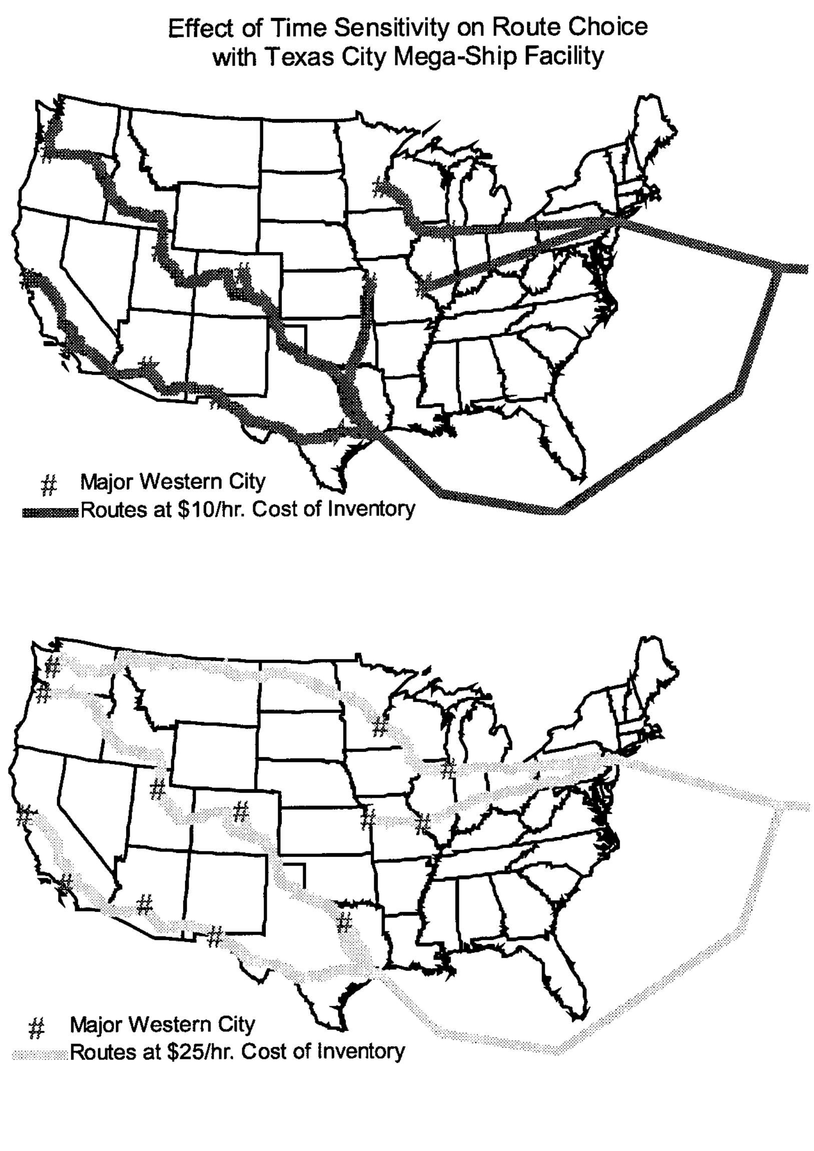


Figure 6.7 Time Sensitivity with Texas City Mega-Ship Facility

A second key observation is that Kansas City and St. Louis appear to form a line of equal cost. South and West of these cities, the least cost route will be through Texas City, while North and East of these locations freight patterns will not change. Figure 6.8 shows this line of equal cost.

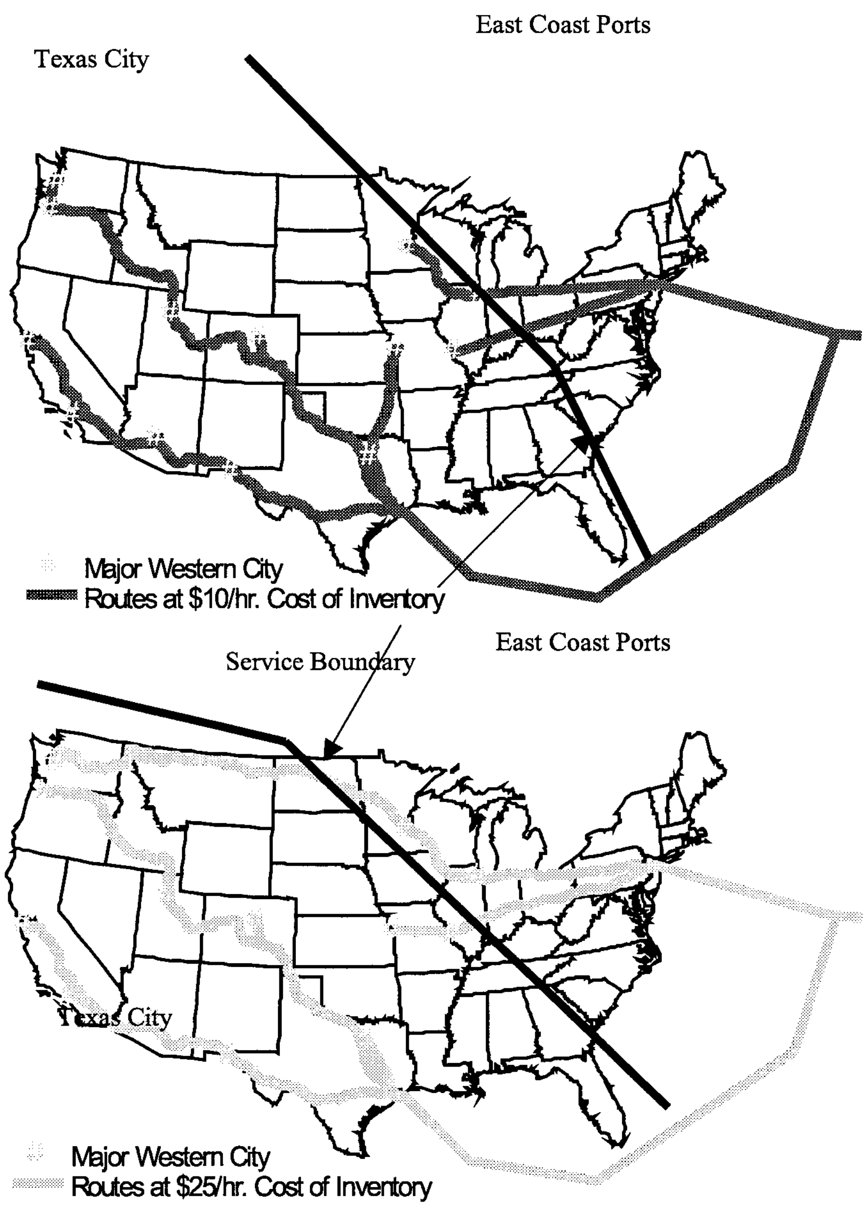


Figure 6.8 Service Area for Texas City Mega-Ship Facility

6.3.3 Impacts to Land-Bridge Services

An important impact of a new facility at Texas City, previously discussed is the movement of freight from Asia to Europe via U.S. land-bridge service. The primary route for this service is from Los Angeles to Newark. The cost structure for this route was compared against usage of a mega-ship via Texas City. Figures 6.9 and 6.10 show these results. Modeled results indicate a drop in shipment costs from $4826 to $4043 per 40 foot container at $10 an hour carrying costs.

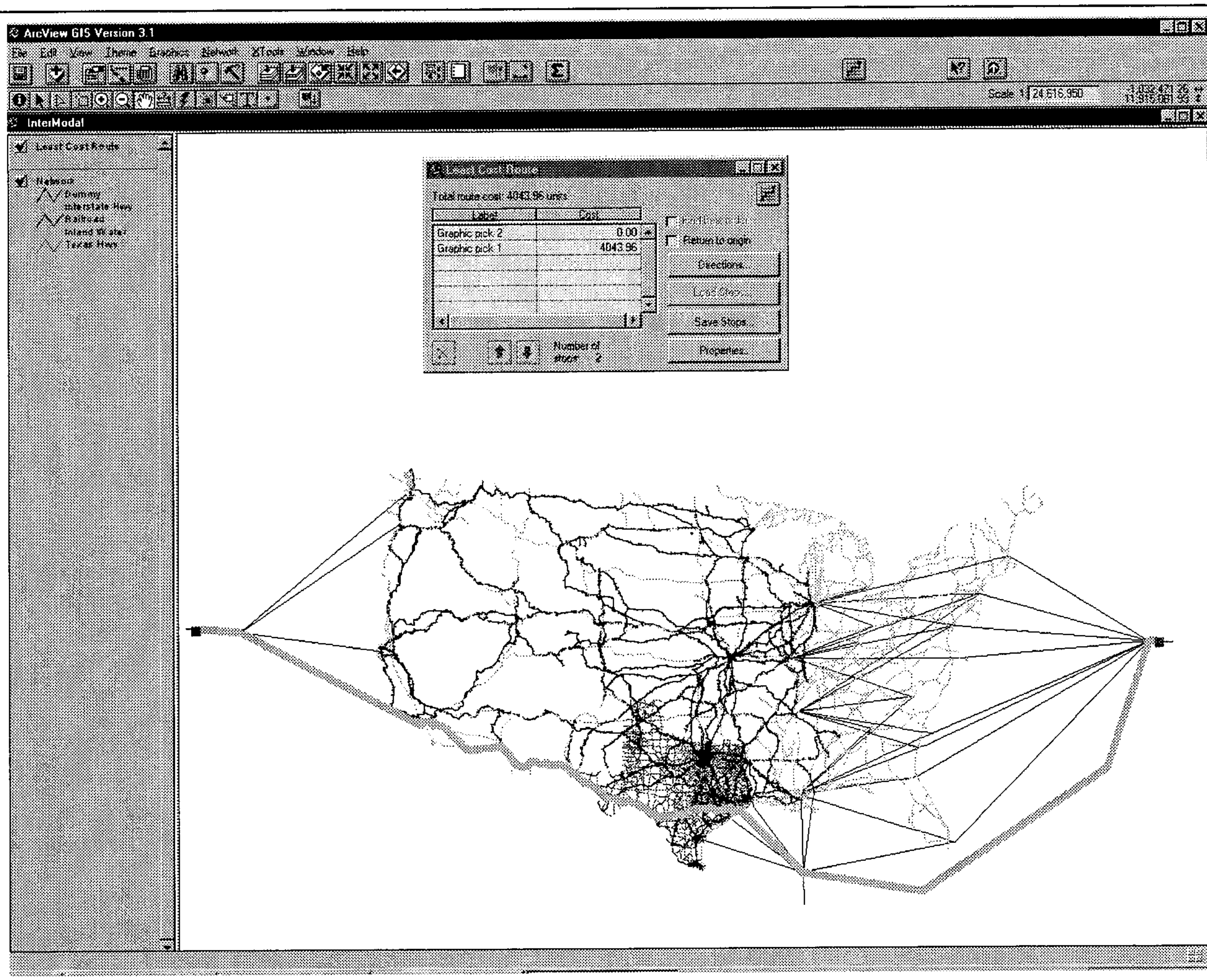


Figure 6.9
Least Cost Route via Texas City Mega-Ship Facility: Europe to Asia via Land-Bridge

Given the proximity of ports on the Gulf of Mexico to South America, a similar analysis can be produced for intermodal shipments from that continent and the Caribbean. For these freight flows, the impact of a mega-ship terminal will likely be much greater than for flows oriented towards the European mark.

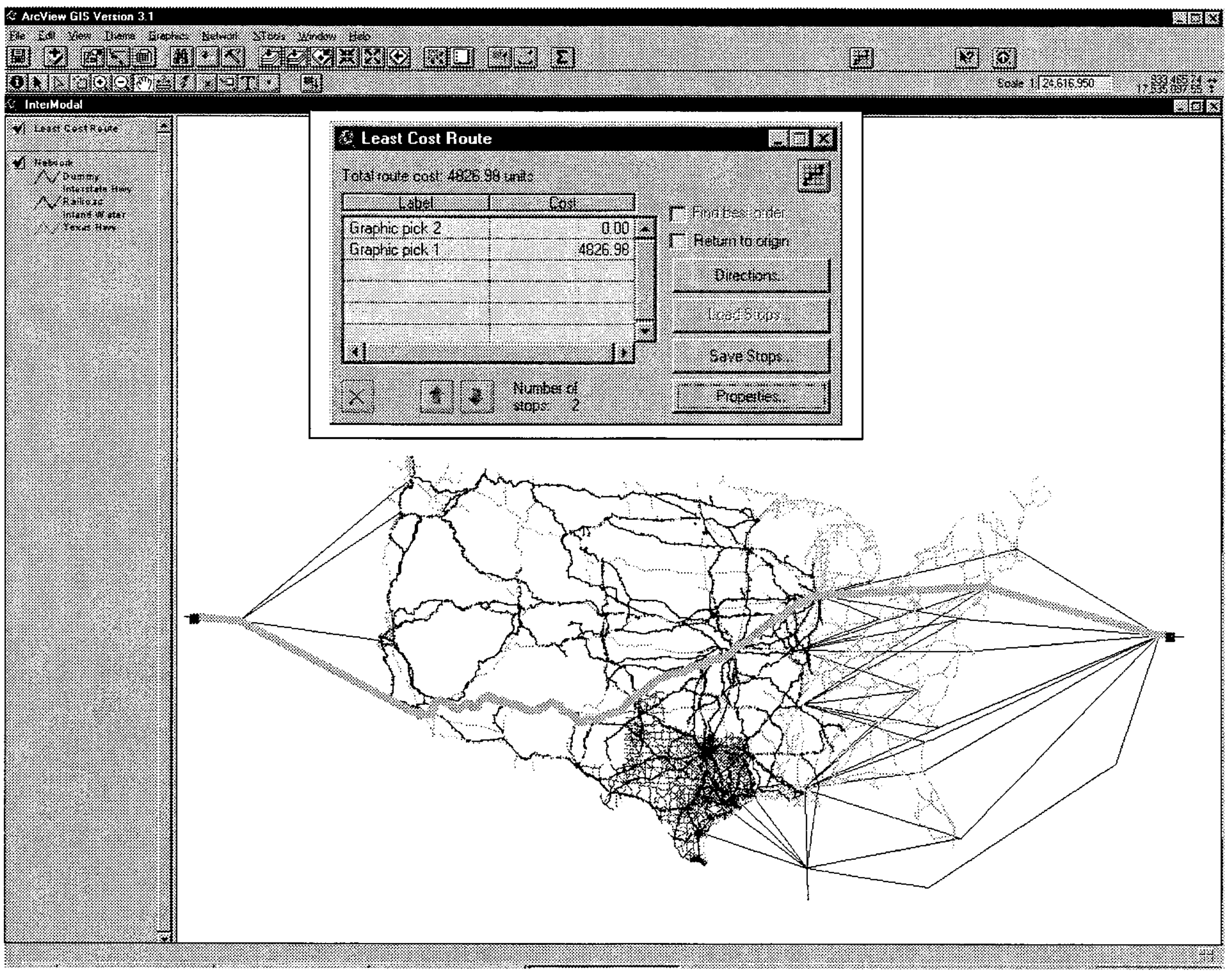


Figure 6.10 Least Cost Route Via Newark, New Jersey: Europe to Asia via Land-Bridge

6.3.4 Model Validation

Cost results from this analysis also offer the opportunity to validate the intermodal model. Table 6.1 shows a comparison of model results to actual numbers.

Table 6.1 Model Cost Validation

Segment	Cost	Total
Asia to U.S.[72]*	$1473	
U.S.-Europe[73]*	$1459	
Los Angeles to Newark*	$.56[74] * 2850=$1596	
Actual Cost		$4528
Model Cost		$4826
Difference		**+$298**

* Ocean Carrier Rate only

**Does not account for reduced land-bridge rate

6.3.5 GIS Limitations in Case Study

Several limitations of the GIS model can be seen in these maps. However, for a specific analysis adjustments can be made to correct these errors. First, using a single line for all flows does not allow for pricing to vary among destinations sharing a common route. This distinction is particularly important in representing rail land-bridge rates, which are often significantly lower than normal rates. Examining Figure 6.8, one can see that the line from New York to Chicago moves from a straight rail dummy link to the interstate highway network. In reality, a bridge rate would likely apply for this movement, and interlining might occur in Chicago. These changes would significantly reduce costs, possibly shifting this travel back to the rail mode. Second, access to containers is not ubiquitous along rail, ship, and barge routes. There are specific locations where unloading can occur for these modes. Therefore, the results from any analysis must be modified to show only those points with access, specifically roads and relevant barge facilities.

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[72] Muller 1999 pg. 332

[73] Muller 1999 pg. 332

[74] Muller, Gerhardt Intermodal Freight Transportation, 3rd Edition, Eno Transportation Foundation Washington, D.C. 1995 pg. 106

6.3.6 Summary of Texas City Case Study

The Texas City case study shows the full power of a multi-modal GIS- based system. Modal transfers are integrated into the network, allowing one to test impacts on road, rail, ship, and barge within one system. Analysis' performed included impact of inventory carrying costs, diversion of freight to Texas City, and determination of the service area for Texas City. The impact of a new facility at this site was easily quantified and displayed, providing excellent data for decision-makers. GIS provided a clear demonstration that that a mega-ship facility at Texas City will dramatically alter freight flows.

6.4 SUMMARY

The results shown in this chapter clearly prove feasibility of GIS as an intermodal analysis tool. The three case studies examined provide strong examples of how to apply GIS to the problems inherent in the intermodal freight industry. In each of these studies the three basic tools in ArcView, closest facility, least cost routing, and service area/network were applied to produce vivid results in am easily understood viewable format. The case studies were able to identify costs on routes, determine changes in market area due to changed cost structures, examine the impact of inventory carrying costs, and provide data on closest intermodal facilities. Additionally, in the Permian Basin study, the power of GIS as a data integration tool was highlighted, with population from census data summed over a time contour. This model represents an integrated solution for analysis within the intermodal industry.

CHAPTER 7: CONCLUSION

Chapter 7 describes the challenges in creating a GIS based intermodal freight application. This research aims to demonstrate usage of GIS as an analysis and policy tool for routing and determination of market area and characteristics. Major issues in achieving these goals will be addressed, with relevant observations, results and conclusions outlined to aid future research efforts.

In the context of this research, creation of a GIS based intermodal transportation network, proper identification of the scope of work and scope of analysis was crucial. Four steps can be identified within this research effort; project conception, determination of data needs, identification of network development and data preparation processes, and network implementation. Each of these issues must be addressed to successfully implement a model for GIS based freight model.

7.1 PROJECT CONCEPTION

The first step, project conception, is the determining of desired results. The most important task within project conception is developing an understanding of the processes to be modeled. The intermodal industry, freight modeling, and GIS techniques and usage were all examined to define project goals.

7.1.1 Project Context

The primary context for this report is the intermodal freight industry. The practices and performance of this industry provide the basis for the model described herein. Specifically, this research applies to containerized traffic, a segment within intermodal freight that has more than doubled since 1980[75]. The increasing usage of intermodal freight and shipment of international goods has led to new challenges as these portions of the freight industry expand. Specifically, massive investments are being made in terminal modernization, ITS (Intelligent Transportation Systems), and basic infrastructure such as ships, cranes, and clearance for double stack trains.

[75] Cambridge Systematics, Volume I pg. 1-11, Volume II pg. 1-7

7.1.2 GIS and Freight Research Overview

A second issue within project conception is the ability of GIS to model intermodal freight. In order to develop an appropriate set of goals, GIS capability was determined. The state of the art was examined, and it was found that much research had been done using each mode individually within GIS. This type of work is well documented in the applicable literature. However, examples of true multi-modal integration within a GIS framework were scarce. Examples of recent GIS usage for freight include commodity flows, single mode gravity models, and GIS as a visualization tool. Chapter 1.3.1 identifies several such research endeavors.

7.1.3 GIS Techniques

While examining usage of GIS for modeling transportation, applicable techniques were noted for data conflation and establishment of movement rules. The first issue, of data conflation, refers to the placement of attribute data onto specific geographic confines. Two primary techniques exist, dynamic segmentation and link-node structures. Dynamic segmentation is "linear" referencing, usually based upon mileposts, allowing data to be placed between any two points along a line. In contrast a link-node structure allows one to place data only onto pre-defined links, typically the span between intersections of network features. Techniques for establishment of movement rules such as artificial "dummy" links, planar separation and turn penalties (turntables) were also examined, and applicability determined. Each of these methods is used within the completed model. Planar separation, a method intended to model overpasses was identified as applicable to those cases where turning movements at a given node were to be prohibited. A second method is turntables, which establish impedance at a node for specific link to link movements at a given node and allow variability of impedance between movements. Finally, movement could be controlled via dummy links, artificial links used to apply non-standard attribute values in a network.

7.2 DATA NEEDS

While creation of a network within GIS is a substantial effort, the underlying data determines the applicability of the final product. Therefore, data is a crucial component to model freight flow. The twin issues of geographic data, attribute data, and performance functions were addressed.

Data acquisition proved far more difficult than anticipated. This was particularly true regarding performance functions for different modes. Intermodal freight is a highly competitive business controlled by private firms. Therefore data on costs and time is often difficult to obtain as distribution of this data is felt to reduce competitive advantages.

Potential sources for project data included public domain, proprietary, and privately collected data. The primary goals in acquiring appropriate data sets were to establish accuracy, relevancy, sufficiency, and organization. Gathered data needed to be accurate so that non-modeling error was minimized, relevant to the research effort, sufficient to describe the system being modeled, and structured in a rational manner consistent with other components. Much of the data was obtained from public sources. However, performance data was necessarily approximate and was obtained via inference, industry references, and interviews.

Primary geographic data was obtained from the Texas Department of Transportation (TxDOT) for Texas roadways. Geography for railroads and inland waterways was obtained from the National Transportation Atlas Database (NTAD). Additional data was obtained from the University of Texas and ESRI. Attribute data was obtained from TxDOT, the NTAD, major railroads, and relevant literature and key persons.

7.3 NETWORK DEVELOPMENT

The next step after data identification and acquisition was network development. Three distinct processes; data processing, data conflation, and network development were undertaken. The first two tasks refer to organizing and manipulating the acquired data into a usable format, accurate and consistent with geographic units. Finally, after data conflation, the full network was constructed.

7.3.1 Data Processing

The final network in this application contains over 40,000 links. Given this size, automated routines were required to process the data and establish network characteristics. Specific automated processes in this research included checks for errors, preparation for dynamic segmentation, relational linkage of associated data, assignment of attributes, and creation of network turning rules. These tasks were accomplished via use of both custom applications written in the 'C' language and standard database and spreadsheet software.

7.3.2 Data Conflation and Network Development

After processing the required data, network building was undertaken. This process is primarily one of data conflation, the association of attribute data within specific geographic space. The model network was built in three stages. First, each modal network was prepared, with separate networks for inland waterways, Texas roads, interstate highways, and for each of the three class I railroads in Texas. The Texas road network was created using dynamic segmentation, with the remaining sub-networks using the more traditional link-node typology. Second, these networks were merged to create a single unified network, with planar separation used to control routing between modes and rail companies. Finally, transfer facilities and artificial "dummy" links were added in order to model the interactions between modes and to assign costs at transfer facilities. Movement costs were assigned either to the appropriate network link or controlled via a turntable. Figure 7.1 shows the resulting network.

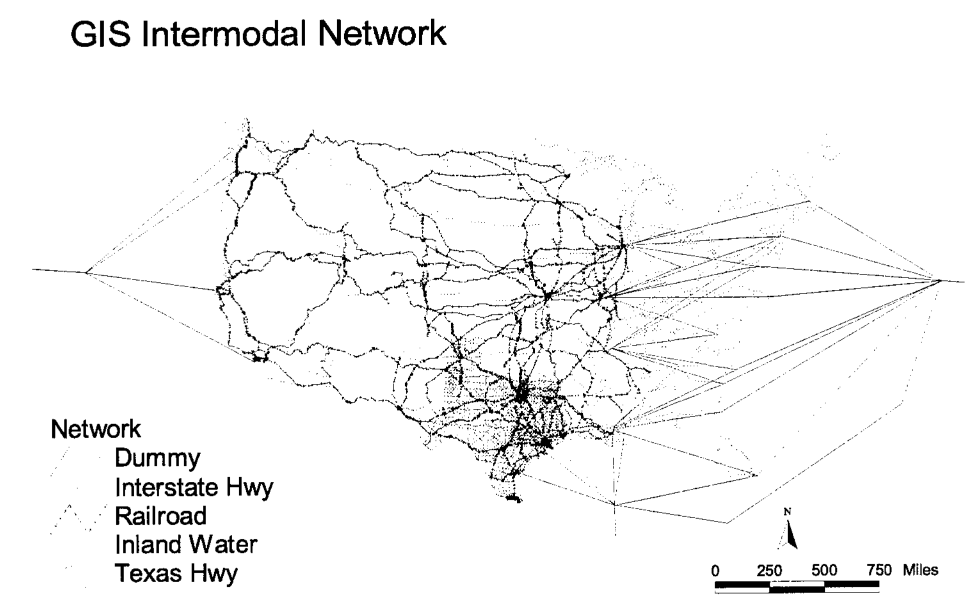

Figure 7.1 GIS Intermodal Network

7.4 MODEL IMPLEMENTATION

The last stage in completing the intermodal freight network was network implementation. Specifically, implementation of performance measures, fine tuning, trouble-shooting, and finally, application was undertaken. Within this stage, application to several real-world scenarios was demonstrated. A case study of usage of GIS to determine spatial bounds of accessibility to intermodal facilities and sum attributes for the geographic region enclosed by a time contour was shown. An analysis of closest facilities was completed, showing the power of GIS as a routing tool. The relative advantages of a mega-ship terminal at Texas City was examined, and market area determined for this potential new service. Finally, the impact of differing time value of money was studied using the GIS model to quantify the impact of speed on modal choice.

7.5 RECOMMENDATIONS

Several recommendations can be gleaned from this research experience. First is a set of recommending regarding scope. Specifically the effect of scope vis-à-vis analysis capabilities and data requirements is examined.

Analysis capabilities should be examined before selecting a software package. Specifically, project goals must be compared against GIS capabilities. GIS software can be somewhat limited in "off-the-shelf" capabilities. In the context of this research effort, the selection of ArcView was a trade-off limiting analysis to routing problems in exchange for ease of use. Future efforts might choose to use a software package with more complete GIS-T analysis capabilities.

Based upon the experience documented in this report, it is imperative that data be considered early in the process. Therefore, the first step in any similar effort should be an assessment of data needs in the context of availability and requirements to achieve project goals. Quality of data must also be considered. It is recommended that data acquisition efforts begin before scope is finalized, as the process can be quite lengthy, and failure to obtain data can cause substantial difficulties in fulfilling project goals. In essence, feasibility of attaining project goals must be firmly established.

Available data must be evaluated in the context of analysis techniques to determine whether both items can be used in concert. This is largely a question of compatibility and quality. Within this research effort, the process used to prepare the Texas road data was unnecessarily cumbersome. The geographic and attribute data sets were in fundamentally different formats. Usage of compatible data units would have greatly eased this process and improved accuracy.

A last recommendation is to examine available data and appropriate analysis processes before finalizing project goals and scope. The original project conception must be altered to match available data and utilize feasible analysis techniques. This will ensure overall project feasibility. Additionally, an early examination of data and processes provides a framework for executing project goals. In the case of this research effort, scope was altered substantially after examining GIS capabilities and data requirements. Rather than develop a detailed, localized application, a decision was made to fully utilize the spatial analysis capabilities of GIS by expanding the study area.

7.6 FUTURE APPLICATION

This research project aimed to demonstrate usage of GIS for intermodal freight analysis. As such, it provides a platform for future expansion and application. It is hoped that this project will be a basis for future work, with features gradually being added.

Future research utilizing this system might wish to modify the basis for facility performance. Current assumptions provide for uniform costs between similar facilities. However, in reality these costs vary. Determination of more realistic cost assumptions, perhaps in cooperation with an industry participant could greatly improve the final product of this effort.

A second potential modification might be addition of an option to limit intermodal movements to existing origin-destination pairs and exactly define performance on these routes. This would require either a route-based system or addition of more dummy links. The current model assumes that all facility pairs are served, which is appropriate for planning purposes. This change would require more research into rail intermodal performance but will increase accuracy substantially.

Two categories of potential future expansion in analysis capability are creation of a customized GUI (Graphical User Interface), and the automation of analysis processes. In the GIS network's current state, much user knowledge of GIS is necessary to formulate a set of test conditions. A GUI allowing a set of specialized applications would be most useful for policy analysts and others who desire to test hypothesis but may not have extensive GIS knowledge.

Future applications are likely to pertain to routing, market area analysis, or examination of policy impacts. The case studies demonstrated possibilities within these problem classes, however the basic process can be applied to a wide variety of questions relevant to the intermodal industry. Specific problems might include locational analysis of new facilities for both freight firms and shippers, impacts of rate and speed changes, ands effects of regulatory changes.

7.7 CONCLUSION

Results from this research efforts demonstrate feasibility of GIS to model intermodal freight transportation. A comprehensive network accurately depicting movement rules and costs was developed, allowing a rich set of analyses. This network was successfully applied to develop least cost routes, determine market area and market characteristics, test the effects of a new facility, and examine the impact of carrying costs for high value freight on route choice. The final product represents a powerful, easily utilized tool that will provide an excellent platform for industrial users, policy applications, and future research efforts.

APPENDIX A

CUSTOM ‘C’ CODE TO CONVERT FROM COUNTY-BASED TO STATEWIDE MILEPOSTS

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>

void array (void);
void nodecount(void);
void printcty(void);
void thru(void);
void error(void);
/* all variables defined globally..functions only to avoid code repitition*/
int nodes[4][2];            /* node 1-4 used to hold nodes attached to other counties*/
int numnodes = 0;           /* holds number of nodes connecting counties*/
int true = 0;               /* used to hold true/false values*/
int z=0;                    /* counters*/
int q=0;
int counties[20];           /* holds counties..note no more than twenty allowed*/
char route[6];              /* stores route to be summed*/
double sumlength=0.00;              /* sum of length before leaving county*/
FILE* start_ptr;
FILE* arc_ptr;
FILE* trm_ptr;
FILE* out_ptr;
FILE* error_ptr;
int prevcty;
int cty; /* holds cty currently being worked*/
int ctycount; /*holds number of counties with route*/
int ctyenter; /*holds number of counties entered*/
int intermcty = 0;/* holds county that route passes through*/
int nextcty = 0;      /* holds next county for through function*/
double maxdfo = 0;          /* holds current maximum mileage*/
double dfold;               /* holds max mileage of previous county*/
struct record         /* stores input data from nodes file, input should be in this order*/
{
int fnode;
int tnode;
int cty;
char rte[7];
double length;
};
struct record arcs;
struct data
{
        int ctynum;
        char hwy[7];
        double begdfo;
        double enddfo;
```

```
            double aadt;
            double taadt;
            int speed;
            int functclass;
            int lanes;
            double peroff;
};
struct data TRM;
/* hold links for each route, invoked once at start of route analysis*/
struct record ctyrte[500];
/* holds number of links so that ctyrte can be stopped*/
int i = 0;
/* hold file names*/
char start[15];
char arcfile[15];
char trmfile[15];
char out[15];
char errorstr[15];
/* declare functions */


void main (void)
{
/* get file names*/
printf("Enter name of file containing starting county data by route\n");
scanf ("%s", &start);
printf("Enter name of file containing arc data\n");
printf("Data should be tab seperated with fields; fnode tnode county route length\n");
scanf ("%s", &arcfile);
printf("Enter name of file containing TRM data\n");
printf("Data should be tab seperated with fields; ctynum hwy begdfo enddfo aadt taadt speed class lanes peroff\n");
scanf ("%s", &trmfile);
printf("Enter name of file for output\n");
scanf ("%s", &out);
printf("Enter name of file for errors\n");
scanf ("%s", &errorstr);
/* open start file */
start_ptr = fopen(start, "r");
error_ptr = fopen(errorstr, "w");
/* initialize output file*/
out_ptr = fopen(out, "w");
/* print field names?*/
fclose(out_ptr);
/* Beginning of main loop .. keeps going until end of route/start county file*/
mainloop:;
maxdfo = 0;
dfold = 0;
prevcty = 0;
cty = 0;
ctyenter = 0;
while(fscanf(start_ptr, "%s", route) != EOF)
{
            fscanf(start_ptr, "%d", &cty);
```

```
array();
/*Begins county loop which returns on condition that all counties are not entered*/
countyloop:;
nodecount();
printf("Rte-%s\tCty-%d\tNumnodes-%d\n", &route, cty, numnodes);
if (numnodes == 0)
{
        if (prevcty != 0)
        {
                error();
                goto mainloop;
        }
        printcty();
        ctyenter++;
        if(ctyenter == ctycount)
        {
                goto mainloop;
        }
        printf ("Enter next county number after %d for route %s, or -1 to go to next route\n", cty, route);
        scanf("%d", &cty);
        if (cty == -1)
        {
        prevcty = 0;
        cty = 0;
        error();
        goto mainloop;
        }
        goto countyloop;
}
if(numnodes == 1)
{
        if (prevcty == 0)
        {
                printcty();
                ctyenter++;
                prevcty = cty;
                cty = nodes[0][1];
                goto countyloop;
        }
        ctyenter++;
        if(ctyenter == ctycount)
        {
                printcty();
                goto mainloop;
        }
        printcty();
        printf ("Enter next county number after %d for route %s, or -1 to go to next route\n", cty, &route);
        prevcty = 0;
        scanf("%d", &cty);
        if (cty == -1)
        {
        cty = 0;
        prevcty = 0;
```

```
			error();
			goto mainloop;
			}
			goto countyloop;
	}
	if (numnodes == 2)
	{
			if ((prevcty == 0) || (nodes[0][1] == nodes[1][1]))
			{
					error();
					goto mainloop;
			}
			printcty();
			ctyenter++;
			if (nodes[0][1] != prevcty)
			{
					prevcty = cty;
					cty = nodes[0][1];
					goto countyloop;
			}
			prevcty = cty;
			cty = nodes[1][1];
			goto countyloop;
	}
	if (numnodes == 3)
	{
			if(prevcty == 0);
			{
					if((nodes[0][1] == nodes[1][1]) || (nodes[0][1] == nodes[0][2]))
					{
							intermcty = nodes[0][1];
							if (nodes[0][1] == nodes[1][1])
							{
									nextcty = nodes[1][2];
									thru();
									ctyenter+=2;
									prevcty = cty;
									goto countyloop;
							}
							nextcty = nodes[1][1];
							thru();
							ctyenter +=2;
							prevcty = cty;
							goto countyloop;
					}
					if (nodes[1][1] == nodes[1][2])
					{
							intermcty = nodes[1][1];
							nextcty = nodes[0][1];
							thru();
							ctyenter +=2;
							prevcty = cty;
							goto countyloop;
```

```
				}
		if (prevcty != 0)
		{
			if((nodes[0][1] == nodes[1][1]) || (nodes[0][1] == nodes[0][2]))
			{
				intermcty = nodes[0][1];
				if (nodes[0][1] == nodes[1][1])
				{
					nextcty = 0;
					thru();

				}
				nextcty = nodes[1][1];
				thru();
			}
			if (nodes[1][1] == nodes[1][2])
			{
				intermcty = nodes[1][1];
				nextcty = 0;
				thru();
			}
			/*if no same nodes error()*/
			if ((nodes[0][1]!= nodes[1][1] ) && (nodes[0][1]!= nodes[2][1]) &&(nodes[1][1]!= nodes[2][1]))
			{
			error();
			goto mainloop;
			}
			ctyenter += 2;
			prevcty = cty;
			goto countyloop;
		}
	error();
	goto mainloop;
	}
	if (numnodes == 4)
	{
		true = 0;
		for (z=0; z < numnodes ;z++)
		{
			if (prevcty == nodes[z][1])true++;
		}
		if(true != 1)
		{
			error();
			goto mainloop;
		}
		if (prevcty == 0)
		{
			error();
			goto mainloop;
		}
		true = 0;
		for (z=0;z<numnodes;z++)
```

```
		{
			for(q=0;q<numnodes;q++)
			{
				if (nodes[z][1]== nodes[q][1])
				{
					if(z != q)
					{
						true++;
						intermcty = nodes[z][1];
					}
				}
			}
		}
		if (true != 2)
		{
			error();
			goto mainloop;
		}
		thru();
		ctyenter+=2;
		prevcty = cty;
		goto countyloop;
	}
	goto mainloop;
	}/*end county loop*/
	error();
	goto mainloop;
	}/* end of main while*/
	fclose(error_ptr);
	fclose(start_ptr);
	printf("Records Outputted");
	}/* ending*/


	void nodecount(void)
	{

		/*checks for nodes attached to other counties .. if over 4 error message generated*/
		numnodes = 0;
		for (z=0; z <= i; z++)
		{
			for (q=0; q <= i; q++)
			{
				if ((ctyrte[z].fnode == ctyrte[q].fnode) || (ctyrte[z].fnode == ctyrte[q].tnode))
				{
					if(q != z)
					{
						if ((ctyrte[z].cty == cty) && (ctyrte[q].cty !=cty))
						{
							nodes[numnodes][0] = ctyrte[z].fnode;
							nodes[numnodes][1] = ctyrte[q].cty;
							numnodes++;
```

```
							printf("route- %s\tcounty- %d\t numnodes- %d\t adjacent
county %d\n",&route, cty, numnodes, nodes[numnodes][1]);
							if (numnodes == 5)
							{
							printf("Error, greater than four adjoining nodes for county
%d and route %s", cty, &route);
							fprintf(error_ptr,"route%s\tcounty%d\n", &route, cty);
							}
						}
					}
				}
				if ((ctyrte[z].tnode == ctyrte[q].fnode) || (ctyrte[z].tnode == ctyrte[q].tnode))
				{
					if(q != z)
					{
						if ((ctyrte[z].cty == cty) && (ctyrte[q].cty !=cty))
						{
							nodes[numnodes][0] = ctyrte[z].tnode;
							nodes[numnodes][1] = ctyrte[q].cty;
							numnodes++;
							printf("route- %s\tcounty- %d\t numnodes- %d\t adjacent
county %d\n",&route, cty, numnodes, nodes[numnodes][1]);
							if (numnodes == 5)
							{
							printf("Error, greater than four adjoining nodes for county
%d and route %s", cty, &route);
							fprintf(error_ptr,"route%s\tcounty%d\n", route, &cty);
							}
						}
					}
				}

			}
		}
}


void printcty(void)
{
trm_ptr=fopen(trmfile,"r");
out_ptr=fopen(out, "a");
			while (fscanf(trm_ptr, "%d", &(TRM.ctynum)) != EOF)
			{
				fscanf (trm_ptr, "%s", &(TRM.hwy));
				fscanf (trm_ptr, "%lf", &(TRM.begdfo));
				fscanf (trm_ptr, "%lf", &(TRM.enddfo));
				fscanf (trm_ptr, "%lf", &(TRM.aadt));
				fscanf (trm_ptr, "%lf", &(TRM.taadt));
				fscanf (trm_ptr, "%d", &(TRM.speed));
				fscanf (trm_ptr, "%d", &(TRM.functclass));
				fscanf (trm_ptr, "%d", &(TRM.lanes));
				fscanf (trm_ptr, "%lf", &(TRM.peroff));
				if(TRM.ctynum == cty)
```

```
                        {
                                if (strcmp (TRM.hwy, route) == 0)
                                {
                                /* add previous total mileage*/
                                TRM.enddfo += dfold;
                                TRM.begdfo += dfold;
                                /* check for max mileage and update if neccesary*/
                                if (TRM.enddfo > maxdfo) maxdfo = TRM.enddfo;
                                fprintf (out_ptr, "%d\t%s\t%lf\t%lf\t%lf\t%lf\t%d\t%d\t%d\t%lf\n", TRM.ctynum,
TRM.hwy, TRM.begdfo,
                                   TRM.enddfo, TRM.aadt, TRM.taadt, TRM.speed,
                                        TRM.functclass, TRM.lanes, TRM.peroff);
                                }
                        }
                }
                /* update old max mileage*/
        dfold=maxdfo;
        fclose(trm_ptr);
        fclose(out_ptr);
}


/* prints error message to screen and to file*/
void error(void)
{
error_ptr= fopen(errorstr, "a");
printf ("Error in county %d and route %s", cty, &route);
fprintf(error_ptr, "Error in county %d and route %s", cty, &route);
fclose(error_ptr);
}

void thru(void)
{
printf("3 or four nodes\nprevcty%d \t cty%d \t intermcty%d \t rte%s\n", prevcty, cty, intermcty, &route);
error_ptr= fopen(errorstr, "a");
fprintf(error_ptr, "3 or four nodes\nprevcty%d \t cty%d \t intermcty%d \t rte%s\n", prevcty, cty, intermcty, &route);
fclose(error_ptr);
}

void array(void)
{
        arc_ptr = fopen(arcfile, "r");
        /* initializes route loop*/
        ctycount = 0;
        i = 0 ;
        /* gets all the link data into array ctyrte*/
        while (fscanf(arc_ptr, "%d",  &(arcs.fnode)) != EOF)
        {
                fscanf(arc_ptr, "%d", &(arcs.tnode));
                fscanf(arc_ptr, "%d", &(arcs.cty));
                fscanf(arc_ptr, "%s", &(arcs.rte));
                fscanf(arc_ptr, "%lf", &(arcs.length));
                if (strcmp(arcs.rte, route) == 0)
```

```
		{
			ctyrte[i].fnode=arcs.fnode;
			ctyrte[i].tnode=arcs.tnode;
			ctyrte[i].cty=arcs.cty;
			strcpy(arcs.rte, ctyrte[i].rte);
			ctyrte[i].length=arcs.length;
			/* calculate number of counties*/
			true =0;
			/* takes 1st cty and enters it too initialize*/
			if(ctycount == 0)
			{
				counties[0]=ctyrte[0].cty;
				ctycount++;
			}
			for (z=0; z <ctycount; z++)
			{
				if(ctyrte[i].cty == counties[z])true++;
			}
			if (true==0)
			{
				counties[ctycount]=ctyrte[i].cty;
				ctycount++;
			}
			if (ctycount == 20)
			{
				error_ptr= fopen(errorstr, "a");
				printf ("Error in county %d and route %s", cty, &route);
				fprintf(error_ptr, "Error in county %d and route %s", cty, &route);
				fclose(error_ptr);
			}
			i++;

		}
}	/*close to while loop*/

	/* preps arc_ptr for use again by closing*/
	fclose(arc_ptr);
						}
```

Appendix B
Custom 'C' Code to Remove Redundant Data

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>

void main(void)
{
	struct data
	{
		int ctynum;
		char hwy[7];
		double begdfo;
		double enddfo;
		double aadt;
		double taadt;
		int speed;
		int functclass;
		int lanes;
		double peroff;
	};
	struct data TRMone;
	struct data	TRMtwo;
	struct data	TRMthree;
	FILE* trm_ptr;
	FILE* out_ptr;
	char trmfile[15];
	char outfile[15];
	int stop=0; /*used to determine if EOF occured in a loop 2= getting TRMtwo and 3= getting TRMthree*/
	printf("Enter name of file with formatted TRM data, i.e. DXXout.txt\n");
	printf("Note that all data must be in order..copy to Access by pasting\n");
	printf("from Notepad, then filter the data in ascending order first by route and\n");
	printf("then by beginning feet\n");
	scanf ("%s", &trmfile);
	printf("Enter output file, ie. DXXfin.txt\n");
	scanf ("%s", &outfile);
	trm_ptr = fopen(trmfile, "r");
	out_ptr = fopen(outfile, "w");
	fscanf(trm_ptr, "%d", &(TRMone.ctynum));
	fscanf (trm_ptr, "%s", &(TRMone.hwy));
	fscanf (trm_ptr, "%lf", &(TRMone.begdfo));
	fscanf (trm_ptr, "%lf", &(TRMone.enddfo));
	fscanf (trm_ptr, "%lf", &(TRMone.aadt));
	fscanf (trm_ptr, "%lf", &(TRMone.taadt));
	fscanf (trm_ptr, "%d", &(TRMone.speed));
	fscanf (trm_ptr, "%d", &(TRMone.functclass));
	fscanf (trm_ptr, "%d", &(TRMone.lanes));
	fscanf (trm_ptr, "%lf", &(TRMone.peroff));

	fscanf(trm_ptr, "%d", &(TRMtwo.ctynum));
```

```
		fscanf (trm_ptr, "%s", &(TRMtwo.hwy));
		fscanf (trm_ptr, "%lf", &(TRMtwo.begdfo));
		fscanf (trm_ptr, "%lf", &(TRMtwo.enddfo));
		fscanf (trm_ptr, "%lf", &(TRMtwo.aadt));
		fscanf (trm_ptr, "%lf", &(TRMtwo.taadt));
		fscanf (trm_ptr, "%d", &(TRMtwo.speed));
		fscanf (trm_ptr, "%d", &(TRMtwo.functclass));
		fscanf (trm_ptr, "%d", &(TRMtwo.lanes));
		fscanf (trm_ptr, "%lf", &(TRMtwo.peroff));

		fscanf(trm_ptr, "%d", &(TRMthree.ctynum));
		fscanf (trm_ptr, "%s", &(TRMthree.hwy));
		fscanf (trm_ptr, "%lf", &(TRMthree.begdfo));
		fscanf (trm_ptr, "%lf", &(TRMthree.enddfo));
		fscanf (trm_ptr, "%lf", &(TRMthree.aadt));
		fscanf (trm_ptr, "%lf", &(TRMthree.taadt));
		fscanf (trm_ptr, "%d", &(TRMthree.speed));
		fscanf (trm_ptr, "%d", &(TRMthree.functclass));
		fscanf (trm_ptr, "%d", &(TRMthree.lanes));
		fscanf (trm_ptr, "%lf", &(TRMthree.peroff));

		loop:;
		/*if one == two and 1!=3 print one and two, one=three and get two more*/
		if (((TRMone.ctynum==TRMtwo.ctynum)&&(strcmp (TRMone.hwy, TRMtwo.hwy) ==
0)&&(TRMone.aadt==TRMtwo.aadt)&&(TRMone.taadt==TRMtwo.taadt)&&(TRMone.speed==TRMtwo.speed)&&
			(TRMone.functclass==TRMtwo.functclass)&&(TRMone.lanes==TRMtwo.lanes))&&
			((TRMone.ctynum!=TRMthree.ctynum)||(strcmp (TRMone.hwy, TRMthree.hwy) !=
0)||(TRMone.aadt!=TRMthree.aadt)||(TRMone.taadt!=TRMthree.taadt)||(TRMone.speed!=TRMthree.speed)||

		(TRMone.functclass!=TRMthree.functclass)||(TRMone.lanes!=TRMthree.lanes)))
		{
			fprintf (out_ptr, "%d\t%s\t%lf\t%lf\t%lf\t%lf\t%d\t%d\t%d\t%lf\n", TRMone.ctynum, TRMone.hwy,
TRMone.begdfo,
					TRMtwo.enddfo, TRMone.aadt, TRMone.taadt, TRMone.speed,
TRMone.functclass,
					TRMone.lanes, TRMone.peroff);

			TRMone.ctynum=TRMthree.ctynum;
			strcpy(TRMone.hwy, TRMthree.hwy);
			TRMone.begdfo=TRMthree.begdfo;
			TRMone.enddfo=TRMthree.enddfo;
			TRMone.aadt=TRMthree.aadt;
			TRMone.taadt=TRMthree.taadt;
			TRMone.speed=TRMthree.speed;
			TRMone.functclass=TRMthree.functclass;
			TRMone.lanes=TRMthree.lanes;
			TRMone.peroff=TRMthree.peroff;
			if (fscanf(trm_ptr, "%d", &(TRMtwo.ctynum)) == EOF)
			{
				stop=1;
				goto end;
			}
			fscanf (trm_ptr, "%s", &(TRMtwo.hwy));
```

```
		fscanf (trm_ptr, "%lf", &(TRMtwo.begdfo));
		fscanf (trm_ptr, "%lf", &(TRMtwo.enddfo));
		fscanf (trm_ptr, "%lf", &(TRMtwo.aadt));
		fscanf (trm_ptr, "%lf", &(TRMtwo.taadt));
		fscanf (trm_ptr, "%d", &(TRMtwo.speed));
		fscanf (trm_ptr, "%d", &(TRMtwo.functclass));
		fscanf (trm_ptr, "%d", &(TRMtwo.lanes));
		fscanf (trm_ptr, "%lf", &(TRMtwo.peroff));
		if (fscanf(trm_ptr, "%d", &(TRMthree.ctynum)) == EOF)
		{
			stop=2;
			goto end;
		}
		fscanf (trm_ptr, "%s", &(TRMthree.hwy));
		fscanf (trm_ptr, "%lf", &(TRMthree.begdfo));
		fscanf (trm_ptr, "%lf", &(TRMthree.enddfo));
		fscanf (trm_ptr, "%lf", &(TRMthree.aadt));
		fscanf (trm_ptr, "%lf", &(TRMthree.taadt));
		fscanf (trm_ptr, "%d", &(TRMthree.speed));
		fscanf (trm_ptr, "%d", &(TRMthree.functclass));
		fscanf (trm_ptr, "%d", &(TRMthree.lanes));
		fscanf (trm_ptr, "%lf", &(TRMthree.peroff));
		goto loop;
	}

	/*if one !=two print one, make 1=2 and 2=3, and get three*/
			/*record new data*/
	if ((TRMone.ctynum!=TRMtwo.ctynum)||(strcmp (TRMone.hwy, TRMtwo.hwy) != 
0)||(TRMone.aadt!=TRMtwo.aadt)||(TRMone.taadt!=TRMtwo.taadt)||(TRMone.speed!=TRMtwo.speed)||

	(TRMone.functclass!=TRMtwo.functclass)||(TRMone.lanes!=TRMtwo.lanes))
	{
		fprintf (out_ptr, "%d\t%s\t%lf\t%lf\t%lf\t%lf\t%d\t%d\t%d\t%lf\n", TRMone.ctynum, TRMone.hwy, 
TRMone.begdfo,
					TRMone.enddfo, TRMone.aadt, TRMone.taadt, TRMone.speed, 
TRMone.functclass,
					TRMone.lanes, TRMone.peroff);

		TRMone.ctynum=TRMtwo.ctynum;
		strcpy(TRMone.hwy, TRMtwo.hwy);
		TRMone.begdfo=TRMtwo.begdfo;
		TRMone.enddfo=TRMtwo.enddfo;
		TRMone.aadt=TRMtwo.aadt;
		TRMone.taadt=TRMtwo.taadt;
		TRMone.speed=TRMtwo.speed;
		TRMone.functclass=TRMtwo.functclass;
		TRMone.lanes=TRMtwo.lanes;
		TRMone.peroff=TRMtwo.peroff;

		TRMtwo.ctynum=TRMthree.ctynum;
		strcpy(TRMtwo.hwy, TRMthree.hwy);
		TRMtwo.begdfo=TRMthree.begdfo;
		TRMtwo.enddfo=TRMthree.enddfo;
```

```
                TRMtwo.aadt=TRMthree.aadt;
                TRMtwo.taadt=TRMthree.taadt;
                TRMone.speed=TRMthree.speed;
                TRMtwo.functclass=TRMthree.functclass;
                TRMtwo.lanes=TRMthree.lanes;
                TRMtwo.peroff=TRMthree.peroff;
                if (fscanf(trm_ptr, "%d", &(TRMthree.ctynum)) == EOF)
                {
                        stop=3;
                        goto end;
                }
                fscanf (trm_ptr, "%s", &(TRMthree.hwy));
                fscanf (trm_ptr, "%lf", &(TRMthree.begdfo));
                fscanf (trm_ptr, "%lf", &(TRMthree.enddfo));
                fscanf (trm_ptr, "%lf", &(TRMthree.aadt));
                fscanf (trm_ptr, "%lf", &(TRMthree.taadt));
                fscanf (trm_ptr, "%d", &(TRMthree.speed));
                fscanf (trm_ptr, "%d", &(TRMthree.functclass));
                fscanf (trm_ptr, "%d", &(TRMthree.lanes));
                fscanf (trm_ptr, "%lf", &(TRMthree.peroff));
                goto loop;
        }

        /*if one ==two and 1==3, one = one, two = three, and get three*/
        if (((TRMone.ctynum==TRMtwo.ctynum)&&(strcmp (TRMone.hwy, TRMtwo.hwy) ==
0)&&(TRMone.aadt==TRMtwo.aadt)&&(TRMone.taadt==TRMtwo.taadt)&&(TRMone.speed==TRMtwo.speed)&&
                (TRMone.functclass==TRMtwo.functclass)&&(TRMone.lanes==TRMtwo.lanes))&&
                ((TRMone.ctynum==TRMthree.ctynum)&&(strcmp (TRMone.hwy, TRMthree.hwy) ==
0)&&(TRMone.aadt==TRMthree.aadt)&&(TRMone.taadt==TRMthree.taadt)&&(TRMone.speed==TRMthree.speed)&&
                (TRMone.functclass==TRMthree.functclass)&&(TRMone.lanes==TRMthree.lanes)))
        {
                TRMtwo.ctynum=TRMthree.ctynum;
                strcpy(TRMtwo.hwy, TRMthree.hwy);
                TRMtwo.begdfo=TRMthree.begdfo;
                TRMtwo.enddfo=TRMthree.enddfo;
                TRMtwo.aadt=TRMthree.aadt;
                TRMtwo.taadt=TRMthree.taadt;
                TRMtwo.speed=TRMthree.speed;
                TRMtwo.functclass=TRMthree.functclass;
                TRMtwo.lanes=TRMthree.lanes;
                TRMtwo.peroff=TRMthree.peroff;

                if (fscanf(trm_ptr, "%d", &(TRMthree.ctynum)) == EOF)
                {
                        stop=4;
                        goto end;
                }
                fscanf (trm_ptr, "%s", &(TRMthree.hwy));
                fscanf (trm_ptr, "%lf", &(TRMthree.begdfo));
                fscanf (trm_ptr, "%lf", &(TRMthree.enddfo));
                fscanf (trm_ptr, "%lf", &(TRMthree.aadt));
                fscanf (trm_ptr, "%lf", &(TRMthree.taadt));
                fscanf (trm_ptr, "%d", &(TRMthree.speed));
```

```
                fscanf (trm_ptr, "%d", &(TRMthree.functclass));
                fscanf (trm_ptr, "%d", &(TRMthree.lanes));
                fscanf (trm_ptr, "%lf", &(TRMthree.peroff));
        goto loop;
        }

        end:;
        if (stop==0)printf("Oh Shit..error somewhere..did not terminate normally\n");
        if (stop==1)
        {
                fprintf (out_ptr, "%d\t%s\t%lf\t%lf\t%lf\t%lf\t%d\t%d\t%d\t%lf\n", TRMone.ctynum, TRMone.hwy,
TRMone.begdfo,
                                TRMone.enddfo, TRMone.aadt, TRMone.taadt, TRMone.speed,
TRMone.functclass,
                                TRMone.lanes, TRMone.peroff);
        }
        if (stop==2)
        {
        /* if 1==2 print 1 and two together, else print seperately*/
                if((TRMone.ctynum==TRMtwo.ctynum)&&(strcmp (TRMone.hwy, TRMtwo.hwy) ==
0)&&(TRMone.aadt==TRMtwo.aadt)&&(TRMone.taadt==TRMtwo.taadt)&&(TRMone.speed==TRMtwo.speed)&&
                (TRMone.functclass==TRMtwo.functclass)&&(TRMone.lanes==TRMtwo.lanes))
                {
                        fprintf (out_ptr, "%d\t%s\t%lf\t%lf\t%lf\t%lf\t%d\t%d\t%d\t%lf\n", TRMone.ctynum,
TRMone.hwy, TRMone.begdfo,
                                TRMtwo.enddfo, TRMone.aadt, TRMone.taadt, TRMone.speed,
TRMone.functclass,
                                TRMone.lanes, TRMone.peroff);
                }
                else
                {
                        fprintf (out_ptr, "%d\t%s\t%lf\t%lf\t%lf\t%lf\t%d\t%d\t%d\t%lf\n", TRMone.ctynum,
TRMone.hwy, TRMone.begdfo,
                                TRMone.enddfo, TRMone.aadt, TRMone.taadt, TRMone.speed,
TRMone.functclass,
                                TRMone.lanes, TRMone.peroff);
                        fprintf (out_ptr, "%d\t%s\t%lf\t%lf\t%lf\t%lf\t%d\t%d\t%d\t%lf\n", TRMtwo.ctynum,
TRMtwo.hwy, TRMtwo.begdfo,
                                TRMtwo.enddfo, TRMtwo.aadt, TRMtwo.taadt, TRMtwo.speed,
TRMtwo.functclass,
                                TRMtwo.lanes, TRMtwo.peroff);
                }
        }
        if (stop==3)
        {
                fprintf (out_ptr, "%d\t%s\t%lf\t%lf\t%lf\t%lf\t%d\t%d\t%d\t%lf\n", TRMtwo.ctynum, TRMtwo.hwy,
TRMtwo.begdfo,
                                TRMtwo.enddfo, TRMtwo.aadt, TRMtwo.taadt, TRMtwo.speed,
TRMtwo.functclass,
                                TRMtwo.lanes, TRMtwo.peroff);
        }
        if (stop==4)
        {
```

```
			fprintf (out_ptr, "%d\t%s\t%lf\t%lf\t%lf\t%lf\t%d\t%d\t%d\t%lf\n", TRMone.ctynum, TRMone.hwy,
TRMone.begdfo,
					TRMtwo.enddfo, TRMone.aadt, TRMone.taadt, TRMone.speed,
TRMone.functclass,
					TRMone.lanes, TRMone.peroff);
		}
printf("Please cut and Paste Files to MSAccess and save as *.dbf\n");
}
```

APPENDIX C

CUSTOM 'C' CODE TO ACCOUNT FOR CONCURRENT HIGHWAY SECTIONS

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <math.h>
void main(void)
{
        int i=0;
        int z=0;
        int q=0;
        int p=0;
        struct gap
        {
                char route[8];
                double from;
                double add;
                int district;
                /* 0/1
                0 adds to all and sets at district line
                1 is specific to a segment
                0 must be done first,
                then 1's */
        };
        struct  gap miles[850];
        struct data
        {
                int ctynum;
                char hwy[8];
                double begdfo;
                double enddfo;
                double aadt;
                double taadt;
                int speed;
                int functclass;
                int lanes;
                double peroff;
                int district;
        };
        struct data TRM[1350];
        /*file pointers*/
        FILE* trm_ptr;
        FILE* out_ptr;
        FILE* in_ptr;
        /* file names*/
        char trmfile[15];
        char outfile[15];
        char infile[15];
```

```
	printf("Enter file with route names and mileages to add for a district.\n These MUST be in the correct,
increasing mileage order \n");
	scanf ("%s", &infile);
	printf("Enter name of file with formatted TRM data, Note that all data must be in order\n");
	printf("of beginning milepost\n");
	scanf ("%s", &trmfile);
	printf("Enter output file name\n");
	scanf ("%s", &outfile);
	trm_ptr = fopen(trmfile, "r");
	out_ptr = fopen(outfile, "w");
	in_ptr = fopen(infile, "r");

	/* Main Body*/

	i=0;

	while ((fscanf(in_ptr, "%s", miles[i].route)) != EOF)
	{
		fscanf(in_ptr, "%lf", &(miles[i].from));
		fscanf(in_ptr, "%lf", &(miles[i].add));
		fscanf(in_ptr, "%d", &(miles[i].district));
		i++;
	}

	z=0;

	while (fscanf(trm_ptr, "%d", &(TRM[z].ctynum)) != EOF)
	{
			fscanf (trm_ptr, "%s", &(TRM[z].hwy));
			fscanf (trm_ptr, "%lf", &(TRM[z].begdfo));
			fscanf (trm_ptr, "%lf", &(TRM[z].enddfo));
			fscanf (trm_ptr, "%lf", &(TRM[z].aadt));
			fscanf (trm_ptr, "%lf", &(TRM[z].taadt));
			fscanf (trm_ptr, "%d", &(TRM[z].speed));
			fscanf (trm_ptr, "%d", &(TRM[z].functclass));
			fscanf (trm_ptr, "%d", &(TRM[z].lanes));
			fscanf (trm_ptr, "%lf", &(TRM[z].peroff));
			fscanf (trm_ptr, "%d", &(TRM[z].district));
			z++;
	}

	q=0;
	while(q<i)
	{
		p=0;
		while(p<z)
		{

			if( (strcmp(TRM[p].hwy, miles[q].route)==0) && ( TRM[p].begdfo > miles[q].from ) &&
(TRM[p].district == miles[q].district))
			{
				TRM[p].begdfo += miles[q].add ;
				TRM[p].enddfo += miles[q].add ;
```

```
                        }

                        p++;
                }
                q++;
        }


        for(q=0;q<z;q++)
        {
                fprintf(out_ptr, "%d\t%s\t%lf\t%lf\t%lf\t%lf\t%d\t%d\t%d\t%lf\t%d\n", TRM[q].ctynum, TRM[q].hwy,
                        TRM[q].begdfo, TRM[q].enddfo, TRM[q].aadt, TRM[q].taadt, TRM[q].speed,
                        TRM[q].functclass, TRM[q].lanes, TRM[q].peroff, TRM[q].district);
        }
fclose(trm_ptr);
fclose(out_ptr);
fclose(in_ptr);
}
```

APPENDIX D
CUSTOM 'C' CODE TO START ALL ROUTES AT ZERO MILEAGE

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <math.h>

void main(void)
{
	struct data
	{
		int ctynum;
		char hwy[8];
		double begdfo;
		double enddfo;
		double aadt;
		double taadt;
		int speed;
		int functclass;
		int lanes;
		double peroff;
	};
	struct data first;
	struct data second;
	FILE* out_ptr;
	FILE* in_ptr;
	/* file names*/
	char outfile[15];
	char infile[15];
	/* retrieve file names and open them*/
	printf("Enter file with all data, ie. in.txt.\nData must be in ascending order by route\n");
	scanf ("%s", &infile);
	printf("Enter output file\n");
	scanf ("%s", &outfile);
	out_ptr = fopen(outfile, "w");
	in_ptr = fopen(infile, "r");
	/* main body sets previous begdfo to from value and sets 0 as start of route*/
		/* initialize with first data point*/
		fscanf(in_ptr, "%d", &(first.ctynum));
		fscanf (in_ptr, "%s", &(first.hwy));
		fscanf (in_ptr, "%lf", &(first.begdfo));
		fscanf (in_ptr, "%lf", &(first.enddfo));
		fscanf (in_ptr, "%lf", &(first.aadt));
		fscanf (in_ptr, "%lf", &(first.taadt));
		fscanf (in_ptr, "%d", &(first.speed));
		fscanf (in_ptr, "%d", &(first.functclass));
		fscanf (in_ptr, "%d", &(first.lanes));
		fscanf (in_ptr, "%lf", &(first.peroff));
		first.begdfo=0;
		fprintf(out_ptr, "%d\t%s\t%lf\t%lf\t%lf\t%lf\t%d\t%d\t%d\t%lf\n", first.ctynum, first.hwy,
```

```
                                                  first.begdfo, first.enddfo, first.aadt, first.taadt,
first.speed,
                                                  first.functclass, first.lanes, first.peroff);
          while (fscanf(in_ptr, "%d", &(second.ctynum)) != EOF)
          {
               fscanf (in_ptr, "%s", &(second.hwy));
               fscanf (in_ptr, "%lf", &(second.begdfo));
               fscanf (in_ptr, "%lf", &(second.enddfo));
               fscanf (in_ptr, "%lf", &(second.aadt));
               fscanf (in_ptr, "%lf", &(second.taadt));
               fscanf (in_ptr, "%d", &(second.speed));
               fscanf (in_ptr, "%d", &(second.functclass));
               fscanf (in_ptr, "%d", &(second.lanes));
               fscanf (in_ptr, "%lf", &(second.peroff));
               if(strcmp(second.hwy,first.hwy)==0) second.begdfo=first.enddfo;
               if(strcmp(second.hwy,first.hwy)!=0) second.begdfo=0;
               fprintf(out_ptr, "%d\t%s\t%lf\t%lf\t%lf\t%lf\t%d\t%d\t%d\t%lf\n", second.ctynum,
second.hwy, second.begdfo, second.enddfo, second.aadt, second.taadt, second.speed,second.functclass,
second.lanes, second.peroff);
               first.ctynum = second.ctynum;
               strcpy((first.hwy),(second.hwy));
               first.begdfo = second.begdfo;
               first.enddfo = second.enddfo;
               first.aadt = second.aadt;
               first.taadt = second.taadt;
               first.speed = second.speed;
               first.functclass = second.functclass;
               first.lanes = second.lanes;
               first.peroff = second.peroff;

          }
     }
```

APPENDIX E

ESRI RESPONSE TO NETWORK ANALYST MALFUNCTION

Original Tech Support Request:

I am attempting to create a turntable using Network Analyst at a node with 11 connecting links using Arcview 3.1. I have installed Net Analyst 1.0b patch and 1.0b incremental patch. I noticed 1.0b fixed the problem in question for flags on locations with more than 10 connecting links, however it appears that the similar scenario for turntables was not addressed. If I use a partial turntable at this location it will work just fine. However attempting to load all turn penalties results in "error: segmentation violation", and a short DOS screen giving an error message which flashes too quickly for me to read. It appears to me that insufficient memory is being allocated. Please advise me on this problem.
Thank You,
Glenn Standifer

ESRI Response:

Subject:
Arcview incident 73491
Date:
Mon, 24 Jan 2000 10:54:48 -0800
Glenn,
This problem has been logged as a bug with Network Analyst (CQ00065712) and a fix has currently been postponed to a future release of Network Analyst. I was able to reproduce the problem you specified and I will add the notes to the bug. Currently there is no known workaround. Feel free to check in periodically on the status of the bug.

REFERENCES

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