CONF-9703823--1

DEVELOPMENT OF ANALYTIC INTERMODAL FREIGHT NETWORKS FOR USE WITHIN A GIS

May 1997

by

Frank Southworth
Demin Xiong
David Middendorf

Center for Transportation Analysis
Oak Ridge National Laboratory
Oak Ridge, TN 37831-6206

Energy Division
OAK RIDGE NATIONAL LABORATORY
P.O. Box 2008
Oak Ridge, TN 37831, U.S.A.

managed by
LOCKHEED-MARTIN ENERGY RESEARCH
for the
US DEPARTMENT OF ENERGY
under contract no. DE-AC05-96OR22464

DISCLAIMER

Frank Southworth
Demin Xiong
David Middendorf

Center for Transportation Analysis
Oak Ridge National Laboratory
P.O. Box 2008, MS 6206
Oak Ridge, TN 37831

DEVELOPMENT OF ANALYTIC INTERMODAL FREIGHT NETWORKS FOR USE WITHIN A GIS.

Abstract. The paper discusses the practical issues involved in constructing intermodal freight networks that can be used within GIS platforms to support inter-regional freight routing and subsequent (for example, commodity flow) analysis. The procedures described can be used to create freight-routable and traffic flowable interstate and intermodal networks using some combination of highway, rail, water and air freight transportation. Keys to realistic freight routing are the identification of intermodal transfer locations and associated terminal functions, a proper handling of carrier-owned and operated sub-networks within each of the primary modes of transport, and the ability to model the types of carrier services being offered.

INTRODUCTION

It has long been perceived that the integration of GIS and transportation models will provide solutions to many practical transportation routing, costing and flow-based analysis problems. Yet the difficulty involved in transforming a spatially referenced network database into an analytically useful one can prove a major obstacle to this integration. While the analysis of a single source-to-market shipment of goods may not require a great deal of analytic capability, the analysis of multiple source-to-market options rapidly assumes the status of a major time consuming exercise. As our economy becomes more global and, consequently, more competitive, trans-continental as well as interstate freight shipment options are likely to receive more detailed geographic attention. Automated techniques for route construction can therefore prove extremely cost-effective in cases where repeated application of routing selection, traffic assignment, or comparative route costing models are involved

In this paper we discuss some of the technical challenges that have to be dealt with if *analytically tractable* network databases are to be used more extensively in the modeling of long haul, inter-regional freight traffic movements at the source-to-market and route-specific level. In recent years the authors, along with other staff at Oak Ridge National Laboratory (ORNL), have been developing and working with a set of national transportation network databases. These databases have a number of potential uses (see Southworth, 1997) including support for multi-state and cross-border freight flow estimation and forecasting, the routing and scheduling of military convoy movements, and assessment of infrastructure closure impacts on goods movements during wide geographic area disruptions in travel: such as that caused by the 1993 Midwestern floods. In 1993 a set of national highway, rail, waterway and air freight networks were used by ORNL to derive inter-regional ton and ton-mileage estimates for the nation's 1993 Commodity Flow Survey (CFS) (Middendorf et al, 1995). Improved and expanded versions of these network databases (networks for short) are currently being used to support the 1997 CFS. Other versions of these national networks can also be found in the Bureau of Transportation Statistics (BTS) National Transportation Atlas Database (NTAD: Spear, 1995).

In the paper we pay particular attention to the challenges presented to network database construction by *intermodal* transportation routing. To many freight analysts intermodal traffic implies containerized movements, notably those involving truck-rail and ocean vessel- rail mode combinations. Such shipments are now an important part of the nation's economy. For the purposes of this paper a broader definition of intermodalism is used, of which such containerized movements are a special case. That is, freight is taken to involve intermodal transportation if it requires any kind of end-on transfer of goods between two different primary modes of transport on its journey from source to market. The "primary modes" of freight transportation are defined here to be highway (truck), rail, water, air and pipeline. Pipelines are not discussed further in the present paper.

The paper is used to describe the steps involved in constructing one or more intermodal freight network databases, including (i) the linking together of different primary modal networks through an intermodal terminals database (ii) the development of carrier-, and in some cases service- specific sub-networks necessary to the generation of sensible intermodal routing alternatives, including the problems of developing intermodal routing costs for the very common situation in which freight rates or actual shipment cost data are not available, and (iii) the attachment of intermodal networks to a set of traffic analysis zones (i.e. traffic origination and termination). The process is seen to be a demanding one where large networks and multiple traffic corridors are involved, warranting automation of the process, with subsequent editing of route selections within a GIS a valuable adjunct to applied studies.

CONSTRUCTION OF ROUTABLE INTERMODAL NETWORKS.

The Basic Network Merging Procedure.

A network database is said to be "routable" if it is possible to use the network to find the shortest, fastest, least costly or otherwise defined best, second best, etc. routes through it, for a set of pre-specific traffic origination and destination pairs. These same routes can then be used to display the link by link connections, and any flows assigned to them, within a geographic information system. An analytically useful intermodal network database is created by defining three different sets of "notional" links:

1. traffic generator/traffic attractor links,
2. intermodal terminals transfer links, and
3. intra-modal, carrier-based interlining links.

These various notional links, each discussed in more detail below, can be generated either "on the fly" within a computer code, or more usefully (for repeated application), they can be created as a set of add-on links to a network database already populated with a set of "real" highway, rail, water, air, and/or pipeline links, as appropriate to the problem at hand. Table 1 provides an example of such a file's records for a combined air, highway, rail, and waterways network.

Table 1. Example Contents of An Intermodal Network Link File.

1. Real or notional traffic generator and/or attractor network access links:
    - 1.1 Centroid to Airline A, Airline B,..Airline N access links
    - 1.2 Centroid to Railroad A, Railroad B,...Railroad R access links
    - 1.3 Centroid to highways access link(s)
    - 1.4 Centroid to deep, shallow or Great Lakes waterway access links
2. Airport-to-airport links:
    - 2.1 Airline A network links
    - 2.2 Airline B network links
    - ...
    - 2.N Airline N network links
    - 2.N+1.. N+M Interline (i.e. inter-airline) connector links (notional)
3. Highway links
4. Railway links:
    - 4.1 Railroad A network links
    - 4.2 Railroad B network links
    - ...
    - 4.R Railroad R network links
    - 4.R+1.. R+M Interline (i.e. inter-railroad) connector links (notional)
5. Waterway links:
    - 5.1 Deep draft network links
    - 5.2 Shallow draft (inland and intra-coastal waterways) network links
    - 5.3 Great Lakes network links
    - 5.4 Deep-shallow draft network connector links (notional)
    - 5.5 Great Lakes - shallow draft connector links (notional)
    - 5.6 Great Lakes - deep draft connector links (notional)
6. Bi-modal transfer links (i.e. real or notional intermodal connectors):
    - 6.1 Highway -Water (inland barge, seaport, or Great Lakes port) transfer links
    - 6.2 Highway-Airport transfer links (assumed same for all airlines)
    - 6.3 Highway-Railroad (A,B,...R) (TOFC/COFC, Breakbulk, Dry Bulk, Liquid Bulk, Autoramp) transfer links
    - 6.4 Railroad (A,B,...R)-Water (inland barge, seaport, Great Lakes) transfer links

---

In practice, it is usually the case that separate air-highway and highway-rail-water transportation files will be created for flowing freight, given the limited overlap between the sort of commodities moved by air and those moved solely by ground transportation modes. Where specific commodities or classes of commodity are to be routed, the bi-modal transfer links listed in Table 1 will usually benefit from further sub-division, presenting a challenge for existing databases: a topic also discussed further below.

Access and Egress Links: Getting Traffic Onto and Off The Networks.

The first step in any routing procedure is to get traffic onto the network. Traffic origination and destination locations are termed centroids. Centroids can be linked to any modal network via one or more real or notional access connectors, by attaching such connections to spatially adjacent network links or, more commonly, network nodes. Where the volume of traffic assigned to a network is based on the freight shipped out of or into a specific region such centroids represent the location of a set of traffic analysis zones (TAZs). For relatively small TAZs, such as Census Blocks, such a centroid may be located at the geographic center of the zone. One benefit of this procedure is that it is comparatively easy to automate over a complete set of network nodes, using nearest node attachment commands now found within commercial GIS packages. However, this is often a poor solution as TAZ size increases, since the major traffic generating and attracting locations, of which there may be more than one, may be located elsewhere within the TAZ. An alternative is to place such a centroid at the population-weighted or activity-weighted center of the zone. Some attention must then be given to how to select the best link(s) or node(s) on the network to link to this centroid. The most suitable procedure will often be determined by the sparseness of the network relative to the number and size of the TAZs used to load traffic onto the system. It will often be necessary to select the most appropriate network access point on the basis of the intended destination of travel, requiring the attachment of a number of notional access/egress links for each TAZ centroid in order to obtain the best route (reasons for this will become apparent below).

One approach to automating a network-to-TAZ attachment procedure is a travel direction-sensitive quadrant by quadrant search. ORNL used such a procedure in deriving its 1993 CFS ton-mileage calculations (Middendorf et al, 1995). Figure 1(A) shows how this procedure can be used to attach zip code-based TAZs to the Federal Railroad Administration's 1:2,000,000 National Rail Network database. In this instance the sparseness of the rail network and the length of its network links compared to the size of a typical TAZ often warranted attachment of centroids to the nearest segment of a rail link, rather than to a link's end-node, allowing more accurate computation of network access/egress distances. In each case the "local access threshold" shown in Figure 1 is used to bound the space searched when looking for the nearest network links in each of the four quadrants. More general search procedures can also be used to scan for appropriate network connections throughout a full 360 degrees of arc. Figure 1(B) shows how the access threshold concept can be used to limit the number of links searched during the subsequent routing process. Such a procedure was used to search for alternative rail routes as part of the 1993 CFS, using the over 40,000 zip code areas to represent the national set of TAZs (Middendorf et al, 1995). In this example railroads 1 and 2 (RR1 and RR2) fall within the local

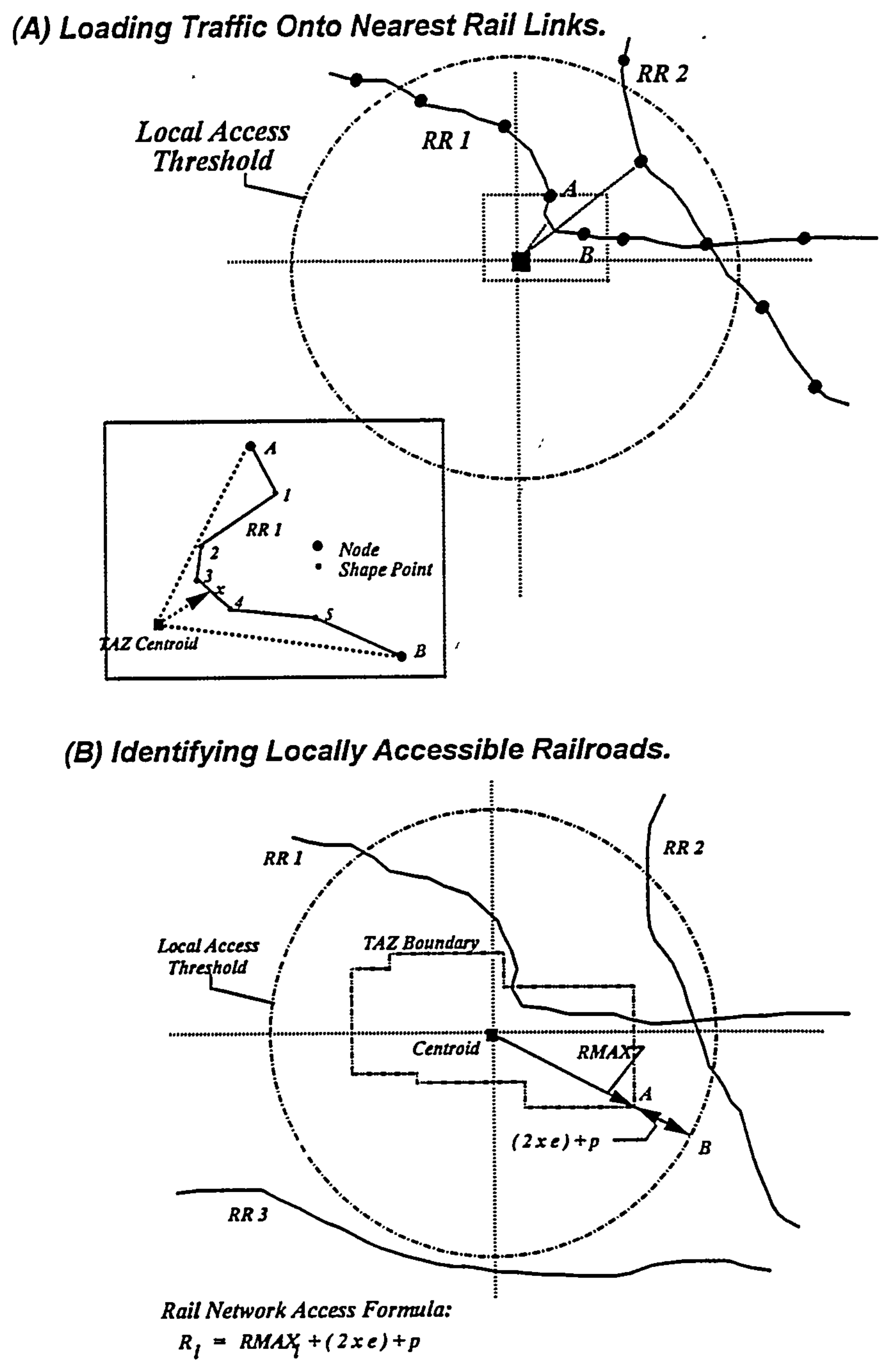

Figure 1. Finding Rail Connections: Threshold and Quadrant Search

access threshold of the TAZ, while railroad 3 (RR 3) falls outside it. Given both the costs of interlining between railroads and the different geographic regions served by different carriers (see below), the nearest links on both RR1 and RR2 are attached to the TAZ's centroid using the method shown in Figure 1B. If more than one railroad company has trackage rights on either of these rail lines, then multiple access links are created to this link, one per company using the rail line. The radius R_i for TAZ " i" is computed using the rail network access formula shown in the figure. Here RMAX refers to the distance from the TAZ's geographic centroid to the farthest point on the TAZ boundary (point A). Point B is then (2 x e) + p distance from point A, where p refers to the maximum length of an industrial rail spur not included in the network database, and e represents the average error level associated with the geographic location of links in the network database (estimated to be about 1 mile for the 1:2,000,000 FRA national rail network).

The above procedure is readily adapted for use with other modes. For highways, however, threshold search procedures are rarely required since most locations are served by at least local roads. Where much larger TAZs are to be used, as in the case of U.S. Counties or BEA Regions, the best approach to defining highway (or other modal) centroid access depends largely on the level of accuracy sought.

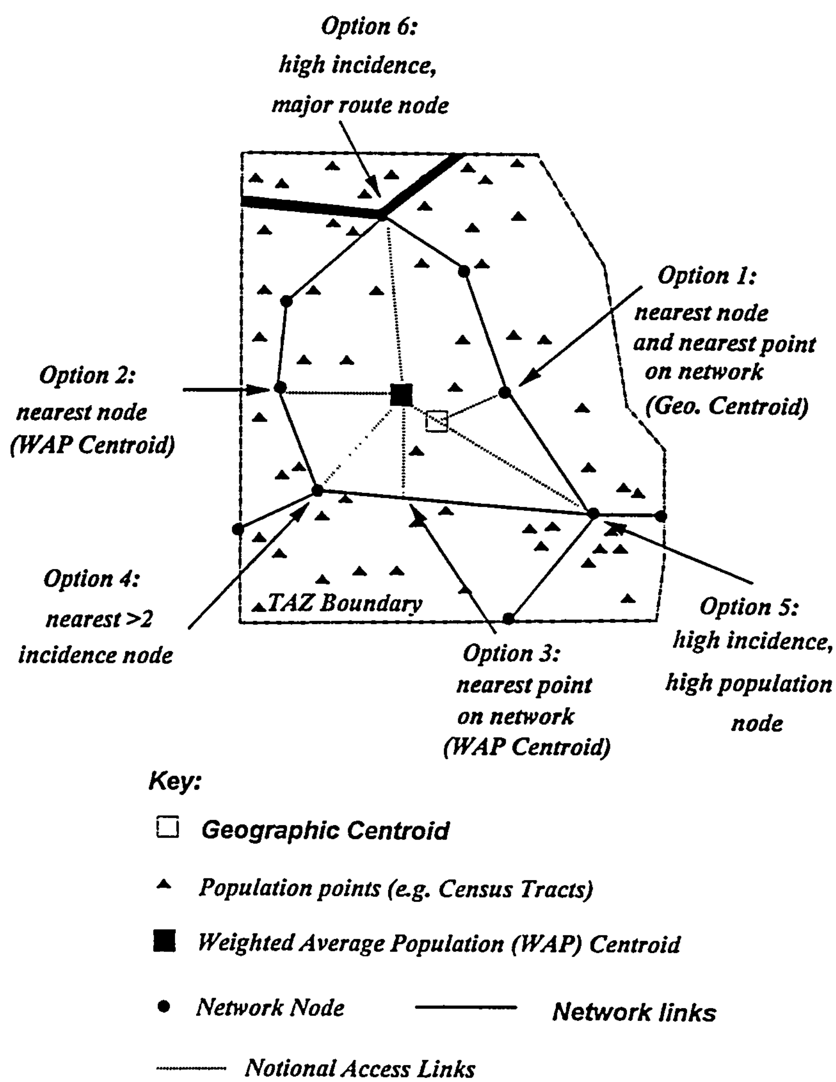

Figure 2. Some Access Link Options for The Highway Mode.

Six options for selecting an appropriate network node to act as a large TAZ's traffic loading/unloading point are shown in Figure 2. Option 1 simply assigns traffic to the network node nearest to the TAZ's geographic centroid, which is also the nearest point on this network to that location. Options 2 through 6 connect access links to the weighted average population (WAP) center of the zone. Options 2 and 3 connect this centroid to the nearest network node and nearest (mid-link) point on the network, respectively. Option 4 in Figure 2 identifies the nearest high (in this case > 2) link-incidence node to this centroid. Option 5 in this hypothetical case is even better, being located at a high population incidence as well as high link-incidence node. Option 6 offers yet another solution: a high incidence node located along the zone's major transport route (e.g., along an Interstate). The longer the hauls and the more strategic the analysis the less such differences tend to matter. However, no systematic assessment of the effects of these choices on routing cost estimates, or on results derived from such estimates, such as locational accessibilities or traffic flow assignments, appears to have been carried out for a range of different TAZ sizes, at least not with respect to national networks.

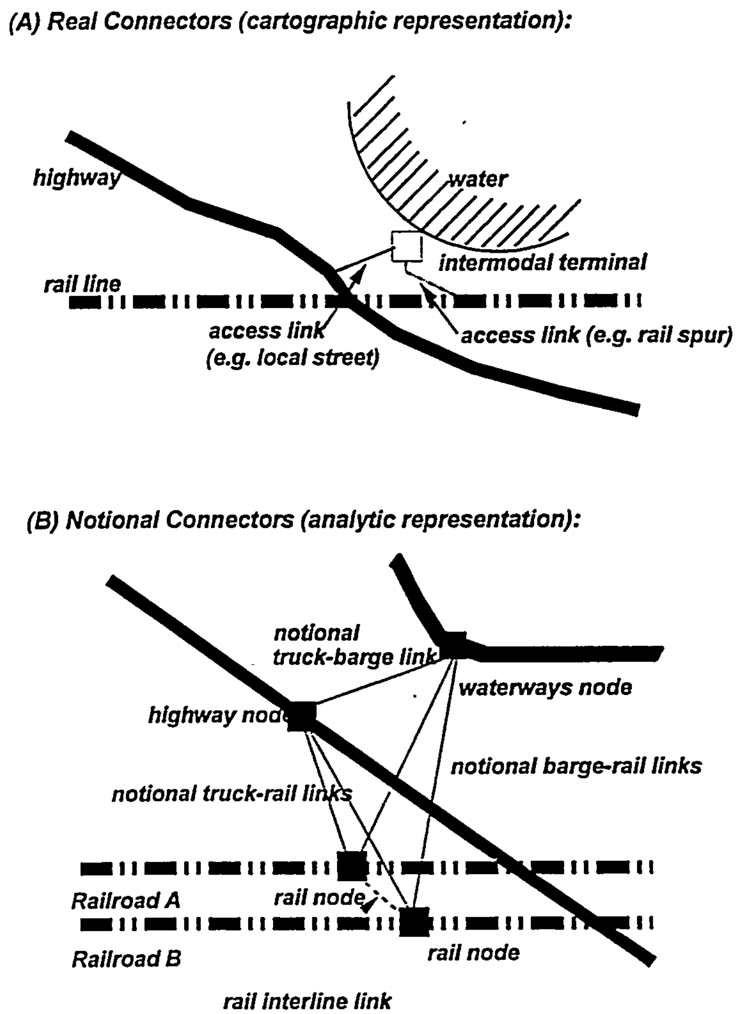

Figure 3. Intermodal Connections: Real and Notional.

Intermodal Transfer Modeling.

Routing Via Bi-Modal Connectors. The last set of network links listed in Table 1 are the bi-modal transfer links. Figure 3 shows how these links are used within the analytic model of the intermodal network. Figure 3(A) shows the location of an intermodal terminal with truck, rail and waterborne commerce access, as it might be displayed on a map or on a GIS screen. Figure 3(B) illustrates how this situation is translated into an analytic representation of the possible intermodal transfers. Each truck-rail, rail-water, and truck-water bi-modal connector link is used not only to connect the primary modal networks together but also to carry any local network access times, intermodal equipment transfer, demurrage, storage, or other costs associated with a transfer between two modes that may influence the carrier route selection process. Also shown is a Railroad A to Railroad B interlining link, discussed further below. The list of intermodal connectors given in Table 1 may be extended to include less likely connections (e.g. direct railroad-airport transfers), if necessary. To support a wide range of intermodal routing applications these simple bi-modal transfer links also require data on the types of commodities and the names of the carriers who use specific terminals, a topic to which we now turn.

Creating An Intermodal Terminals Database. For the purpose of database development and maintenance, as well as mapping within a GIS, these bi-modal transfer links are usefully derived from data stored in a separately maintained intermodal terminals database, containing the geographic location of the transfer activities, as well as the attribute data necessary for traffic routing studies: notably data on the number and types of intermodal transfers, data on per unit freight handling costs, data on which railroads use the facility, and (where traffic congestion is an issue) data on facility throughput and holding capacities. A major deterrent to the accuracy of current studies of inter-regional freight movement is the cost and difficulty of constructing a suitably comprehensive intermodal terminals database. In considering how best to support the intermodal routing of traffic through the nation's terminals, a recent review of intermodal terminal data by Middendorf and Hillsman (1996) found numerous partial and difficult to piece together data sources. These same authors found not only a tremendous number but also a considerable variety in the types of facilities which act as intermodal terminals. Some terminals act as long term as well as short term storage facilities while others are simply pass-through points. They also vary considerably in the services they offer, in the volume and types of freight they handle, and in the modes involved in making the transfers. For example, a major seaport is a very different type of operation to a truck-rail autoramp, yet both are important freight transfer points whose location may impact routing costs significantly. As with networks, and perhaps more so, data coverage and quality varies a great deal both across and also within modes of transport. A mixture of public domain and private data sources are needed to get a proper picture of how terminal facilities impact freight routes.

Two additional concerns also need to be addressed. First, the surprisingly dynamic nature of these enterprises must be recognized: terminal functions as well as the terminals themselves come and go at a rate that is observable (if not yet measured) on at least an annual basis. Second, in searching for suitable sources of such data it has become apparent that when reported, the information on commodities does not conform readily to existing commodity or industry coding schemes (e.g. the Census' Standard Industrial Classification codes; the railroads' Standard

Transportation Commodity Classification codes; the DOT's Standard Classification of Transported Goods codes). Rather, data is available in most instances only at a comparatively aggregate level. While specific studies may get more accurate and detailed information to work with, especially if a well researched commodity such as coal, grain or petroleum is being studied, broader based national, multi-commodity, and inter-regional analyses are unlikely to do much better at the present time than a breakdown into containerized versus bulk freight, with bulk further subdivided, as in Table 1, between dry, liquid, and break-bulk operations. Table 2 shows the sort of commodity breakdowns we are currently working with.

Table 2. Candidate Cargo Classification For A National Intermodal Terminals Database.

100 Containerized Cargo*

200 Breakbulk - Unitized Cargo**
- 210 Food Products
- 220 Lumber & Wood
- 230 Metal Products
- 240 Machinery
- 250 Motor Vehicles
- 260 Pulp & Paper Products
- 270 Clay, Concrete, Glass & Stone Building Materials
- 280 Livestock
- 290 Other Breakbulk Cargo

300 Dry Bulk Cargo***
- 310 Coal
- 320 Grain
- 330 Metallic Ores
- 340 Wood Chips
- 390 Other Dry Bulk Cargo
  - 391 Chemicals
  - 392 Dry Edibles
  - 393 Minerals & Other Dry Bulk Materials

400 Liquid Bulk Cargo****
- 410 Crude Petroleum
- 420 Petroleum Products
- 490 Other Liquid Bulk Cargo
  - 491 Chemical Products
  - 492 Liquid Edibles

* cargo shipped in marine and domestic intermodal containers and highway trailers.

** non-containerized cargo shipped in bags, barrels, boxes, bundles, cartons, crates, drums, or other package form, and cargo shipped and handled as individual units or items.

*** loose, granular, free-flowing cargo that is shipped in bulk rather than in package form

**** liquid cargo not packaged or broken into smaller units.

Intra-Mode Carrier Sub-Networks and Other Routing Issues.

The more accurate and more detailed the routing analysis, the more attention needs to be paid to carrier-specific, and often within-carrier service specific shipment options. Many of these options influence what types, and indeed whether in the first place, intermodal transportation is likely to occur. Issues are dealt with mode by mode below.

Railroad Routing: Interlining Required. Separate railroad companies usually need to be identified within the intermodal network database for traffic routing purposes, because carriers in this highly competitive industry own and operate their own tracks, and tend to want to move as much freight as possible over their own networks: with inter-railroad deals on trackage rights allowing some use of other carrier's tracks where competition and logistics requires or recommends it. In particular, the regionally concentrated sub-networks of the (now shrinking number of) major railroads requires interlining in the middle of the country for most East-West shipments. A good idea of how rail freight actually moves across the country can be obtained from an analysis of the Public Use Rail Waybill sample (see Bureau of Transportation Statistics, 1995, page 327). To route rail traffic successfully requires that the location of such interlining points be known and a suitable penalty (cost) assigned to their use when routing goods by train. This in turn means keeping up with changes in not only track ownership but also trackage rights and carrier-imposed conditions on use. As described in the example study presented later, many smaller, mainly feeder railroads often need to be identified and included in the routing analysis where they connect into or have trackage rights agreements with the major carriers.

An efficient way to handle the routing mechanics is to build a set of notional railroad interlining links to which such penalties can be assigned (see Peterson, 1985). Depending on the functionality of the specific GIS package, routing studies may then be carried out either within the package or by calling out to externally written routing algorithms, passing the results from these algorithms back to the GIS for displaying or highlighting selected routes. The presence of such zero length notional links, such as those used in our routing models to add transfer penalties to inter-railroad and inter-airline routings, may cause problems if a GIS package is not built to accommodate a feature that is physically dimensionless to the GIS. In such cases the routes, and any flows that may subsequently be assigned to them, need to be displayed in what is usually the original form of the network database. For display purposes an intermodal terminals database can be displayed as part of a separately constructed points data layer or cover. A more efficient process allows such notional links to reside in the same data layer or cover with the "real" or physical link records, including the ability to build such dimensionless interlining links into the database in the first place.

Figure 4 shows a set of trans-continental, containerized rail routes and their links to a set of trans-Pacific ocean-vessel routes. These routes were generated as part of an R&D study looking into the feasibility of developing comparative land-bridge freight routes, based on the existence of traffic bottlenecks at different west coast US seaports: and how capital investments leading to greater port cargo throughput capacity might affect each seaport's comparative advantage in routing costs (Southworth et al, 1996). Port throughput costs are simulated using notional bi-modal transfer links of the type described above. However, to construct a routable oceanic-

Figure 4. Selected Oceanic Vessel - Containerized Rail Routes Through Three Pacific Seaports.

continental rail network required some care. In particular, due to a lack of detailed shipment costing or carrier route selection data, existing trackage rights agreements between local branch railroads and the major western railroads required a careful setting of interline link penalties to obtain sensible routes into/out of the port areas. Once constructed, however, the analytic network is easily re-used to simulate future freight routing scenarios, in which both interlining and real network link impedances (costs) are changed by simply editing the appropriate link attribute fields and re-running the routing model. In this manner we can test to see what happens if railroad mergers take place or if other trackage rights agreements are assumed to prevail. In such instances it is preferable to carry out link edits interactively within the GIS itself, then re-run the routing model from a callable menu provided by or built into the GIS user interface. Edits which automatically assign changes to the attributes of all links within pre-selected routes, within specific railroad companies, or by trackage rights, prove most efficient. Using GIS packages for which the analyst does not have to export or re-code this edited link data to match the data formats required by the routing models, then re-code it again for display purposes, can save time and effort here.

Waterborne Commerce: Importance of Vessel Type. To route traffic on the nation's inland and coastal waterways two, and preferably three distinct waterborne commerce sub-networks are needed to capture all possible inter-regional routings. Linked sub-networks are most usefully developed to handle, respectively, ocean-going vessels, Great Lakes vessels, and the shallow draft barges used on the nation's inland and intra-coastal waterways. Inland barges usually cannot operate safely in either Great Lakes or ocean sized waves, while there is a class of vessels built for efficient operation on the Great Lakes but not on coastal oceanic routes. Usually, freight movements will be assigned to one of these three vessel-defined networks. How commodities move over the waterways can be seen from the U.S. Army Corp of Engineers (USACE) data on annual commodity flows, broken down by its own (Waterborne Commerce Statistics Center) commodity classes, between all pairs of major inland and coastal ports. USACE has also added an estimate of traffic volumes to the links in the NTADs National Waterways Network database: although these are apparently maximum-within-the-link tonnages and not actual across-the-link flows. Using value per ton data and final US shipment origin and destination data from the 1993 CFS (Bureau of the Census, 1995) it should now be possible to derive useful estimates of where, which routes, how much, and what dollar value of freight is moving around the nation's coastal and river systems.

Air Freight: Competing Carriers, Hub-and-Spoke Systems, and Dedicated versus Belly Freight. This mode differs from the ground modes because congestion occurs entirely at the network nodes: i.e. at airports. Multi-carrier networks are also required for routing air freight. Here a challenge is to recognize those routes which carry freight within the belly of passenger airplanes, from those devoted exclusively to freight carriage. Air travel is today dominated by the use of hub-and-spoke systems, with an aircraft transfer at the hub airport sometimes required as a result. Where the origin of the freight is located roughly equidistant between more than one freight hub, or close to a small hub but with possibly better service through a more distant, larger hub, a multi-airport access and egress model may be required to identify competitive routes. As with rail freight routing, the selection of air freight routes and their intermediate terminals or interline points requires detailed knowledge of the effects of destination as well as origin location on comparative route costs. If a truck-air-truck move is required to get the goods from source to final destination (e.g. processing plant, market) then knowing which airport or rail terminal is closest to the final point of delivery may influence which carrier, and hence which sub-network, is chosen. A good deal of parcel freight also today goes exclusively by truck ,where the carrier finds this mode most cost effective. This sort of intermodal carrier operations is likely to become more popular as customers in general focus more and more on "just-in-time" deliveries, irrespective of the mode(s) by which they are shipped.

Fortunately, in the search for air freight routes, there is a good deal of historical data on scheduled commercial carrier activities. This includes data updated quarterly by the Office of Airline Statistics (OAS), with information on individual airport-to-airport flights (Domestic and International Air Segment Data) and on flight origin airport to destination airport traffic volume data (Domestic and International O-D Market Data) (see Bureau of Transportation Statistics, 1995, page 131 et seq). While some work is still required to match O-D activities to specific airline routes, a good sense of route circuity can be obtained from this data. Unfortunately (perhaps for the analyst only!) the air freight industry has been expanding and changing rapidly over the past decade, with changes in both dedicated and mixed (passenger-freight) airline operations presenting a challenge to database maintenance.

Highways: Long-Haul and Local Access Options. Besides long haul trucking, a key role for highways in intermodal transportation is obviously as an access/egress mode - to the nearest airport, seaport, barge or rail transfer terminal, grain elevator or other storage facility. Most air transportation from source-to-market is really a highway-air-highway movement, for example. In contrast to the other primary modes of travel, the ubiquity of the highway mode offers little trouble to long haul routing models as long as sufficient attribute data can be attached to the network's links. Here data at the fully national level requires more work, some of it ongoing currently within the Federal Highway Administration (see Southworth, 1997). Improvements such as the attachment of Highway Performance Monitoring System (HPMS) data to National Highway System links will help here. Physical restrictions to large trucks in the form of bridge and tunnel capacities also need to be dealt with, requiring the attachment of data such as that contained within the National Bridge Inventory onto the network's links. Longer combination vehicles are frequently restricted to selected highways when operating within or across different States, with an active debate about truck size and weight restrictions ongoing for a number of years. Hazardous materials movements are also subject to federal, state, or local restrictions on which highways they may use, and may further complicate intermodal route construction. Southworth (1997) provides a list of suggested network link attributes for this and for the other modes discussed in this paper, in the context of developing the Bureau of Transportation Statistics' National Transportation Atlas Database for (i) strategic routing and (ii) more demanding, operation level routing, studies.

There is no single or readily available composite source database of route-based truck traffic flows for the nation as a whole within the public domain. The 1993 CFS provides tons, ton-mileages, and value of goods shipped by two and three digit commodity codes for the 50 States and 89 National Transportation Analysis Regions (NTARs). A good deal of work is required to use this information in truck routing studies, including the translation of freight volumes to loaded vehicle equivalents (see Southworth, 1997).

Incorporating Different Types of Intermodal Service: The Slow, The Fast, and The Just-in-Time. What all of the above means is that an analyst trying to find the best (least costly, most likely) set of routes between any pair of locations within the continental United States may be dealing with only two primary modes and yet have to model as many as three or four different carriers. For many types of detailed costing study this will also not be good enough: since carriers often offer more than one type or quality of service. This includes airlines and railroads, both of which today may send a particular shipment over the same links in the network at travel speeds which vary from rapid, and therefore more expensive delivery, to low cost, much slower multi-day delivery options. In studying the market conditions within any modal industry a GIS can be a very useful tool, mapping and highlighting the different routing structures and geographic sub-networks covered by different carriers, as well as (data permitting) those routes where high-speed, high -cost service options are available. For example, double-stack trains are restricted to those routes which have the requisite structural clearances. That is, infrastructure mapping alone will rarely suffice.

Intermodal Transportation Cost Functions: A Major Challenge. Difficulties soon arise as we try to spread the geographic coverage of a study to include multiple freight generating and receiving locations, and across different commodity groups. Most freight cost data is treated as proprietary by carriers and shippers requiring surrogate or resource-based estimates of comparative routing costs. To be consistent across traffic corridors and regions, cost data must be developed from other, secondary sources: either estimated from published or historically reported freight rates, or derived on the basis of expected costs of carrier/modal operation i.e. expenditures on fuel use, labor and other resources. Where such costs are based on specific routing options this can cause problems for the analyst because both the nature as well as the quality of data varies considerably across modes of transport and types of modal service. Also, as the level of geographic detail becomes more critical to an analysis (for example, as part of a facility-specific capacity assessment study) the ability to route intermodal traffic begins to break down due to a lack of consistency in the ways modes incur and report costs. One way to get a reasonable handle on likely routes is to examine the various mode specific sources of traffic flow data referred to above - with obvious problems where highways are concerned (but for which reasonably good estimates of vehicle operating costs can be generated). Engineering methods can be used here to construct average per ton or per hour operating costs using representative, vehicle class specific fuel, maintenance and labor costs. The alternative is to delve into the various modal and carrier specific scheduling and pricing catalogues - a solution that is often not cost effective when dealing with large numbers of traffic origination-destination pairs.

SUMMARY

What this paper demonstrates is that a transportation network represented within a GIS database is not necessarily a network that can be used immediately in traffic routing analysis. This is especially true in the case of intermodal freight routing. Separate modal networks need to be integrated to form a single connected intermodal network database. This database must also contain appropriate representation of intermodal transfer terminals and intra-modal carrier transfers as well as traffic origination and destination links to each of the modes of interest. While specific corridor and commodity type analyses are reasonably effectively accommodated, albeit with work, into GIS-supported analyses, automated techniques and much better network and terminal attribute data coverage are required to accommodate broader national and inter-regional analysis.

REFERENCES

Bureau of the Census, 1995. "1993 Commodity Flow Survey. United States. TC92-CF-52. U.S. Department of Commerce. Washington D.C. 20233.

Bureau of Transportation Statistics. 1995. "Directory of Transportation Data Sources". DOT-VNTSC-BTS-95-1.U.S. Department of Transportation, Washington D.C. 20590.

Middendorf, D.P., Bronzini, M.S., Peterson, B.E., Liu, C. and Chin, S-M. 1995. "Estimation and validation of mode distances for the 1993 Commodity Flow Survey" Proceedings of the 37th Annual Transportation Research Forum: 456-473. Virginia, 22090.

Middendorf, D. P. and Hillsman, E.D. 1996. "Transportation Terminals Database Structure". Report prepared by Oak Ridge National Laboratory for the Bureau of Transportation Statistics, U.S. Department of Transportation, Washington D.C. 20590..

Peterson, B.E. 1985. "INTERLINE. A Railroad Routing Model: Program Description and User's Manual". ORNL/TM-8944. Oak Ridge National Laboratory, Oak Ridge, TN 37831.

Southworth, F., Xiong, D., Bronzini, M.S., and Middendorf, D.P., 1996."A Framework for Considering National Trade and Transportation Impacts of Site Specific Freight Bottlenecks". Report by Oak Ridge National Laboratory for the Investment Analysis Branch, Office of Policy Development, Federal Highway Administration, Washington D.C. 20590. (Draft).

Southworth, F. 1997. "Development of Data and Analysis Tools in Support of a National Intermodal Network Analysis Capability". Report by Oak Ridge National Laboratory for the Bureau of Transportation Statistics, U.S. Department of Transportation. Washington D.C. 20590.

Spear, B., 1995. "Data Dictionary and Data Formats for the National Transportation Atlas Database." Bureau of Transportation Statistics, U.S. Department of Transportation. Washington D.C. 20590.