THE INCREMENTAL COST OF TRANSPORTATION CAPACITY IN FREIGHT RAILROADING: AN APPLICATION TO THE SNAKE RIVER BASIN

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The Tennessee Valley Authority (TVA) and the Center for Business and Economic Research (CBER) have prepared this report at the request of the U.S. Army Corps of Engineers. However, the material and analysis contained herein are those of the authors and do not necessarily represent the positions of TVA, the CBER, or Marshall University.

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SECTION 1

INTRODUCTION AND MOTIVATION

The economic Procedures and Guidelines used by the U.S. Army Corps of Engineers (Corps) to determine project benefits and costs reason that if inland navigation capacity is not expanded to meet this new demand, competing surface transport modes either possess or will add the capacity necessary to accommodate the new traffic.[1] As a consequence, it is possible to assume that any quantity of any transportation alternative can and will be made available with no significant increase in its unit price. Benefits and costs are to be calculated accordingly. These same Procedures and Guidelines do, however, provide for the relaxation or revision of this capacity assumption if there is sufficient reason to do so.

If the typical capacity assumptions employed within the Corps methodology are inappropriate, the resulting analysis could significantly misstate the value of navigation facilities. In particular, if rail carriers do not possess the capacity to accommodate diverted traffic, or if the cost of accommodation would increase overall rail rates, then the value navigation projects will be understated.[2] It is for this reason that the Tennessee Valley Authority (TVA), in conjunction with the U.S. Army Corps of Engineers' Institute for Water Resources, has modified existing models to evaluate rail network capacity and incremental capacity costs in the Snake River Basin.

The remainder of this document is organized as follows: Section 2 provides a general description of rail capacity, as well as a discussion of those factors that determine specific route capacities. Existing models for estimating line-haul route capacity is developed in Section 3 and estimation results are also discussed within that section. Section 4 combines model estimation results, data detailing railroad construction costs, and information of a few select terminal locations to develop estimates of the incremental rail capacity costs that would be necessary to accommodate traffic which is

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[1] See *Economic Principles and Guidelines for Water and Related Land Resources Implementation Studies*, U.S. Army Corps of Engineers, 1983, Section 2.6.11, p. 54.

[2] See, *The Incremental Cost of Transportation Capacity in Freight Railroads, Phase I Analysis*, U.S. Army Corps of Engineers, St. Louis District, May, 1997.

currently transported by barge. Finally, Section 5 concludes the document with a few summary comments.

SECTION 2

RAILROAD CAPACITY

2.1 OVERVIEW

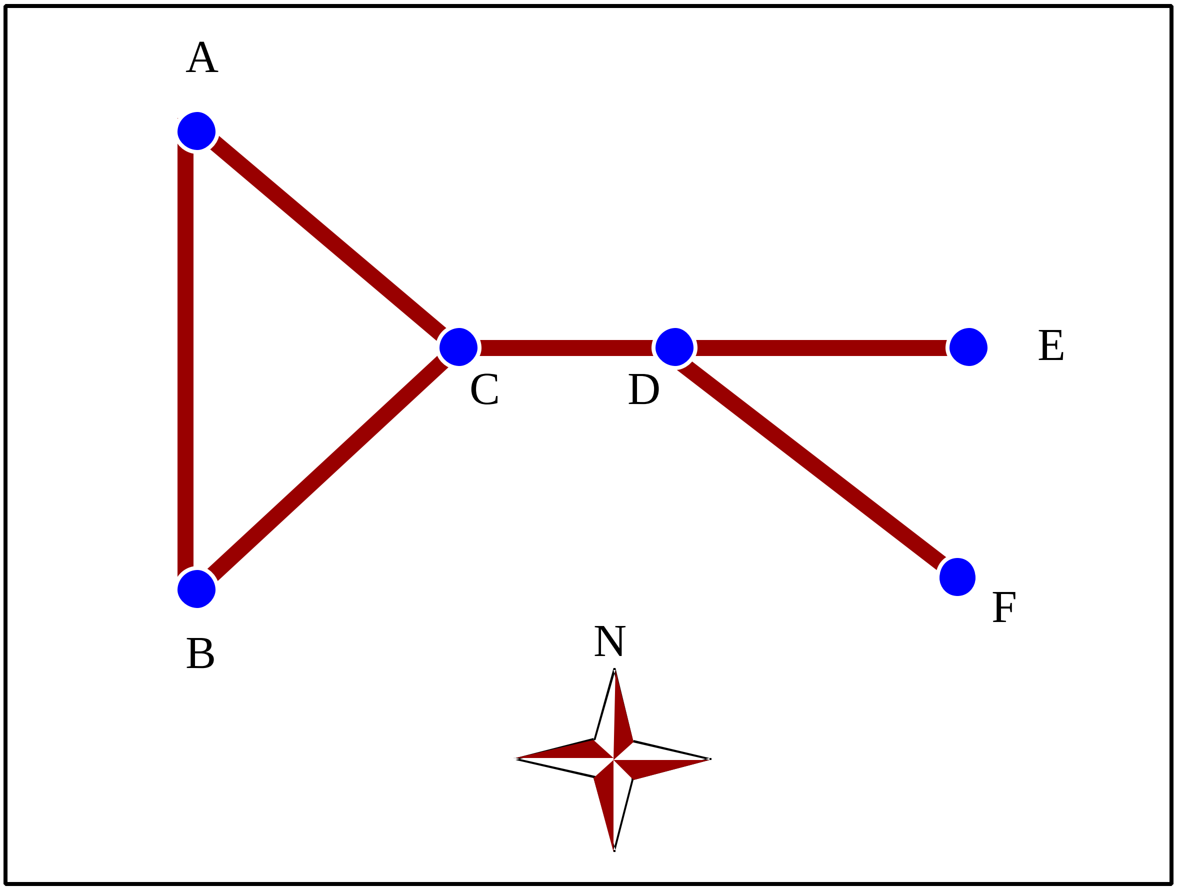
In 1996, U.S. railroads operated roughly 150,000 miles of track over which they moved 1.8 billion tons of freight an average of 756 miles to provide a total of more than 1.36 trillion ton-miles of transportation services. A significant proportion of this total originated and/or terminated in the Pacific Northwest. A summary of this traffic is contained in Appendix 1.

Aggregate statistics, however, cannot be used to adequately evaluate the relationship between barge transportation and the potential need for additional railroad capacity. To the contrary, capacity issues must be investigated by fully disaggregating the rail network and evaluating the capacity of each of the "links" that, together, form specific routes. Both the need for and the complexity of this "link-specific" analysis is made clear through a simple example.

Figure 2.1 portrays a simple network comprised of six nodes (A, B, C, . . .) and six links (AB, AC, BC, . . .). Together, these links form no less than 24 distinct two-way routings. Traffic along such a network could readily move from A to B, from B to F, or from C to E. There are, in fact 15 distinct origin destination pairs that are served by this network. Moreover, in nine cases, there is more than one way to connect a particular pair of points. For example, it is possible to route from A to D by simply going from A to C to D. Alternatively the AC link may be avoided by a routing from A to B to C to D.

It is not sufficient, however, to confine the analysis to individual routes. Even a cursory examination of the network pictured in Figure 2.1 indicates that a number (15) of the specific routes utilize the CD link. Thus, it is impossible to evaluate the capacity necessary over the CD link simply by measuring the traffic that moves from C to D or from D to C. It is also necessary to consider the need to move traffic from B to E, from A to F, etc. Thus, an accurate evaluation of U.S. rail capacity requires an examination of tens of thousands of potential routings over several thousand individual rail network links.[3]

Figure 2.1



2.2 Regarding Railroad Equipment and Crews

Discussions about railroad capacity often involve lengthy debates regarding the availability of railroad locomotives, freight cars, and the crews necessary to train operations. In the short-run, shortages of crews, cars, or power can and do lead to situations in which shippers find it impossible to obtain the level of rail service they demand. In the long-run, however, there is no economic reason that rail carriers cannot purchase additional locomotives and cars and hire and train additional crews.

[3] In fact the consideration of *every* possible routing over *every* possible link would generate millions and millions of distinct routes. The current analysis, however, restricts the potential number of routings to include only those routes over which traffic is observed. Thus, shipments from Cincinnati to New Orleans via Omaha are generally excluded from consideration.

Therefore, the relevant question is not whether railroads can supply the input quantities necessary to adequately serve shippers, but instead, do railroads face the necessary incentives to acquire additional equipment and labor and will the acquisition of these inputs affect unit costs.

The question of incentive is treated in Section 2.4. Suffice it to say, however, if railroads operate in effectively competitive markets, those markets will motivate the railroads to acquire efficient quantities of equipment and labor. Moreover, with regard to the productivity of new equipment, there is every reason to expect, at least in the case of equipment, that the addition of new locomotives and freight cars to existing fleets would act to lower unit costs rather than raise them. Consequently, from a long-run view point – the appropriate vantage for the current analysis – there is little reason for concern about equipment and crews, so long as rail-served markets are effectively competitive.

2.3 THE DETERMINANTS OF LINK CAPACITY

The concept of link capacity encompasses both space and time. Specifically, link capacity is measured by counting the number of output units (freight cars, revenue tons, etc.) that can be moved over the network link in a specific time period (cars-per-day, tons-per-year, etc.).[4] The actual long-run ability of a link to accommodate traffic is determined by the characteristics of the traffic that uses the link, the physical characteristics of the link, and the ability of traffic to move on to and off of the link. Within the context of railroad transport, these determinants include (but are, by no means limited to) the direction and commodity mix of traffic, the configuration and quality of line-haul trackage, and the ability of terminal facilities to yard, switch, and dispatch trains.

2.3.1 *Traffic Mix and Line-Haul Characteristics*. The traffic moving between specific origin and destination pairs is a function of the vector of available transportation rates, the availability of spatial or commodity substitutes, and ultimately, the demand for downstream goods and services. Thus, while railroads can influence origin destination flows by manipulating rates, these flows are also subject to largely exogenous forces. The same may or may not be true of actual routings. Again returning to Figure 2.1, a railroad that operates over this network may have to share control over the quantity of

[4] Within some contexts, the discussion may focus on the length of time it takes to move a single output unit (carload, ton, etc.) over a specific link. Analytically, these approaches are identical.

transportation demanded between A and F with a variety of other economic agents. It does, however, have considerable discretion over some portions of the actual routing of traffic between these points.[5] For example, if the railroad wishes to operate only westbound between C and A, A to F movements may be routed via B instead of utilizing the more direct ACDF route.

Differing traffic mixes require significantly different infrastructure configurations. Routes that handle largely one-way traffic obviously require fewer opportunities to meet opposing trains, so that sidings (passing tracks) or multiple main lines play a smaller role in determining capacity. Conversely, the capacity of routes that must accommodate two-way traffic (most routes) and particularly routes that see a diverse mix of traffic is heavily dependent on the number and spacing of sidings and/or availability of multiple main tracks.

Apart from link configuration, the physical characteristics and quality of the trackage depends both on the volume and mix of intended traffic. Routes that serve a high percentage of fast moving intermodal traffic may require super-elevated curves, greater clearances and enhanced track quality for higher speed operations. Routes that primarily see bulk traffic movements may be particularly sensitive to grade. Ultimately, the weight of rail used, the anchoring and ballast system selected, the type and spacing of signals, decisions regarding grading and grade separations are all impacted by the mix of traffic that the trackage must accommodate. The variety of relationships between traffic mix and infrastructure requirements is expansive. Moreover, because the mix of traffic can change significantly over time and because the reconfiguration or modification of infrastructure is both time consuming and costly, the match between traffic mix and link characteristics may be less than pristine.[6]

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[5] In advance of deregulation, routings were determined through the use of route tariffs published by the rail carriers. In the wake of deregulation, routings may be specified in contractual agreements. Again, however, it is the individual railroads that develop the set of options from which shippers may choose. The only real opportunity for shipper control of routings comes through the process of "Accounting Rule Eleven" moves wherein a shipper treats a movement over two separate railroads as two separate shipments.

[6] For example, as passenger traffic and routings declined, many railroads reduced the elevation in curves in order to reduce the rail wear associated with the operation of heavier slower-moving trains over track designed to accommodate high-speed passenger trains. However, just as many such projects were completed, the volume of intermodal shipments exploded. Intermodal trains are shorter and faster than the typical line-haul freight train, with characteristics that, in many ways, resemble passenger trains. Consequently, many carriers have found it desirable to reverse course and restore the elevated curves in some routes.

2.3.2 *Terminal Facilities*. Network nodes are formed where routes converge or diverge and where traffic can be interchanged from one network to another. In some cases these nodes and their associated functions require a minimal amount of infrastructure. At other locations, the origination, termination, interchange, and reorganization (blocking) of traffic requires acres and acres of facilities comprised of hundreds or even thousands of miles of trackage. The rate at which traffic can be passed along a network link is of little or no consequence if terminal facilities at the end of that link cannot receive the movement and dispatch it onto the next leg of its journey. Thus, terminal facilities of are of paramount importance in determining a route's capacity.[7]

This having been said, it must also be recognized that nearly every terminal facility of any size is characterized by a unique set of attributes that are the result of historical functions and relationships, topographical conditions, political bent, and sheer chance. Thus any attempt to model terminal operations is often, unproductive. Instead, consideration of terminal congestion must be investigated on a case-by-case basis.[8]

2.3.3 *Deregulation and Railroad Mergers*. The recent transaction in which Norfolk Southern and CSX Transportation acquired and divided Conrail assets represents only the latest step along a path of railroad consolidation that began after World War II. This pattern of consolidation has resulted in the movement of 70-80% of all rail traffic by only a handful of surviving Class I railroads. While shippers and policy makers continue to debate the competitive impacts of more recent mergers and acquisitions, from a functional standpoint, the pattern of rail mergers, combined with the pricing flexibility provided by deregulation has very probably led to a more efficient utilization railroad network capacity.

This potentially arguable conclusion rests on three closely related considerations. First, as the number of independent railroads is decreased, any routing flexibility retained by shippers is automatically

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[7] One need only look at the UP's Houston operations or CSX's Queensgate Yard in Cincinnati to appreciate the impact that terminal congestion can have on route or even overall network capacity. Moreover, Chicago, the nation's largest rail hub, continues to produce myriad operating problems for the Class I, regional, and shortline carriers that move traffic within the region. See, "The Keys to Success," *Traffic World*, January 19, 1998, pp. 30-31.

[8] In the simplest sense, a double track main with automatic block signals operated by the Burlington Northern in Oregon may be expected to have capacity characteristics that are, at least, similar to a like piece of trackage operated by Norfolk Southern in Alabama. Thus, the cross-sectional modeling described later in this document is possible. Alternatively, no two terminals are the same, so that cross-sectional comparisons would be of virtually no value.

reduced. Thus, consolidated railroads with a variety of routing options, are freer to equalize traffic over their expanded rail network rather than engage in the capital expenditures necessary to increase the capacity of an isolated segment of track. A second and corollary consideration is the increased ability of merged carriers to run one-way traffic on a variety of network links. Thirdly, to the extent that a carrier wishes to specialize in the movement of specific commodities over specific routes it can simultaneously adjust the configuration or quality of its network links *and* adjust prices to reflect any cost advantages that its reconfigurations in the targeted line of business.

2.4 Carrier Incentives for Capacity Expansion

There are numerous economic settings in which the incentives facing privately held rail carriers may result in something less than the optimal amount of railroad capacity. Specifically, the presence of market externalities or a lack of effective market competition could lead carriers to constrain long-run rail capacity below socially optimal levels. While these issues may or may not reflect areas of legitimate concern, it is our judgment that their consideration within the current analysis is inappropriate.

With regard to effective competition, the traditional Corps approach assumes that all relevant markets are effectively competitive in the long-run. The implications of relaxing this assumption extend far beyond the evaluation of capacity. From a pragmatic standpoint, the competitive assumption allows observed rates to form the basis of estimated long-run costs. As importantly, the economic theory that underpins the whole of benefit calculations is equally dependent on the presence of meaningful competition. If, in fact, there are rail markets where the level of competition is insufficient to produce optimal levels of investment, then those markets should be treated through the appropriate policy prescriptions. However, when evaluating long-run railroad capacity, any necessary remedies should be presumed to be successful so that the underlying assumption of effective competition is retained.

The case of externalities provides a similar circumstance. For the most part the externalities associated with surface freight transportation stem from environmental impacts that would not routinely be captured by the transaction in which transportation services are bought and sold. In a number of instances, extant environmental policies already work to internalize these external costs, so that no further consideration is called for. In those situations where corrective environmental measures are still needed, they should be pursued. However, for the purpose at hand, it should be assumed that all necessary corrections have been (or will be) made.

SECTION 3

MODELING RAILROAD CAPACITY

3.1 MODELING LINE-HAUL CAPACITY

The process for estimating and assessing railroad line-haul capacity was originally developed in 1996 as a part of *The Upper Mississippi Navigation Feasibility Study*. The methodology is relatively straightforward. As noted above, there are many thousands of distinct route segments that vary considerably both in quality and in utilization. It is these variations that provide the basis for statistical estimation. The whole of the process can be characterized by the following three steps:

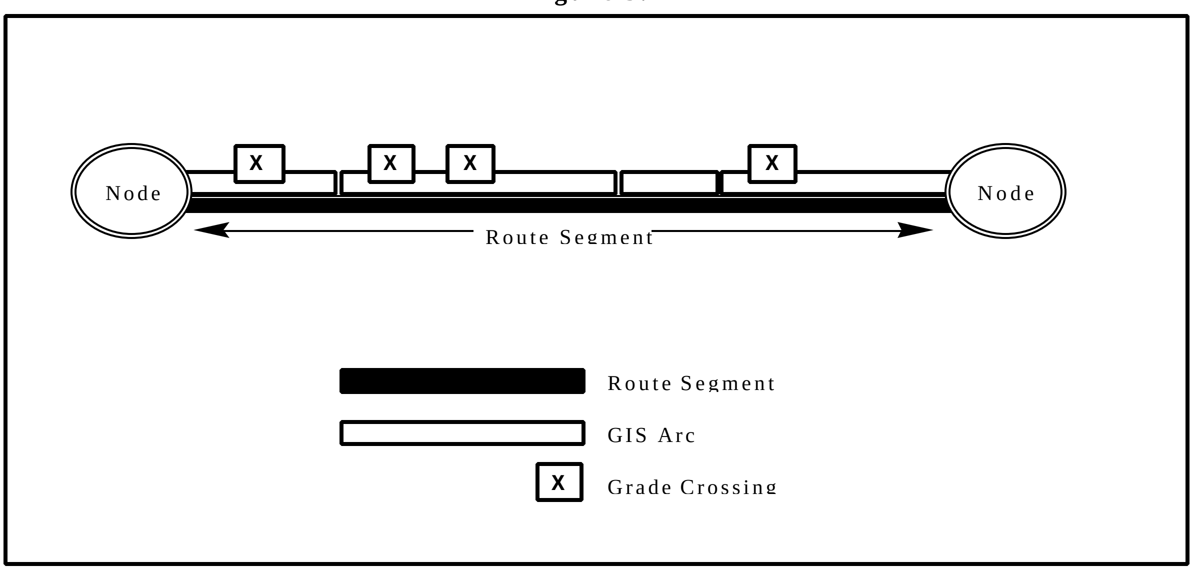
- Identify a cross-section of railroad route segments and collect information describing the physical characteristics of those route segments including the current level of traffic.
- Functionally relate observed traffic levels to route characteristics.
- Using the estimated relationships and the vector of current input prices to estimate the costs of incremental additions to railroad capacity.

3.1.1 *Route Links and Link Characteristics.* The development of Geographic Information Systems (GIS) technologies and coverages has greatly enhanced researchers' abilities to assemble link-specific transportation data and it is four such coverages that provide the basis for the link characteristics used in this analysis.[9] These data were, in turn, modified to incorporate information gleaned from the U.S. Federal Railroad Administration Grade Crossing Inventory files and from other sources.

Initially, a set of roughly 2,500 distinct route segments were defined for use in this analysis. As noted above, a route segment or link for a particular railroad begins and ends at any point where traffic may converge or diverge. Additionally, link end points (or nodes) occur at any location where two railroads may legally interchange traffic. Once the study links were defined, information from four GIS coverages were mapped onto these links. Data from the Bureau of Transportation Statistics' (BTS) 1995 National Transportation Atlas Data (NTAD) 1:100,000 scale railroad network were combined with a newly released Federal Railroad Administration GIS coverage to provide the basic geographic information. These data were combined with data from the BTS 1996 NTAD 1:2,000,000 scale railroad network that contain information describing signaling and a measure of traffic density. The process of developing route characteristics from GIS data is described more fully in Appendix 2. The next step in the data development process involved using a preliminary grade crossing GIS coverage developed by Oak Ridge National Laboratories to locate the position of both separated and grade-level highway crossings. Next, data from the Federal Railroad Administration's Grade Crossing Inventory File were merged with the geographic data in order to provide additional information regarding train speeds, train frequencies and other operating characteristics.

The geographic units, referred to as arcs, are between a few tenths of a mile to several miles in length. However, the shortest route or study segment length is measured in miles and some route segments are several hundred miles in length. Consequently, each route segment generally consists of many arcs. It was, therefore, necessary to aggregate arc level data to conform to the route level unit of measure. This processes is depicted in Figure 3.1. Missing data on some route segments precluded their use in any statistical application. Therefore, the final data set contains roughly 1,400 observations or route segments. The location and extent of their coverage is displayed in Figure 3.2. A full definition of all route level data used within the final model estimation analysis is contained in Table 3.1.

Figure 3.1



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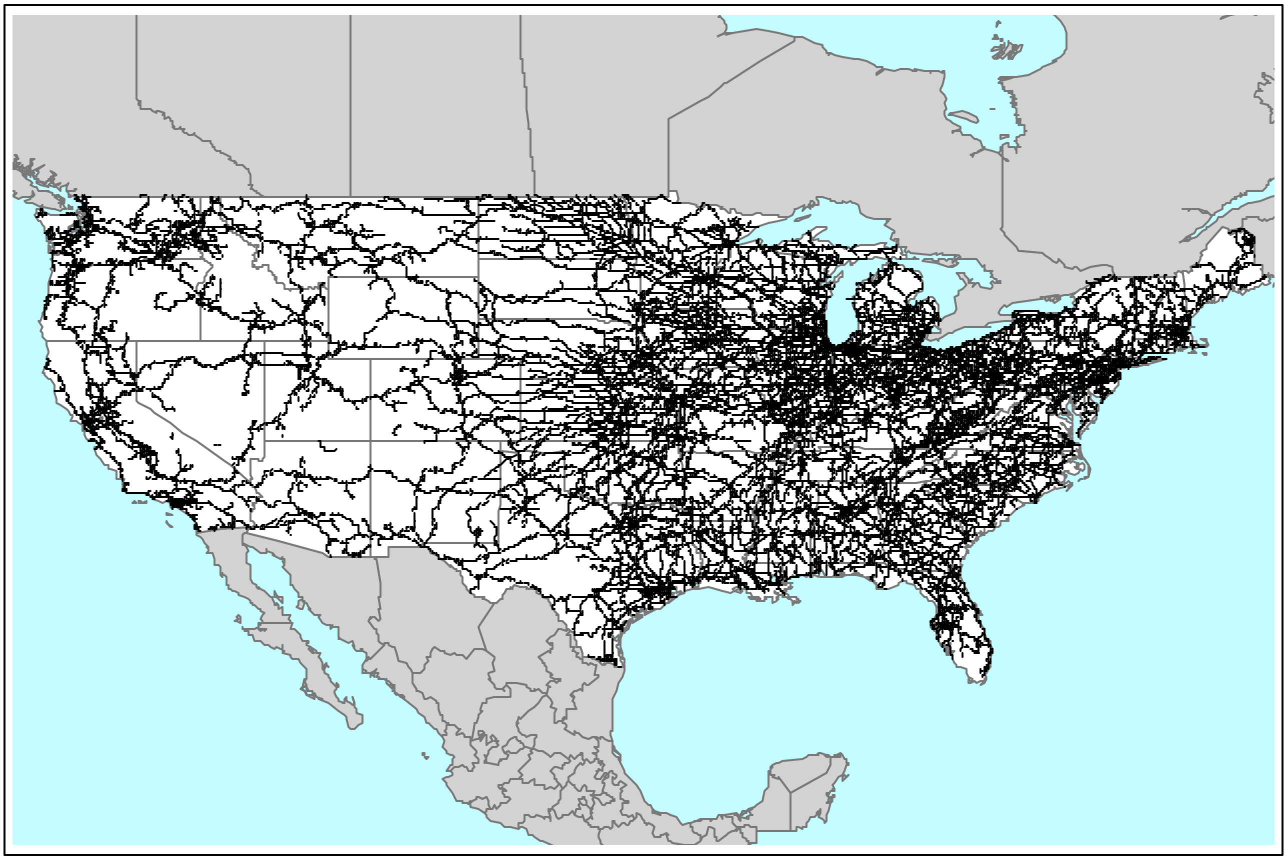
[9] Full documentation of dataset construction, including a description of GIS coverages and manipulations is available upon request.

Figure 3.2



3.2.2 Measuring Observed Traffic. At the center of this analysis is a fundamental assumption that the components of the rail network, as configured in 1994-95, were optimally suited to accommodate the traffic moved during that period. Thus, the traffic observed on each link during the study period stands as measure of that link's capacity.

To measure the traffic over each link, the expanded movements from the Surface Transportation Board's annual Carload Waybill Sample were routed over the 1997 FRA 1:100,000 GIS network. A full description of the routing process is available in Appendix 3. However, several points are worth noting. First, routings were based on actual origin, destination, participating carriers, and recorded points of interchange. Beyond these criteria, routes were selected on the basis of the shortest distance. This "short-line" criteria generally reflects railroad operating practices. This is not, however, true in every case. In order to assess the validity of the algorithm used in the routing process, model outputs for 89 of the 100 hundred most heavily used routes were compared with routings generated by an alternative method.[10] In 80 of the 89 cases, the TVA algorithm generated routes that were virtually identical to the paths generated with the alternative software. In 8 cases, there were significant variations reflecting cases in which railroads opt for a more circuitous routing and in one case, the TVA route varied from the actual routing because of a line sale. The sample of 100 was fully corrected and, because this sample represents between 15% and 20% of all rail traffic, we have complete confidence in a significant portion of the data. Moreover, the remaining rate of error was judged to be within acceptable parameters. Once the CWS records were routed over the rail network, tonnage and car loadings were summed at the route link level to form measures of relative capacity

3.1.3 *Model Specification*. As discussed in Section 2, line-haul link capacity is a function of track configuration and the quality of track components, as well as exogenous factors including, but limited to topography (grade) and weather conditions. A number of model specification and functional forms were discussed with Corps personnel, independent transportation consultants, and other industry experts. Ultimately, the following model was selected.

$$\begin{aligned} MAXCARM_i = \beta_0 \; + \; & \beta_1(TIMETBLS_i) + \beta_2(CTCSPEED_i) + \beta_3(SPEEDRAT_i) + \\ & \beta_4(TRAINLEN_i) + \beta_5(MAINS_i) + \beta_6(CTCMAIN_i) + \beta_7(SIDSIZ_i) + \\ & \beta_8(SIDINGS_i) + \beta_9(SIDINT_i) + \beta_{10}(ABS_i) + \beta_{11}(CTC_i) + \beta_{12}(SWITCH_i) + \\ & \beta_{13}(SWITCH2_i) + \beta_{14}(ROUTLEN_i) + \\ & \beta_{15}(ROUTLN2_i) + \\ & \qquad \Sigma\gamma(CD_i) + \varepsilon_i \end{aligned}$$

variable definitions are provided in Table 3.1

Table 3.1

[10] The 1995 CWS contains nearly 500,000 records that reflect more than 75,000 routings. Except as noted in the GIS documentation, each of the geographic path of each of these unique routes was calculated for use in this analysis. The comparison routes were developed through the use of PC Rail, a software product produced by ALK Associates in Princeton, New Jersey.

Variable	*Description*
MAXCARM	The dependent variable is defined as the natural log of the number of gross carloads accommodated by the i^{th} route link in the busiest 1995 calendar quarter. The log-linear specification was adopted to help capture any non-linear relationships between the dependent variable and explanatory variables. Gross carloads reflect the sum of revenue carloads and estimated empties.[11] The maximum quarterly value was selected to reflect seasonal variations in traffic levels and the assumption that infrastructure is constructed to accommodate the seasonal peak load.
TIMETBLS	Average timetable speed along the route link in question calculated by averaging the reported timetable speed at highway grade crossings. This variable is included as a measure of track component quality.[12]
CTCSPEED	The product of TIMETBLS and CTC, a measure of centralized traffic control described below. This interaction term is included to capture substitutability / complementarities between signal quality and track component quality [13]
SPEEDRAT	The ratio of the minimum train operating speed to the timetable speed, included to capture variations in train speeds.
TRAINLEN	The average train length observed along the network link calculated as the gross number of carloads divided by the total number of daily trains..
MAINS	The estimated proportion of mainline tracks within the route estimated by combing the number of mainline tracks at grade crossings throughout the link in question and the carrier-specific ratio of additional mainline miles to total route miles operated..
CTCMAIN	The product of CTC and MAINTRAK. This term is included to reflect substitutability or complementarity between signal quality and the amount of mainline trackage.
SIDSIZ	The average siding length along the route segment.
SIDINGS	Estimated proportion of sidings to mainline trackage based on the carrier specific ratio of sidings to mainline trackage and the number of "other" tracks observed at highway grade crossings along the specific route.
ABS	The percentage of the route link that is controlled by automatic block signals (ABS). ABS is assumed to be inferior to centralized traffic control (CTC), but superior to unsignaled or "dark" territory.
CTC	The percentage of the route link that is controlled by centralized traffic control (CTC).

[11] Empty return ratios (ERRs) were based on a similar parameter used in cost calculations within the Rebee Rail Costing Model. Gross carloads equal (revenue carloads) X (1+ERR).

[12] As with most such analyses, there are innumerable data problems. In the case of timetable speed, the data reflect freight train speeds where no passenger service is operated, but reflect timetable passenger train speeds where passenger trains are present.

[13] For example the effect of timetable speed is reflected by the partial derivative of the model equation with respect to TIMETBLS. Normally, this would simply be the estimated coefficient for TIMETBLS, but because of the interaction term, the derivative includes is:

$$\frac{\P\ \text{MAXCARM}}{\P\ \text{TIMETBLS}} = b_1 + b_2(\text{CTC})$$

Variable	*Description*
SWITCH	The average number of daily switch movements along the link in question.
ROUTLEN	The route length as calculated from the GIS coverage. Because individual arcs were missing from some links, there are numerous instances in which the calculated route length is less than the actual length. This should not, however, affect the validity of the estimation results. To capture in additional non-linearities a quadratic term ROUTLEN2 is included in the specified model.
CD	Carrier intercept terms.[14]

3.2 ESTIMATION RESULTS

A full set of estimation results is provided in Table 3.2. On the whole, these results support the hypothesized link-specific correlation between observed rail traffic and those variables used to represent the quality and configuration of track structures. We must also conclude, however, that the general degree of model fit and the weak statistical significance of some variables suggests that factors other than track quality and configuration are also important determinants of the level of traffic observed on a particular route segment.

Based on the estimates, the greater train speeds that are facilitated by better track components appear to significantly improve the carload capacity of a network link, while variations in train speed reduce capacity. The coefficient estimates for CTC and ABS clearly indicate that the quality of signaling affects capacity and, as anticipated, the magnitude of CTC is considerably greater than that of ABS. Track capacity is negatively correlated with train length, indicating that, all else equal, it is more difficult to meet and manage trains of greater length. Coefficient estimates for the two interaction terms, CTCSPEED and CTCMAIN, were both negative and statistically significant. Moreover, their magnitudes, relative to estimates for the independent variables from which they are formed, supports the hypothesis that improved signaling increases capacity more when there are fewer mainline tracks or when train speeds are lower, but is a less effective means of adding

[14] A fully interactive model that included interactions between the carrier intercept terms and the other independent variables was tested, but rejected as it offered no measurable improvement.

capacity when multiple main tracks are present or when train speeds are already at relative high levels.[15] The coefficient estimates for

Table 3.2

Variable	*Coefficient Estimate*	*Standard Error*	*"t" (Parm=0)*	*Probability Parm=0*
INTERCEPT	8.289905	0.277913	29.829	0.0001
TIMETBLS	0.033229	0.002437	13.635	0.0001
CTCSPEED	-0.017	0.00365	-4.657	0.0001
SPEEDRAT	0.178289	0.09967	1.789	0.0739
TRAINLEN	-0.00091	6.66E-05	-13.614	0.0001
MAINS	0.7272	0.090022	8.078	0.0001
CTCMAIN	-0.41692	0.131276	-3.176	0.0015
SIDINGS	0.948858	2.394492	0.396	0.692
SIDSIZ	0.095958	0.024872	3.858	0.0001
ABS	0.430842	0.066326	6.496	0.0001
CTC	1.854777	0.177132	10.471	0.0001
SWITCH	0.113847	0.019442	5.856	0.0001
SWITCH2	-0.00517	0.001686	-3.064	0.0022
ROUTLEN	-0.00088	0.001075	-0.815	0.4155
ROUTLEN2	3.46E-06	5.17E-06	0.669	0.5036
CD076	CONFIDENTIAL[16]			
CD190				
CD712				
CD400				
CD555				
CD482				

[15] While the interaction terms work to offset the individual coefficient estimates, the effects of additional mainline trackage or CTC are still positive. In every case the sum of the interaction terms and independent variables was statistically different from zero at a 95% level of confidence.

[16] Because confidential Waybill records were used to develop traffic volumes, carrier-specific estimation results are also held to be confidential.

CD721	
CD802	
Adjusted Model $R^2 = 0.6012$	

SIDSIZ, and SIDINGS display the anticipated signs, although the magnitude and statistical significance of these estimates would, at first glance, appear to under-represent the importance of sidings as a means of adding link capacity.

3.4 Interpreting the Results

The estimation results as depicted in Table 3.2 are useful in evaluating the overall model performance. However, from the standpoint of assessing track capacity, a series of result applications may be more useful. Tables 3.3-5 illustrate the estimated relationship between independent variables and track capacity as measured by observed traffic under three different circumstances.

Table 3.3 illustrates the estimated track capacity for a 100 mile route segment of minimal quality. It is unsignaled, without sidings or additional main tracks, and suitable for train speeds of 20 m.p.h. or less. The estimation results suggest that trackage with this configuration and quality would support roughly five 40 car trains each day.[17] Based on consultation with industry experts, this estimated capacity appears reasonable.

Table 3.4 depicts the estimated capacity for a route segment based on the mean values of the independent variables. These data, therefore, depict an "average" route segment based on the sample of roughly 1,300 such segments. As would be expected this typical track segment reflects both better component quality and a more complex configuration. Consequently, it is estimated to accommodate nearly twice the number of daily trains and nearly four times as many cars as the trackage of minimal quality and configuration. Nonetheless, these results do reveal evidence that the data may not be entirely effective at measuring the intended variables. In particular the mean values for SIDINGS and SIDSIZ highlight the lack of specificity that is likely responsible for the rather lose model fit. It is

[17] Exponentiation of the intercept term reported in Table 3.5 suggests that nearly every piece of trackage, under any configuration and in any condition, will support one train a day.

impossible to discern whether these data reflect 14 equally sized (and very small) sidings or a much smaller number of more usable sidings.

Table 3.3

Variable/Value	*Measure*	*Variable/Value*	*Measure*
TIMETBLS	20	SIDSIZ	0
CTCSPEED	0	ABS	0
SPEEDRAT	1	CTC	0
TRAINLEN	40	SWITCH	0
MAINS	1	SWITCH2	0
CTCMAIN	0	ROUTLEN	100
SIDINGS	0	ROUTLEN2	10000
Estimated Capacity	17,514		
	5	Trains Per Day	

Finally, Table 3.5 depicts a piece of trackage that is clearly superior to the sample mean. The route in this example is fully signaled with CTC, can accommodate 69 m.p.h. train speeds, and features a significant amount of secondary main, as well as a copious volume of passing track. This trackage is estimated to accommodate more than four times the number of daily trains and train cars hosted by the "average" track depicted in Table 3.7. Still, consultants, familiar with the industry, have suggested that the trackage portrayed in Table 3.8 would, in fact, be able to accommodate a volume of traffic that

Table 3.4

Variable/Value	*Measure*	*Variable/Value*	*Measure*
TIMETBLS	38	SIDSIZ	0.321
CTCSPEED	14.858	ABS	0.161
SPEEDRAT	0.4848	CTC	0.391

TRAINLEN	79	SWITCH	1.970
MAINS	1.158	SWITCH2	3.881
CTCMAIN	0.452	ROUTLEN	41
SIDINGS	0.108	ROUTLEN2	1681
Estimated Capacity	64,226		
	9	Trains Per Day	

Finally, Table 3.5 depicts a piece of trackage that is clearly superior to the sample mean. The route in this example is fully signaled with CTC, can accommodate 69 m.p.h. train speeds, and features a significant amount of secondary main, as well as a copious volume of passing track. This trackage is estimated to accommodate more than four times the number of daily trains and train cars hosted by the "average" track depicted in Table 3.7. Still, consultants,

Table 3.5

Variable/Value	*Measure*	*Variable/Value*	*Measure*
TIMETBLS	69	SIDSIZ	5
CTCSPEED	69	ABS	0
SPEEDRAT	1	CTC	1
TRAINLEN	65	SWITCH	0
MAINS	1.2	SWITCH2	0
CTCMAIN	1.2	ROUTLEN	100
SIDINGS	0.2	ROUTLEN2	10000
Estimated Capacity	236,368		
	40	Trains Per Day	

familiar with the industry, have suggested that the trackage portrayed in Table 3.8 would, in fact, be able to accommodate a volume of traffic that significantly exceed the estimated 40 trains p *day. Generally, it is our assessment that the estimation results systematically understate link capacity for higher quality route segments.*

SECTION 4

RAILROAD CAPACITY FOR

SNAKE RIVER BASIN SHIPMENTS

The ultimate purpose of this research is to evaluate the extent to which diverted Snake River traffic would affect the need for and cost of railroad capacity for movements to, from, and within the region. Armed with the estimation results developed in Section 3, predictions of diverted traffic, and rule-of-thumb measures of incremental track component and configuration costs, this section seeks to finally address the central focus of this study.

4.1 CAPACITY COSTS

The cost of building or modifying line-haul railroad trackage is, of course, a function of the quality and configuration of that trackage. It is also, however, affected by a wide array of exogenous factors. Specifically, soil conditions, terrain, environmental concerns, and the degree of urbanization can all significantly impact the cost of a particular construction project. The challenge, within the current context, is to mitigate the effects of these specific factors in order to develop generic cost estimates that can be reasonably applied to a variety of potential infrastructure improvements.

Table 4.1 provides a summary of the generic or "rule of thumb" measures for costing the construction or modification of rail infrastructure developed by civil engineers the University of Tennessee's Transportation Center. Appendix 4 fully documents the methodology, data, and calculations used to produce these estimates. It should be noted, as well, that preliminary estimates were discussed with engineering professionals from a number of Class I railroads and with experts from private construction firms that are routinely engaged in rail project construction. It is, of course, possible to point to innumerable examples of rail infrastructure projects where the actual incurred costs are quite different than those contained within Table 4.1. We are, however, extremely confidant that the UT estimates are both reasonable and reliable.

Table 4.1 also contains the estimated necessary real rate of return on capital investments. Varying this rate, even modestly, has a significant impact on the final costs of multi-million

Table 4.1

Base Case				
Summary	Track $/Mile	Track $/Ft	Turnout cost	Control point cost
Siding Case	$383,730	$73	$98,768	$129,290
Light density case	$411,231	$78	333$92,768	$129,290
Medium density case	$457,013	$87	$98,768	$129,290
Heavy haul case	$489,841	$93	$119,691	$129,290
Variations in Terrain				
	Existing ROW	New ROW		
	Incr. $/Mile	$/Mile		
Flat Terrain		$119,262		
Rolling Terrain	$163,612	$786,241		
Mountainous Terrain	$546,532	$3,795,915		
Isolated Signal Projects[18]				
Signal Upgrades	$605,000			
Finance Costs				
Rate of Return	8%			

dollar projects that span several decades. It is, therefore, important to carefully select this rate. To simplify the estimation, the analysis ignores the potential impact of expected inflation, focussing instead on the *real* necessary rate of return. It is also important that the identified rate reflect the necessary return under conditions of competitive supply. Any observed impacts that result from the exercise of market power must be eliminated. The necessary rate of return should, instead, be a forward-looking, long-run, least-cost estimate of the cost of capital. Ultimately, after numerous machinations in

[18] The University of Tennessee output did not specifically include isolated signal project costs. It did, however, contain data detailing the actual costs associated with a handful of such projects. TVA to develop the cost estimate used within the analysis used these figures.

consultation with a variety of sources, the current analysis settled on a real necessary rate of return of 8%. This figure, in combination with recent price patterns, yields nominal rates of return that are somewhat less than the benchmark rate established by the Surface Transportation Board for the assessment of revenue adequacy, but greater than the historical rates of return for most Class I carriers.

Returning to the expense of actually constructing or modifying trackage, the analysis assumes that siding construction varies from main-line construction both in the quality of track components and in their placement. For example, the calculation of siding costs incorporates the use of re-lay (used) rail. It also is based on tie spacing that is greater than those used to support mainline track. Light density trackage is of the construction typically found on long industrial tracks, small branch-lines, or Class III railroad mainlines. This track classification is designed to handle modest tonnages at moderate speeds. The medium density case provides cost calculations for the type of trackage typically found on Class I mainlines. This track will support moderate to heavy traffic at track speeds up to perhaps 60 m.p.h. Finally, the heavy haul case reflects the costs of constructing state-of-the-art trackage capable of handling continuously moving heavy traffic as might be evidenced in the Powder River region or within the northeast corridor. Here, rail weight is assumed to be, at least, 136 lbs., concrete ties are placed along with advanced anchoring systems, and ballast (and sub-ballast) levels are at their greatest.

The application of the UT cost estimates is reasonably straight forward. For example the construction of a one-mile long siding on existing right-of-way over flat terrain would include $383,730 for actual track construction, two turnouts at $98,768 each, and two control points (If CTC) at a cost of $129,290 per location for a total cost of $839,846. A signal upgrade from ABS to CTC over five miles of trackage would cost 5 x $605,000 or $3,025,000. Finally, the new construction of a 10 mile long second medium-haul main track through hilly terrain would cost $12,712,366 for earth work, track installation, turn-outs, control points and signals.

4.2 TRAFFIC DIVERSIONS AND ALTERNATIVE TRAFFIC FLOWS

Unlike many settings, resolution of the policy issues in the Snake River basin could entail the diversion of currently observed river traffic to alternative modes. Thus, in this case, the phrase "diversion" completely accurate. The "with" condition is assumed to be the status quo, while the "without" condition assumes the elimination of commercial navigation on the Snake River.

Table 4.2 contains a summary of projected traffic diversions for all commodities to alternative routings.[19] Roughly one–half of this tonnage is grain moving from Eastern Washington and Idaho to

Table 4.2

Commodity	*Annual Tons*	*Commodity*	*Annual Tons*
Alfalfa Hay	91,361	Logs (Saw)	224,517
Anhydrous Ammonia	4,096	Lumber	6,373
Barley	609,009	Nitrogen Fertilizer Solution	666,119
Distillate Fuel Oil	155,912	Wheat	798,421
Logs (Pulpwood)	142,070	Wood Chips	44,024
		Grand Total	2,741,902

Export locations in Oregon. The remainder of the traffic is a combination of chemicals and wood products. For the purpose of the current analysis, it is assumed that 100% of this traffic would divert to an all-land alternative that involves rail carriage along the east-west corridors operated by the Burlington Northern – Santa Fe (BNSF) and the Union Pacific (UP). Table 4.3 translates this barge tonnage into railroad activity along these routes, based on the assumption that grain is loaded to 97 tons per car, non-grain commodities are loaded to 80 tons, all tonnage is moved in 70 car trains, all cars are returned empty. Given that most traffic is (or could be) divided evenly between the UP and BNSF, the diversion of Snake River Traffic would, on average, require each railroad to accommodate one loaded and one empty train each day, Monday through Friday.

4.3 Line-Haul Capacity and Capacity Costs

[19] These traffic diversions are developed specifically for application within the current analysis and may differ from the final
traffic diversions estimated within the traditional NED analysis.

The examination of line-haul capacity costs is focused on the railroad route segments that connect the upper Snake River basin with the Portland export gateway. In the event that inland navigation becomes unavailable on the upper Snake, these rail route segments would be required to process more traffic than is currently observed. Using the data developed thus far, we now turn to the task of estimating the incremental capacity cost associated with this traffic increase.

Ideally, it would be possible to divert every affected shipment onto the specific route predicted by current economics in order to precisely gage the incremental capacity necessary on every route-mile of track. However, both temporal and funding constraints preclude the possibility of such an analysis. Moreover, as recognized above, railroads now have more latitude than ever over actual routings, so that even the slightest future cost perturbation could make the currently predicted routings marginally inaccurate. As a second best approach, the current analysis carefully focuses on three representative route segments that, together, comprise roughly 175 miles of mainline trackage that connects the study region to the Portland area. The confidentiality of the waybill records used to develop carload estimates precludes the specific identification of these routes. However, these segments reflect trackage in both Washington and Oregon, as well as operations near export locations and in crop producing areas. Based on the data depicted in Table 4.3, the analysis proceeds under an assumed need to increase segment capacity by 30,000 carloads (loads and empties) a year.

Table 4.3

Diversion-Induced Additional Railroad Activity	*Grain*	*Non-Grain Commodities*
Annual Tons	1,498,791	1,243,111
Loaded Rail Carloads per Year	15,451	14,625
Additional Trains per Year	442	418
Loaded Rail Carloads per Week	1,030	975
Additional Trains per Week	8	8

Route characteristics, segment improvements, and incremental capacity costs for the first line-haul segment are provided in Table 4.4. The route segment characteristics reflect what is probably a high-quality, light-density piece of rural trackage. All but 2.34% of the route is unsignaled. It is single mainline track with only an average number of the meeting or overtaking of trains. There are a modest number of switch movements and substantial variability in timetable speeds. As currently configured, the segment has an estimated capacity of 166,000 carloads a year or between 5 and 10 trains a day, so that an increase of 30,000 a year or two trains a day represents a necessary capacity increase of almost 20%.

Given the light density characteristics of the current structure, there are a variety of ways to achieve the desired capacity increase. For purposes of illustration, the current analysis assumes that the least-cost method of obtaining additional capacity entails the construction of three new 10,000 foot sidings on existing right-of-way and the placement of automatic block signals along 20% of the route.

As Table 4.4 indicates, the cost of actual construction and placement is estimated to be $11 million. The additional cost of financing these improvements brings the total project cost to nearly $30 million, so that the incremental cost of the additional capacity is roughly one cent per ton-mile.

Characteristics, improvements and incremental costs for the second example are provided in Table 4.5. This route segment clearly very different from the first example. Timetable speeds average 59 m.p.h. The entire route is operated under Centralized Traffic Control (CTC). Trains average 55 cars in length. This is clearly a primary route segment capable of supporting 30 or more trains each day, so that the incremental capacity needed to support diverted barge traffic represents only a modest increase (4%) in overall capacity.

This example is illustrative of a situation encountered in earlier studies. It is relatively simple to identify methods for expanding the capacity of light density or low quality route segments. However, when the current infrastructure is already constructed and configured to accommodate large volumes of traffic, the set of choices for further expanding capacity becomes more limited. In this case, again for illustrative purposes only, the additional capacity is generated by the adding 12 miles of secondary mainline trackage on existing right-of-way. The cost of constructing this trackage is estimated to be

Table 4.4

ROUTE CHARACTERISTICS	
Average Timetable Speed	35
Siding Size	
Percent ABS	0.00%
Percent CTC	2.34%
Route Length	71
Daily Switch Movements	3
Average Train Length	16.521
Train Speed Ratio (Minimum / Timetable	0.37987
Number of Mainline Tracks	1
Proportion of Trackage with Sidings	9.91%
Carloads Per-Year Supported	165,748
INFRASTRUCTURE IMPROVEMENT COST	
Install (3) 10,000' Sidings	$2,782,689
Upgrade 20% of Unsignalled Track to ABS	$8,609,876
Construction Costs	$11,392,565
INCREMENTAL CAPACITY IMPROVEMENT	
In Carloads Per-Year	29,977
Percentage of Original	118.09%
In Ton-Miles (100% ERR)	102,386,795
Incremental Per-Ton-Mile Improvement Costs	$0.00371
Financing Cost	$18,701,493
Total Incremental Per-Ton-Mile Capacity Cost	$0.00980

Table 4.5

ROUTE CHARACTERISTICS	
Average Timetable Speed	59
Siding Size	
Percent ABS	0.00%
Percent CTC	100.00%
Route Length	80
Daily Switch Movements	3
Average Train Length	54.716
Train Speed Ratio (Minimum / Timetable	0.64734
Number of Mainline Tracks	1
Proportion of Trackage with Sidings	9.91%
Carloads Per-Year Supported	614,627
INFRASTRUCTURE IMPROVEMENT COST	
Construct 12 miles of Additional Second Main Line	$8,632,716
Construction Costs	$8,632,716
INCREMENTAL CAPACITY IMPROVEMENT	
In Carloads Per-Year	29,234
Percentage of Original	104.76%
In Ton-Miles (100% ERR)	112,439,343
Incremental Per-Ton-Mile Improvement Costs	$0.00256
Financing Cost	$14,171,056
Total Incremental Per-Ton-Mile Capacity Cost	$0.00676

Roughly $8.6 million, while financing costs contribute another $14 million for a total project cost of nearly $23 million. In this case, total incremental cost of the necessary new capacity is estimated to be 0.65 cents per ton-mile.

As Table 4.1 indicates construction costs vary considerable for differing types of base terrain. The figures in Table 4.5 are based on construction in rolling terrain. There are, however, route segments within the study are where the terrain is much more severe. Consequently, Table 4.6 repeats the exercise of expanding route capacity over example segment based on an alternative assumption of mountainous terrain. The additional cost of line-haul capacity expansion under this alternative scenario increases incremental capacity costs to more than 1.1 cents per ton-mile.

The final example described in Table 4.7 reflects yet another distinct type of route segment. The route features a double main-line configuration throughout nearly all its length. The entire route is signaled – half with CTC and half with ABS. In spite of the strength of configuration, construction, and signaling, however, average timetable speeds are relatively low and the variability of train speeds is relatively high. This segment, though technically outside of yard limits, is indicative of the heavily used trackage that often feeds traffic from converging routes into a nearby terminal.

As in the second example, the options for increasing track capacity are limited by the already high-capacity nature of the segment in question. As Table 4.7 indicates, the necessary additional capacity is attained by extending double mainlines to that small portion of the route that does not already have two mains and by upgrading remaining ABS to CTC. Because of the large expense of signal upgrades and the relative short route length, the per ton-mile cost of the incremental capacity improvement is significantly higher (2.1 cents) in this case.

From the standpoint of shippers, the 0.6 to 2.1 cent per ton-mile incremental capacity cost is only relevant when viewed in comparison to the capacity costs currently embedded in observed railroad rates. If the incremental cost exceeds current capacity costs, the future average will increase, so that cost-based rates would also be forced to increase. Alternatively, if the incremental cost of the capacity necessary to accommodate increased demand is less than the capacity costs currently embodied within rates, then the future average capacity cost would be lowered and competitively determined rates would decline. While a formal comparison of these
costs is beyond the scope of the current research, an arms' length examination suggests that the incremental cost of additional capacity along this route is unlikely to adversely affect competitively determined rates. Using 4.5 cents per ton-mile as an average rate across all commodities and regions, traditional rail costing models would assume that roughly two-thirds of

Table 4.6

ROUTE CHARACTERISTICS	
Average Timetable Speed	59
Siding Size	
Percent ABS	0.00%
Percent CTC	100.00%
Route Length	80
Daily Switch Movements	3
Average Train Length	54.716
Train Speed Ratio (Minimum / Timetable	0.64734
Number of Mainline Tracks	1
Proportion of Trackage with Sidings	9.91%
Carloads Per-Year Supported	614,627
INFRASTRUCTURE IMPROVEMENT COST	
Construct 12 miles of Additional Second Main Line	$14,413,092
Construction Costs	$14,413,092
INCREMENTAL CAPACITY IMPROVEMENT	
In Carloads Per-Year	29,234
Percentage of Original	104.76%
In Ton-Miles (100% ERR)	112,439,343
Incremental Per-Ton-Mile Improvement Costs	$0.00427
Financing Cost	$23,659,847
Total Incremental Per-Ton-Mile Capacity Cost	$0.01129

Table 4.7

ROUTE CHARACTERISTICS	
State of Operation	
Average Timetable Speed	38
Siding Size	
Percent ABS	50.00%
Percent CTC	50.00%
Route Length	25
Daily Switch Movements	9
Average Train Length	22.652
Train Speed Ratio (Minimum / Timetable	0.26
Number of Mainline Tracks	1.78
Proportion of Trackage with Sidings	9.91%
Carloads Per-Year Supported	690,262
INFRASTRUCTURE IMPROVEMENT COST	
Complete an Additional Two Miles of Second Main	1,438,786
Upgrade Remainder of Route to CTC	7,719,800
Construction Costs	9,158,586
INCREMENTAL CAPACITY IMPROVEMENT	
In Carloads Per-Year	32,592
Percentage of Original	104.72%
In Ton-Miles (100% ERR)	38,359,770
Incremental Per-Ton-Mile Improvement Costs	$0.00796
Financing Cost	15,034,299
Total Incremental Per-Ton-Mile Capacity Cost	$0.02102

this rate is attributable to variable costs, while the remaining 1.5 cents per ton-mile is a necessary contribution toward fixed costs. Determining the precise proportion of that penny and one-half that accounts for the historical cost of line-haul capacity would constitute and arduous (and very probably contentious) accounting exercise. Again, however, using the current ratio of right-of-way expenditures to total capital expenditures, a rule-of-thumb division of the 1.5 cent total would apportion approximately one cent per ton-mile to right-of-way capital expenditures. This rather arbitrary and capriciously determined value will serve as the basis for the illustration that follows. However, the reader is cautioned that actual values may vary.

Table 4.8 contains the incremental cost and route segment information developed above along with national means for observed rates and total shipment distance. Additional incremental capacity costs are integrated with the assumed one cent line-haul capacity costs to develop a new vector of railroad rates that reflects the expansion. In two of the four example cases, because incremental capacity costs are lower than current costs the average rate is made lower. In the two remaining cases, the expansion l

Table 4.8

Case	*Route Length*	*Shipment Length*	*Incremental Cost per Ton-Mile*	*Existing Rate*	*Post-Expansion Rate*
Example 1	71	756	$0.00980	$0.045	$0.04498
Example 2 (A)	80	756	$0.00676	$0.045	$0.04466
Example 2 (B)	80	756	$0.01129	$0.045	$0.04514
Example 3	25	756	$0.02102	$0.045	$0.04536

leads to rates that are marginally higher. In this example, however, the overall impact on rates is quite small. This result owes in part to the weight given to the portion of the routing for which capacity costs do not change. In the case of Example 3, this is equal to 731 of 756 total miles. Recognizing that most shipments to and from the Pacific Northwest have an origin or destination hundreds or even thousands of miles to the east of the region, this weighting seems appropriate. Nonetheless, even when a 256 mile route is constructed from the four example segments so that the capacity costs for all segments change, the resulting post-expansion rate is only $0.04541.

Certainly some readers may challenge the validity of the one cent capacity cost and 4.5 cent rate. To demonstrate the robustness of the result, Table 4.8 results are recalculated in Table 4.9 under the

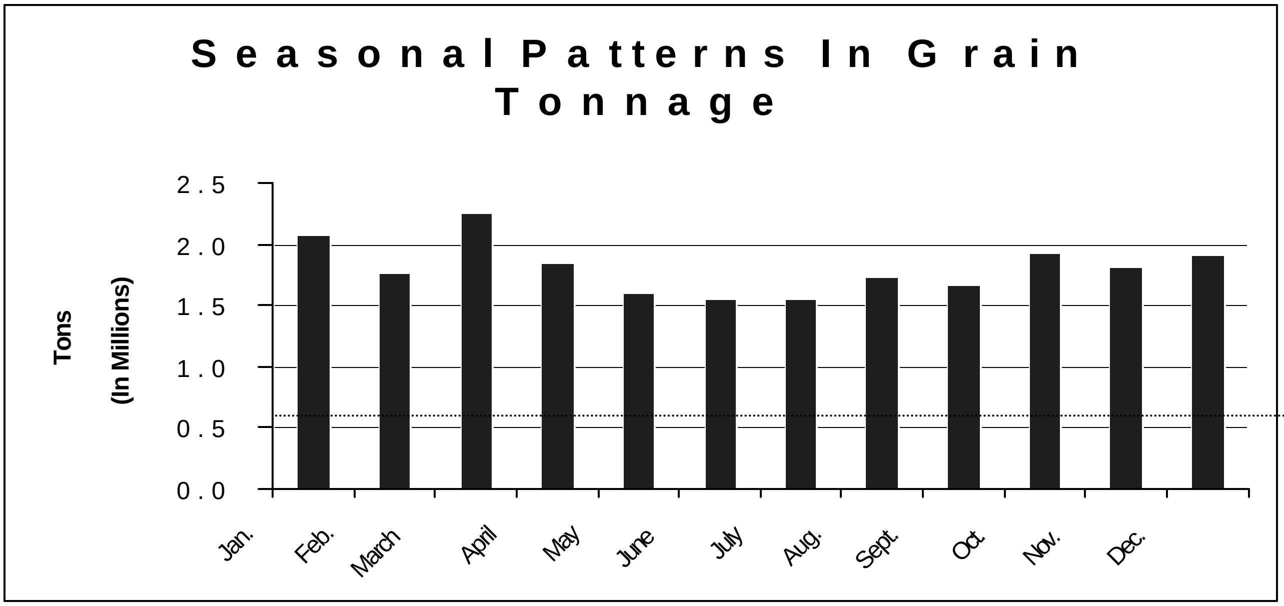
Table 4.9

Case	*Route Length*	*Shipment Length*	*Incremental Cost per Ton-Mile*	*Existing Rate*	*Post-Expansion Rate*
Example 1	71	756	$0.00980	$0.03	$0.03045
Example 2 (A)	80	756	$0.00676	$0.03	$0.03019
Example 2 (B)	80	756	$0.01129	$0.03	$0.03066
Example 3	25	756	$0.02102	$0.03	$0.03053

alternative assumption that current line-haul capacity costs one-half cent per ton-mile and that a more appropriate rate base is 3 cents per ton-mile. Under these alternative assumptions, increased capacity raises rates for all segments because the incremental capacity cost is greater than the current capacity cost in every case. The overall impact is, however, still very small, so that no individual rate is increased by even as much as one-tenth of a cent.

The incremental capacity requirements in Table 4.3 are based on the assumption that rail traffic to and from the region do not exhibit strong seasonal tendencies. Certainly in the case on non-grain commodities, this might be expected to be the case. Moreover, data indicate that there is also no strong seasonal trend in grain movements. Figure 4.1 graphically describes monthly rail tonnages for grain that terminated in the Pacific Northwest regardless of origin. While there is clearly a peak in March and the summer months are somewhat slack. It is our judgement that these seasonal variations not sufficient to threaten the validity of the foregoing analysis.

Figure 4.1



4.4 TERMINAL CAPACITY

The dominant terminal capacity issue is the ability of export elevators to handle the additional rail traffic that would result from a wholesale diversion of barge traffic. Table 4.10 summarizes current operations and capacity at a number of these export facilities.

Export grain is not loaded directly from barge to vessel. Instead, all cargo moves through storage, so that storage capacity is the same under both the status quo and any diversion scenario. The diversion of barge grain traffic from the Snake River would, however, necessitate the yarding and unloading of approximately 15,000 additional rail cars each year. Unloading rates were immediately available for only three terminals – two at Kalama, Washington and one at Vancouver, Washington.

Even, however, when only these three terminals are considered, the available unloading capacity seems sufficient to handle the incremental additions to rail traffic. Table 4.11 provides a summary.

Table 4.10

Name	*Location*	*Storage Tracks*	*Car Capacity*	*Rail Carriers*	*Total Storage (Bushels x 1M)*	*Processing Rate (cars per hour)*
Peavey Co.	Kalama, WA	6	480	BNSF, UP	2.0	25
Harvest States	Kalama, WA	4	270	BNSF, UP	6.4	10
United Grain	Vancouver, WA		57	BNSF, UP	5.0	18
Port of Portland[20]	Portland, OR	4		UP		
Port of Portland[21]	Portland, OR	4		UP	7.7	
Cargill	Portland, OR	4	60	UP		
Louis Dreyfus	Portland, OR	4	30	UP	1.8	

Table 4.11

Name	*Location*	*Weekly Capacity*	*Share of Total Capacity*	*Proportionally Distributed Incremental Demand*	*Distributed Percent of Weekly Capacity*
Peavey Co.	Kalama, WA	4,200	47.17%	136 cars	3.37%

[20] Berth 401; operated by Cargill.

[21] Berths 403, 404, 405; operated by PM Ag Products, Cargill

Harvest States	Kalama, WA	1,680	18.87%	54 cars	3.37%
United Grain	Vancouver, WA	3,024	33.96%	98 cars	3.37%

The addition of 15,000 unloadings translates to roughly 288 rail cars per week. The entire volume could be unloaded at the Peavey facility at Kalama with only a 7% increase in capacity at that location. If the 288 car total is distributed equally among the three facilities for which loading rates are known, the incremental volume could be absorb with only a 3.4% capacity increase at each location. In view of these figures, the additions to terminal capacity necessary to accommodate diverted Snake River grain would seem to be minimal.

SECTION 5

CONCLUSIONS AND SUMMARY COMMENTS

Those familiar with the empirical data and methods commonly used in transportation economics are sure to conclude that the above analysis pushes the available data to the limits of their usefulness and, simultaneously, employs myriad simplifying assumptions that are routinely violated within the day-to-day world of transportation. The ambitious nature of this investigation combined with the paucity of useful information simply demanded that the analysis be both inventive in approach and accepting of a certain level of imprecision. Thus, the conclusions drawn from this study rest on a relatively fragile analysis. Even, however, after noting this qualifications, the authors remain convinced that both the methods and results reported above represent the best generalized treatment of railroad capacity currently available. Moreover, they are sufficiently confident in the empirical results to urge their incorporation into the more traditional economic analyses that are being conducted with respect to Snake River navigation.

The transportation infrastructure that is the focus of more broadly framed policy questions is the product of a remarkably dynamic and resilient spatial equilibrium in which producers, transportation providers, and downstream consumers continually modify their behaviors to reflect changing market conditions. Thus, any number of exogenous changes could disrupt the interrelated predictions that form the basis for this rail capacity analysis. If, however, future events and market outcomes unfold in ways that are not radically different from those foreseen at the present time, then the current analysis supports the following conclusions:

- The unavailability variable inputs such as locomotives, rail cars, and train crews can lead to serious short-run capacity constraints. However, in the long-run optimal levels of these inputs can and will be acquired at prices that will not adversely affect rates if rail carriers face effective competition in rail-served markets.
- In most cases, the line-haul segments that, together, form the routes over which regional rail traffic flows could be modified to accommodate Snake River barge traffic without placing a

significant upward pressure on competitively developed railroad rates. While some specific route segments might require substantial incremental expenditures to accommodate additional traffic, the adverse rate effects of these expenditures would be largely offset by the efficiencies gained through expanding the capacity of related route segments.

- At least in the case of the Snake River, concerns regarding terminal congestion and the adverse effects this congestion may have on railroad pricing are unfounded.
- The traditional Corps assumption of ample alternative modal capacity is valid for use in the analysis of Snake River navigation.

In order that there be no confusion, we wish to explicitly note that these results *do not* imply that Snake River navigation is without economic benefit. Even under traditional capacity assumptions, available Snake River navigation confers measurable NED benefits through shipper savings. It also provides regional benefits to rail shippers in the Pacific Northwest who often pay lower rates because of the competitive influence navigation provides. The current results do, however, support the traditional methods by which National Economic Development benefits are calculated. These methods require analysts to assume that alternative modes have sufficient capacity to accommodate any diverted traffic unless there is clear evidence to the contrary. Based on the current analysis, such evidence is not available.

Appendix 1

Origin State	Two Digit STCC	1996 Originating Tonnage
Idaho	1	4,008,261
	14	3,285,060
	20	1,552,104
	24	2,324,977
	26	167,676
	28	975,764
	32	197,972
	33	7,320
	36	4,600
	37	29,840
	40	99,920
	46	79,480
Montana	1	5,306,096
	10	243,620
	11	28,386,492
	14	367,609
	20	327,472
	24	1,836,080
	26	486,860
	28	370,000
	29	1,988,316
	32	480,780
	33	191,200
	37	4,880
	40	45,020
	42	7,000
	46	27,760
	48	7,440
Oregon	1	848,396
	8	14,600
	10	516,420
	14	284,860
	20	797,052
	24	5,434,940
	26	2,566,664
	27	23,760
	28	563,064
	29	114,772
	30	7,200
Oregon (cont.)	32	319,544
	33	717,220
	34	32,440
	35	2,520
	36	12,920
	37	230,256
	39	12,960
	40	320,764
	41	8,920
	42	101,680
	44	14,480
	46	1,675,762
	47	46,440
	48	18,040
Washington	1	2,046,136
	8	17,600
	9	49,960
	10	1,043,292
	11	46,976
	14	182,268
	20	1,355,560
	24	2,662,920
	25	5,560
	26	1,422,700
	28	1,123,280
	29	1,306,632
	30	21,480
	32	815,532
	33	964,080
	34	4,360
	35	14,948
	36	3,920
	37	230,240
	39	11,120
	40	2,310,582
	41	33,780
	42	105,790
	43	3,920
	44	8,760
	45	45,880
	46	3,529,955
	47	3,360
	48	51,700

Terminus State	Two Digit STCC	1996 Terminating Tonnage	Terminus State	Two Digit STCC	1996 Terminating Tonnage
Idaho	1	1,677,937	Oregon	28	3,730,621
	10	3,680	(cont.)	29	630,524
	11	228,744		30	77,480
	14	3,874,032		32	1,235,192
	20	403,280		33	397,884
	24	473,345		34	26,840
	26	173,664		35	18,680
	28	1,120,672		36	25,320
	29	604,924		37	456,792
	30	8,720		39	86,440
	32	119,048		40	1,668,194
	33	14,640		41	25,152
	35	4,560		42	282,510
	37	19,840		43	4,200
	40	32,320		44	140,720
	42	34,440		45	7,840
	46	7,960		46	2,489,295
	48	35,600		47	83,800
Montana	1	102,252		48	19,720
	10	391,944	Washington	1	18,999,820
	11	742,787		10	1,443,828
	14	192,740		11	252,624
	20	144,500		14	415,217
	24	592,200		20	2,409,520
	25	7,640		23	22,120
	26	9,840		24	2,779,792
	28	414,640		25	24,200
	29	754,520		26	887,080
	32	108,720		27	35,400
	33	168,576		28	2,380,855
	35	6,000		29	2,472,080
	37	57,080		30	49,240
	40	104,060		32	1,490,236
	41	9,040		33	753,352
	44	16,400		34	36,120
	46	103,280		35	39,800
Oregon	1	5,896,982		36	78,360
	10	154,524		37	553,340
	11	858,512		39	16,600
	13	6,840		40	2,125,980
	14	230,980		41	56,380
	20	1,396,276		42	553,120
	23	7,440		44	109,960
	24	1,333,992		45	14,840
	25	19,560		46	4,309,254
	26	645,480		47	9,200
	27	10,360		48	11,000

Appendix 2

GIS PROCESS OVERVIEW for the RAILROAD LINE-HAUL CAPACITY PROJECT

Geographic Information Systems Group
Engineering Services
Tennessee Valley Authority
Norris, Tennessee

May 1997

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

AML - Arc Macro Language

BTS - Bureau of Transportation Statistics

DEM - Digital Elevation Model

FRA - Federal Railroad Administration

FTP - File Transfer Protocol

GIS - Geographic Information System

NTAD - National Transportation Atlas Databases

ORNL - Oak Ridge National Laboratory

USGS - United States Geological Survey

INTRODUCTION

Members of the TVA Norris GIS Group accepted a project from the TVA Navigation Team in February 1997 to assist them in determining the line haul capacity of selected railroad lines in the United States. The objective of the GIS phase of the project was to merge *attribute* information from multiple transportation and topographic data sources. This was a pilot project to be accomplished in the least amount of time and finances possible — not to provide a topologically correct routing network.

The primary attributes requested by the customer were:

- specialized route identification numbers
- railroad ownership names/abbreviations
- USGS Digital Line Graph major and minor attribute codes
- density categories
- signaling system types
- slope information
- railroad grade crossing identification numbers and street names

A specialized route identification number was manually added by an undergraduate student interning with the TVA Navigation Team. The railroad ownership names and major and minor attribute codes were taken from a 1:100,000 scale railroad network provided by the Bureau of Transportation Statistics. The density and signaling information was taken from a 1:2,000,000 scale railroad network also provided by BTS. Slope information was calculated from USGS Digital Elevation Model data. Railroad grade crossing data were acquired from the Oak Ridge National Laboratory.

Because of the lack of common attribute information (no key fields), it was necessary to use a Geographic Information System to *spatially* join each database together. For instance, the 1:2,000,000 scale network arc attributes were joined to the 1:100,000 scale network arc attributes based on their proximity. Figure 1 and Tables 1, 2, and 3 illustrate the process of joining an arc from the 1:2,000,000 scale network to an arc from the 1:100,000 scale network. An example arc (Arc #1) from the 1:100,000 scale network is shown in Figure 1 and its attributes in Table 1. An example arc (Arc #99) from the 1:2,000,000 scale network is also shown in Figure 1 and its attributes are depicted in Table 2. In this example, Arc #99 is the arc nearest to Arc #1, therefore its attributes are appended to the Arc #1 attributes. The resulting attribute table is shown in Table 3.

Members of the GIS Group used this type of process to merge all of the initial databases together to produce the final output for the project (Figure 2). The GIS Group used Arc/Info® 7.0.4 and ArcView® 2.1 running on a network of Sun Ultra Workstations. The final digital data files were transferred to the customer on a network Pentium PC.

Unlike most GIS tasks, the final products of this pilot project were listings of attribute information only. In most GIS transportation applications, the primary objective is to produce a topologically correct network at a maintained scale. In this case, the emphasis was not on the connectivity of the geographic data, but on the amount of time taken to merge the attribute

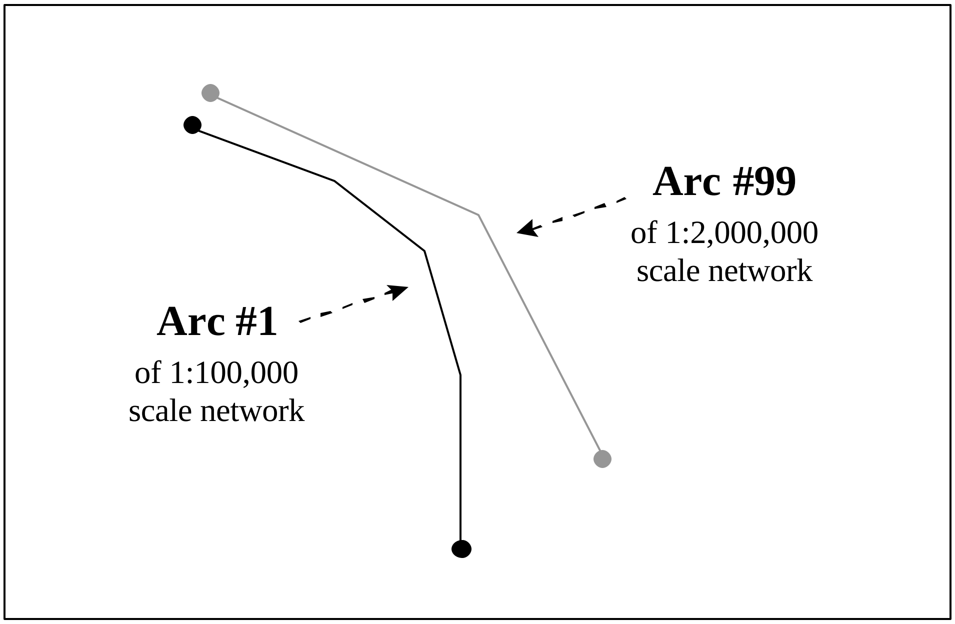


Figure 1. Spatail Join Example

Arc100k #	Route #	Owner	Major Code	Minor Code
1	2462	WC	180	208

Table 1. Example 1:100,000 Scale Railroad Network Attributes

Arc2m #	Density	Signaling
99	1.0	Manual

Table 2. Example 1:2,000,000 Scale Railroad Network Attributes

Arc100k #	Route #	Owner	Major Code	Minor Code	Arc2m #	Density	Signaling
1	2462	WC	180	208	99	1.0	Manual

Table 3. Resulting Railroad Join Attributes

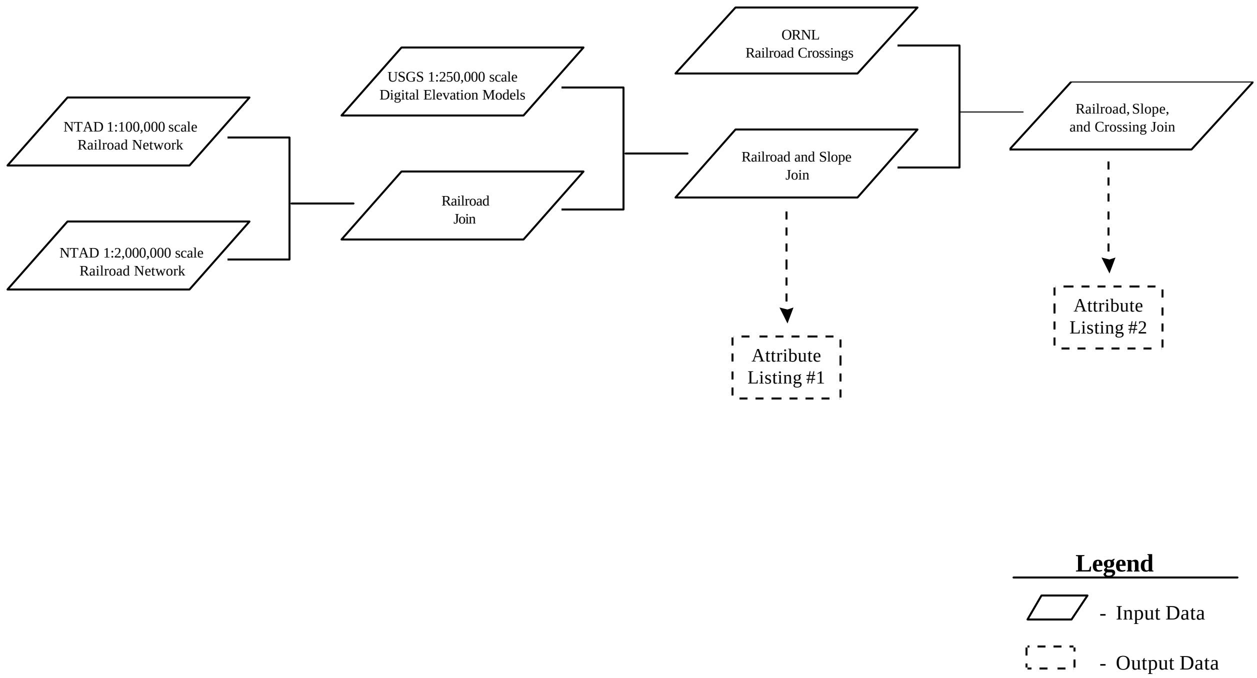


Figure 2. Multiple Joining of Input Data to Produce the Final Output Data

information together. Therefore, although the 1:100,000 scale railroad network did not maintain connectivity, it was chosen as the base network for the project since the 1:2,000,000 scale network did not contain secondary routes. For the next phase of the project, however, a topologically correct 1:100,000 scale railroad network should be available.

INPUT DATA

There were four main input data sets used for the project:

1). 1:100,000 scale railroad network taken from the 1995 National Transportation Atlas Databases (NTAD) compact disc. The CD was ordered via the Department of Transportation's Bureau of Transportation Statistics website: **http://www.bts.gov**
C code and ARC Macro Language (AML) routines were written to import the data into Arc/Info®.

2). 1:2,000,000 scale railroad network taken from the 1996 National Transportation Atlas Databases (NTAD) compact disc. The CD was ordered via the Department of Transportation's Bureau of Transportation Statistics website: **http://www.bts.gov**
The data was imported into Arc/Info® using an AML macro downloaded from the internet (btsarc.aml) and a user written AML macro routine.

3). 1:250,000 Digital Elevation Models downloaded from the United States Geological Survey website:
http://edcwww.cr.usgs.gov/glis/hyper/guide/1_dgr_demfig/index1m.html
The DEMs were downloaded from the internet and copied to recordable compact disks. Another set of CDs was also made which contained only those DEMs thought to be necessary for the project. AML macros were written to copy each of these DEMs from CD to a disk drive, uncompress them, and use the Arc/Info® DEMLATTICE command to convert them to an Arc/Info® LATTICE.

4). Railroad grade crossing data received from Bruce Peterson of the Oak Ridge National Laboratory via FTP. The railroad crossing data were imported into Arc/Info® manually using Info™ commands.

In addition, the Navigation Team student used an Arc/Info® coverage of the 1995 NTAD Place Names provided by the Norris GIS Group, and a list of railroad routes along with a PC Rail© network provided by the customer.

PROCESS OVERVIEW

A simplified graphical description of the GIS process is shown in Figure 3. Crucial network routes were first extracted from the NTAD 1:100,000 scale network to create a new, reduced network. Attributes from the NTAD 1:2,000,000 scale network were then joined to the new 'crucial route network'. Slope attributes were calculated for each arc in the new network and an output listing was created which contained all attribute information for every arc. Afterwards, the network arc attributes were joined to the railroad crossing point attributes and another output listing was created. Both output listings were then delivered to the customer.

SELECTING CRUCIAL ROUTES

A list of crucial railroad routes was defined and provided by the customer along with a PC Rail© railroad network to the Navigation Team undergraduate intern. For each route on the list provided, the intern used the origin, destination, and ownership names to visually locate the route on the PC Rail© network on a desktop PC. A Sun workstation running Arc/Info® was used to visually locate the identical route on the 1:100,000 scale network. The arcs for the route were selected[22] in ArcEdit and put into (appended to) a new data layer. A unique identification number was manually assigned to each route via the listing received from the customer. The final Arc/Info® output coverage containing the crucial routes was then given to the Norris GIS Group. Because of some of the following problems, not all routes were matched.

1. The two networks were not displayed in the same projection. The 1:100,000 scale network was in a Geographic coordinate system (latitude and longitude in decimal degrees) and the PC Rail© network projection was unknown.
2. There were discrepancies amongst railroad ownership names.
3. The topology differed between the two networks.

[22] Arc/Info® commands are underlined

GIS PROCESS OVERVIEW

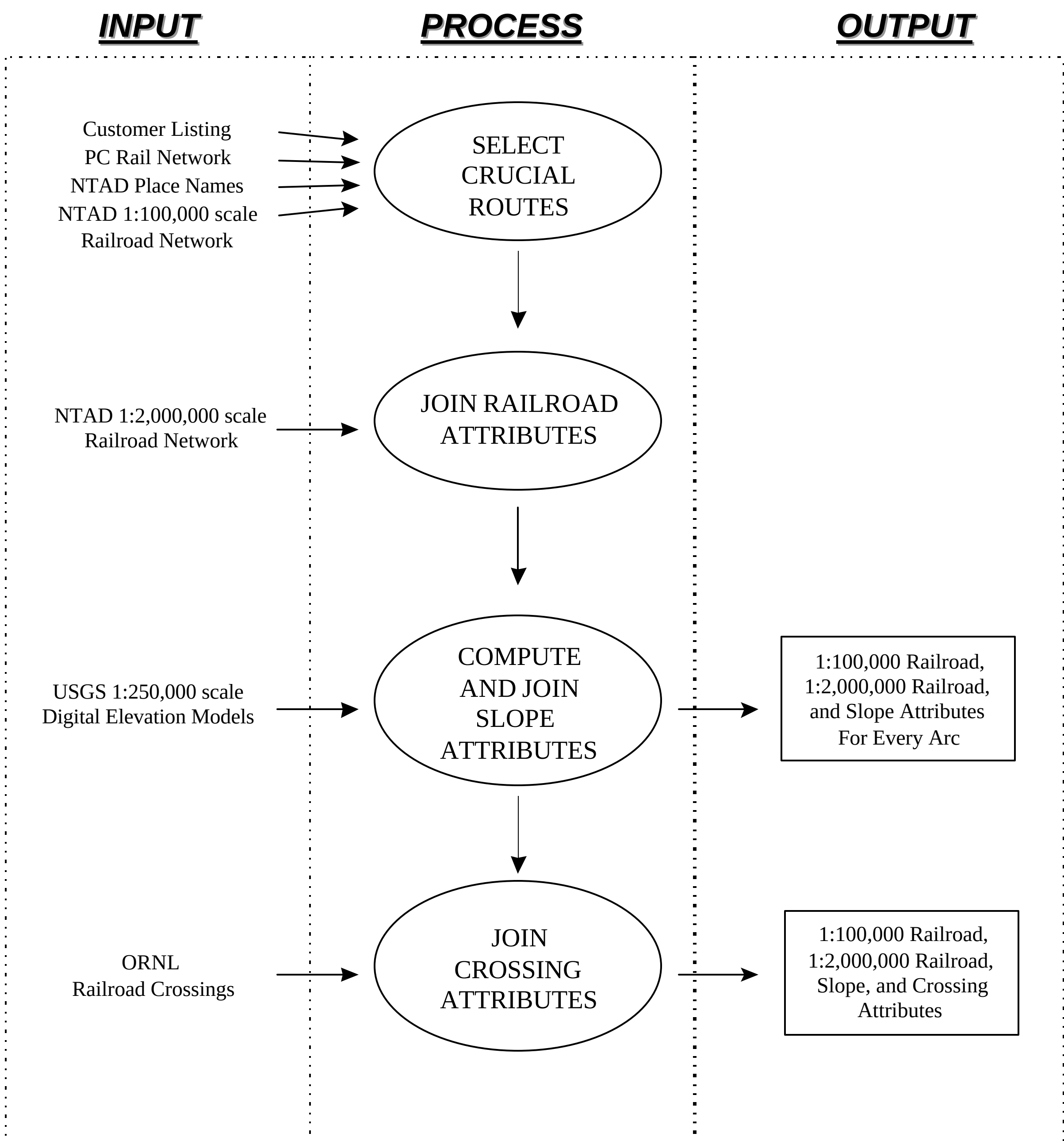


Figure 3. GIS Process Overview

JOINING RAILROAD NETWORK ATTRIBUTES

After receiving the crucial route network, the Norris GIS Group joined the 1:2,000,000 scale NTAD railroad network attributes to it through a two step procedure. First, the following Arc/Info® commands were used to automate matching the attributes:

ARCLABEL -	to create a coverage containing the midpoint of each arc in the crucial route network.
BUILD -	to build the point topology for the coverage.
NEAR -	to place a pointer in the midpoint coverage to the nearest 1:2,000,000 scale arc (within a specified tolerance).
JOINITEM -	to join the 1:2,000,000 attributes to the midpoint coverage.
JOINITEM -	to join the midpoint coverage attributes (now containing the 1:2,000,000 attributes) back to the 1:100,000 scale crucial route network.

The primary challenge encountered in the first step was to determine the tolerance level setting so that as many attributes as possible from the 1:2,000,000 scale NTAD network could be joined without creating incorrect matches at intersections or near parallel lines. The poor topology (lack of connectivity and duplicate arcs) of the original NTAD 1:100,000 scale network was also a factor. The Arc/Info® CLEAN command was used in an attempt to lessen the problem.

After finishing the automated procedure, the second step was to make a visual pass of the network and manually correct any problems, i.e. verify that the correct 1:2,000,000 scale attributes had been joined. The crucial route network was divided into two separate coverages so that two GIS technicians could correct it simultaneously. AML macros and menus were written to aid the technicians in transferring attributes. Attributes for arcs in which a match could not be determined were set to zero. Problems encountered were mainly due to the differing topology and scale between the 1:100,000 scale crucial route network and the 1:2,000,000 scale NTAD network. The crucial route network was re-appended upon completion of the manual corrections.

COMPUTING AND JOINING SLOPE ATTRIBUTES

The next phase of the project was to compute the slope for each arc in the crucial route network and join the slope attributes to the network. As mentioned before, AML macros were used to copy each DEM from CD to a disk drive, uncompress them, and convert them to an Arc/Info® LATTICE. The slope (in percent) was then computed for each LATTICE using the Arc/Info® GRID function SLOPE. These slope LATTICEs were written to a set of 8 recordable compact disks.

ArcView® was used to review each file on the CDs for anomalies. Many of the files had ‘streaks’ which originated from the USGS data collection procedures, but they were not corrected (filtered) as part of the pilot project because of time constraints. There were also two anomalous rectangular areas originating from the downloaded DEMs. One was near Texas in DEM files: Brownfield-E, Clovis-E, Lubbock-W, and Plainview-W. The other was in the Norfolk-W file. Therefore, slope was not computed for network data overlaying these areas.

Arc/Info® was used to extract slope data from multiple points along the crucial route network. The following Arc/Info® commands were used:

PROJECT -	to place the network in the same coordinate space as the slope LATTICE files. (Also, the USGS quad map boundaries and names were projected so they could be used as background data).
DENSIFYARC -	to place a vertex at least every 90 meters along the crucial route network (since the slope data was based on 90 meter DEM data).
ARCPOINT -	to create a point coverage from all of the nodes and vertices contained in the crucial route network.
BUILD -	to build point topology for the new point coverage.

SELECT & PUT - to manually divided the point coverage into smaller coverages to correspond with each DEM slope LATTICE. (Because of the large amount of data, it was necessary to process the slope data one file at a time.)

LATTICESPOT - to extract slope values for each point along the crucial route network, therefore providing a slope value at least every 90 meters. This command was used in a series of AMLs which cycled through each point coverage alphabetically and extracted the slope data values from the set of 8 CDs.

The Tables module of Arc/Info® was used to reselect all data that did not have undefined slope values and unload them into ASCII text format files. UNIX commands were used to concatenate all of these files into one large file. The file was imported into ArcView® and the Summary Table Definition function was used to compute the minimum, maximum, variance, and average slope for each arc identification number. This tabular data was exported as an Info™ file and the Arc/Info® JOINITEM command was used to permanently join the slope information to the crucial route network. ArcView® was used to sort the network by arc ID number, add a flag for determining railroad crossing availability, and export all the arc information in ASCII comma-delimited and also dBASE format.

During this phase of the project a few files had to be reprocessed (mostly because of incorrect file names), but the main challenge was managing disk space. The GIS Group used one 4 gigabyte hard drive and four 2 gigabyte hard drives, as well as a CD writer, two CD readers, and an 8 mm tape drive.

JOINING RAILROAD CROSSING ATTRIBUTES

Many of the railroad crossing data points received from ORNL did not have latitude and longitude information and, consequently, were deleted. The crucial route network attributes were then joined to the existing railroad crossing data points using the following Arc/Info® commands:

NEAR - to place a pointer in the railroad crossing coverage to the nearest crucial route network arc (within a very small tolerance).

JOINITEM - to join the crucial route network attributes to the railroad crossing coverage.

ArcView® was used to sort the railroad crossings by their associated arc ID number and export all the point information in ASCII comma-delimited and also dBASE format.

OUTPUT DATA

The following data were produced from the pilot project:

- 2 CDs containing USGS DEMs in GNU Zip compression format
- 2 CDs with pilot project DEMs in GNU Zip compression format
- 8 CDs with slope data for the project in Arc/Info® LATTICE format
- 9 sets of 8mm archival tapes containing pilot project data
- 2 final output files:
  1). A file in dBASE format containing attribute information from all the possible arcs considered important for calculating the line haul capacity of selected railways. See Appendix A for attribute descriptions.
  2). A file in dBASE format containing attribute information from all the railroad grade crossing points located near crucial route arcs and the attribute information from those arcs. See Appendix B for attribute descriptions.

The customer imported the two final output files into SAS, deleted any unnecessary fields, and merged the data together with other FRA data to perform the final analyses. The customer was made aware that the final output contained 78 arcs without slope data attributes. Slope attributes had not been computed for these arcs because they overlayed the anomalous DEM areas mentioned earlier. (These arcs comprised seven partial routes and one whole route.) There were also 687 duplicate arc ID numbers. Unfortunately, these had been created from the Arc/Info®

CLEAN command which was used to clean up the poor topology from the base network. This problem, however, was not a serious detriment to the customer's needs since his main analysis was route-based, not arc-based.

FINAL REMARKS

There were three major difficulties in accomplishing this pilot project:

1) the lack of a topologically correct railroad network which included secondary routes,
2) the challenge of utilizing given GIS tools to accomplish an unconventional task, and
3) the lack of contiguous disk space.

As technology improves, the integrity of input data, the capability of software packages, and the speed and capacity of computer hardware will increase, thus, making a project such as this a much simpler task. Even so, we will continue to push our resources to their fullest capacity to try to solve more complicated problems.

APPENDIX

A

Output File #1 Attribute Descriptions

OUTPUT FILE #1 ATTRIBUTE DESCRIPTIONS

1: 100,000 Railroad Network Attributes

MARKFINAL#:	Record number generated by Arc/Info®
MARKFINAL-ID:	Arc ID number taken from the original 1995 NTAD 1:100,000 scale railroad network
[23]FROMNODE:	Node ID in rail_100.pnt
[2]TONODE:	Node ID in rail_100.pnt
[2]LINKID:	Unique identification number
[2]LINKLEN:	Link length
[2]DIRECTION:	Always 0
[2]MAJORATT:	Major attribute code from USGS digital line graphs

180	Transportation systems - railroads
181	Railroads: minor attribute indicates number of tracks
188	Best estimate of position or classification
189	Coincident feature

[2]MINORATT: Minor attribute code from USGS digital line graphs

0001	Bridge abutment
0002	Tunnel portal
0007	Drawbridge
0100	Void area
0201	Railroad
0202	Railroad in street or road
0204	Carline
0205	Cog railroad, incline railway, logging tram
0207	Ferry crossing
0208	Railroad siding
0209	Perimeter or limit of yard
0210	Arbitrary line extension
0211	Closure line
0400	Railroad station, perimeter of station
0401	Turntable
0402	Roundhouse
0600	Historical
0601	In tunnel
0602	Overpassing, on bridge
0603	Abandoned
0604	Dismantled
0605	Underpassing
0606	Narrow gauge
0607	In snowshed or under structure
0608	Under construction
0609	Elevated
0610	Rapid transit
0611	On drawbridge
0612	Private
0613	U.S. Government
0614	Juxtaposition
0000	Photorevised feature

Note: If major attribute is 181 then minor attribute is number of tracks.

[23] Taken from the 1995 NTAD rail_100.lin file. Refer to the CDs rail_100.txt file for further description.

[2]OWNER: Alphanumeric identifier of the owning railroad
ROUTEID: Mark Burton's route ID number added by Cathy Adams

1: 2 million Railroad Network Attributes

NRAIL2M#: Record number generated by Arc/Info®
NRAIL2M-ID: Arc ID number taken from the original 1996 NTAD 1:2,000,000 scale railroad network
[24]LRECTYPE: Link record type: always 'L'
[3]LVERSION: Link file version number
[3]LREVISION: Link record revision number
[3]LMODDATE: Link record modification date
[3]LINKID2M: Unique sequential line identification
[3]FEATUREID: Unique line identification
[3]ANODE: Node identification for the beginning node of the line
[3]BNODE: Node identification for the ending node of the line
[3]DESCRIPT: Name or identification for the line feature
[3]STFIPS1: Primary State FIPS Code
[3]STFIPS2: Secondary State FIPS Code
[25]RECTYPE: Text record type: Always 'T'
[4]VERSION: Text file version number
[4]REVISION: Text record revision number
[4]MODDATE: Text record modification date
[4]OVERLAY: Country marker
[4]RROWN1: First railroad owner name
[4]RROWN2: Second railroad owner name
[4]RROWN3: Third railroad owner name
[4]TR1: First railroad having trackage rights
[4]TR2: Second railroad having trackage rights
[4]TR3: Third railroad having trackage rights
[4]TR4: Fourth railroad having trackage rights
[4]TR5: Fifth railroad having trackage rights
[4]TR6: Sixth railroad having trackage rights
[4]TR7: Seventh railroad having trackage rights
[4]TR8: Eighth railroad having trackage rights
[4]TR9: Ninth railroad having trackage rights
[4]SSRR: Subsidiary railroad
[4]PRR1: First previous Railroad owner
[4]PRR2: Second previous railroad owner
[4]ABDN: Abandoned flag
[4]PASS: Type of passenger rail flag
[4]MIL: Military importance flag
[4]STATE: Postal Code
[4]USGS_REG: USGS Region Code
[4]FRA_REG: FRA Region Code
[4]DENSITY: Density Category
[4]RR_CLS: Railroad classification
[4]SIGNALS: Type of signaling system
[4]ABDYR: Abandonment Year

[24] Taken from the 1996 NTAD rail2m.lnk file. Refer to the CDs rail_2m.met file for further description.
[25] Taken from the 1996 NTAD rail2m.tl1 file. Refer to the CDs rail_2m.met file for further description.

[4]STFIPS: State FIPS Code

Slope Attributes Generated from USGS DEM Data

COUNT: Number of slope sample points for this arc
MIN_SLOPE: Slope minimum for this arc (percent rise)
MAX_SLOPE: Slope maximum for this arc (percent rise)
VAR_SLOPE: Slope variance for this arc
AVE_SLOPE: Slope average for this arc

Railroad Crossing Attributes

XING: Flag for determining if this arc has associated railroad crossing data:
"1" - means associated railroad crossing data exists,
otherwise the field is blank.

APPENDIX

B

Output File #2 Attribute Descriptions

OUTPUT FILE #2 ATTRIBUTE DESCRIPTIONS

Railroad Crossing Attributes

MARKXINGS#:	Record number generated by Arc/Info®
MARKXINGS-ID:	Arc/Info® Point ID number
[26]GCIS_ID:	Railroad Crossing ID number (same as FRA ID)
[5]X_DD:	Longitude of the railroad crossing
[5]Y_DD:	Latitude of the railroad crossing
[5]SOURCE:	"V" - means located by Paul Cheng in TIGER with a street name or railroad match "M" (by milepoint) - interpolated between V's
[5]RR:	Ownership name abbreviation for the railroad crossing
[5]DIVISION:	Division
[5]SUB_BRANCH:	Sub/branch
[5]MP:	Milepoint
[5]STREET:	Street name of the railroad grade crossing

1: 100,000 Railroad Network Attributes

MARKFINAL#:	Record number generated by Arc/Info®
MARKFINAL-ID:	Arc ID number taken from the original 1995 NTAD 1:100,000 scale rail network
[27]FROMNODE:	Node ID in rail_100.pnt
[6]TONODE:	Node ID in rail_100.pnt
[6]LINKID:	Unique identification number
[6]LINKLEN:	Link ID number
[6]DIRECTION:	Always 0
[6]MAJORATT:	Major attribute code from USGS digital line graphs

180	Transportation systems - railroads
181	Railroads: minor attribute indicates number of tracks
188	Best estimate of position or classification
189	Coincident feature

[6]MINORATT: Minor attribute code from USGS digital line graphs

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0202	Railroad in street or road
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0208	Railroad siding
0209	Perimeter or limit of yard
0210	Arbitrary line extension
0211	Closure line
0400	Railroad station, perimeter of station
0401	Turntable
0402	Roundhouse

[26] Taken from data provided by Bruce Peterson of the Oak Ridge National Laboratory.
[27] Taken from the 1995 NTAD rail_100.lin file. Refer to the CDs rail_100.txt file for further description.

0600	Historical
0601	In tunnel
0602	Overpassing, on bridge
0603	Abandoned
0604	Dismantled
0605	Underpassing
0606	Narrow gauge
0607	In snowshed or under structure
0608	Under construction
0609	Elevated
0610	Rapid transit
0611	On drawbridge
0612	Private
0613	U.S. Government
0614	Juxtaposition
0000	Photorevised feature

Note: If major attribute is 181 then minor attribute is number of tracks.

[6]OWNER: Alphanumeric identifier of the owning railroad
ROUTEID: Mark Burton's route ID number added by Cathy Adams

1: 2 million Railroad Network Attributes

NRAIL2M#: Record number generated by Arc/Info®
NRAIL2M-ID: Arc ID number taken from the original 1996 NTAD 1:2,000,000 scale railroad network
[28]LRECTYPE: Link record type: always 'L'
[7]LVERSION: Link file version number
[7]LREVISION: Link record revision number
[7]LMODDATE: Link record modification date
[7]LINKID2M: Unique sequential line identification
[7]FEATUREID: Unique line identification
[7]ANODE: Node identification for the beginning node of the line
[7]BNODE: Node identification for the ending node of the line
[7]DESCRIPT: Name or identification for the line feature
[7]STFIPS1: Primary State FIPS Code
[7]STFIPS2: Secondary State FIPS Code
[29]RECTYPE: Text record type: Always 'T'
[8]VERSION: Text file version number
[8]REVISION: Text record revision number
[8]MODDATE: Text record modification date
[8]OVERLAY: Country marker
[8]RROWN1: First railroad owner name
[8]RROWN2: Second railroad owner name
[8]RROWN3: Third railroad owner name
[8]TR1: First railroad having trackage rights
[8]TR2: Second railroad having trackage rights
[8]TR3: Third railroad having trackage rights
[8]TR4: Fourth railroad having trackage rights

[28] Taken from the 1996 NTAD rail2m.lnk file. Refer to the CDs rail_2m.met file for further description.
[29] Taken from the 1996 NTAD rail2m.tl1 file. Refer to the CDs rail_2m.met file for further description.

[8]TR5:	Fifth railroad having trackage rights
[8]TR6:	Sixth railroad having trackage rights
[8]TR7:	Seventh railroad having trackage rights
[8]TR8:	Eighth railroad having trackage rights
[8]TR9:	Ninth railroad having trackage rights
[8]SSRR:	Subsidiary railroad
[8]PRR1:	First previous Railroad owner
[8]PRR2:	Second previous railroad owner
[8]ABDN:	Abandoned flag
[8]PASS:	Type of passenger rail flag
[8]MIL:	Military importance flag
[8]STATE:	Postal Code
[8]USGS_REG:	USGS Region Code
[8]FRA_REG:	FRA Region Code
[8]DENSITY:	Density Category
[8]RR_CLS:	Railroad classification
[8]SIGNALS:	Type of signaling system
[8]ABDYR:	Abandonment Year
[8]STFIPS:	State FIPS Code

Slope Attributes Generated from USGS DEM Data

COUNT:	Number of slope sample points for this arc
MIN_SLOPE:	Slope minimum for this arc (percent rise)
MAX_SLOPE:	Slope maximum for this arc (percent rise)
VAR_SLOPE:	Slope variance for this arc
AVE_SLOPE:	Slope average for this arc

Appendix 3

GIS PROCESS OVERVIEW
for
PHASE 2
of the
RAILROAD LINE-HAUL CAPACITY PROJECT

Geographic Information Systems Team
Tennessee Valley Authority
Norris, Tennessee

March 1998

Contributing Norris GIS Team Members:

GIS Project Leader:	Pamela J. Nabors
GIS Senior Technician:	Garry E. Chappelle
GIS Technician:	Veronica A. Long
GIS Technician:	Larry E. Shelton
GIS Technician:	Deborah K. Smith
Arc/Info Consultant:	David A. Hankins

with

Navigation Team GIS Specialist:	M. Carolyn Koroa
Navigation Team GIS Intern:	Jim W. Cunningham

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

AML - Arc Macro Language

BTS - Bureau of Transportation Statistics

FTP - File Transfer Protocol

GIS - Geographic Information System

NTAD - National Transportation Atlas Databases

INTRODUCTION

In late June 1997, the TVA Navigation Team employed members of the TVA Norris GIS Team to conduct the second phase of a research and development project for determining the line- haul capacity of selected railroad lines in the United States. The objective was to use a Geographic Information System to simulate routing railroad shipments over a digital line network and produce a list of specialized route identification numbers for the customer. An overview of the process is graphically depicted in Figure 1. The input data, processes, and output data are discussed further in the following sections.

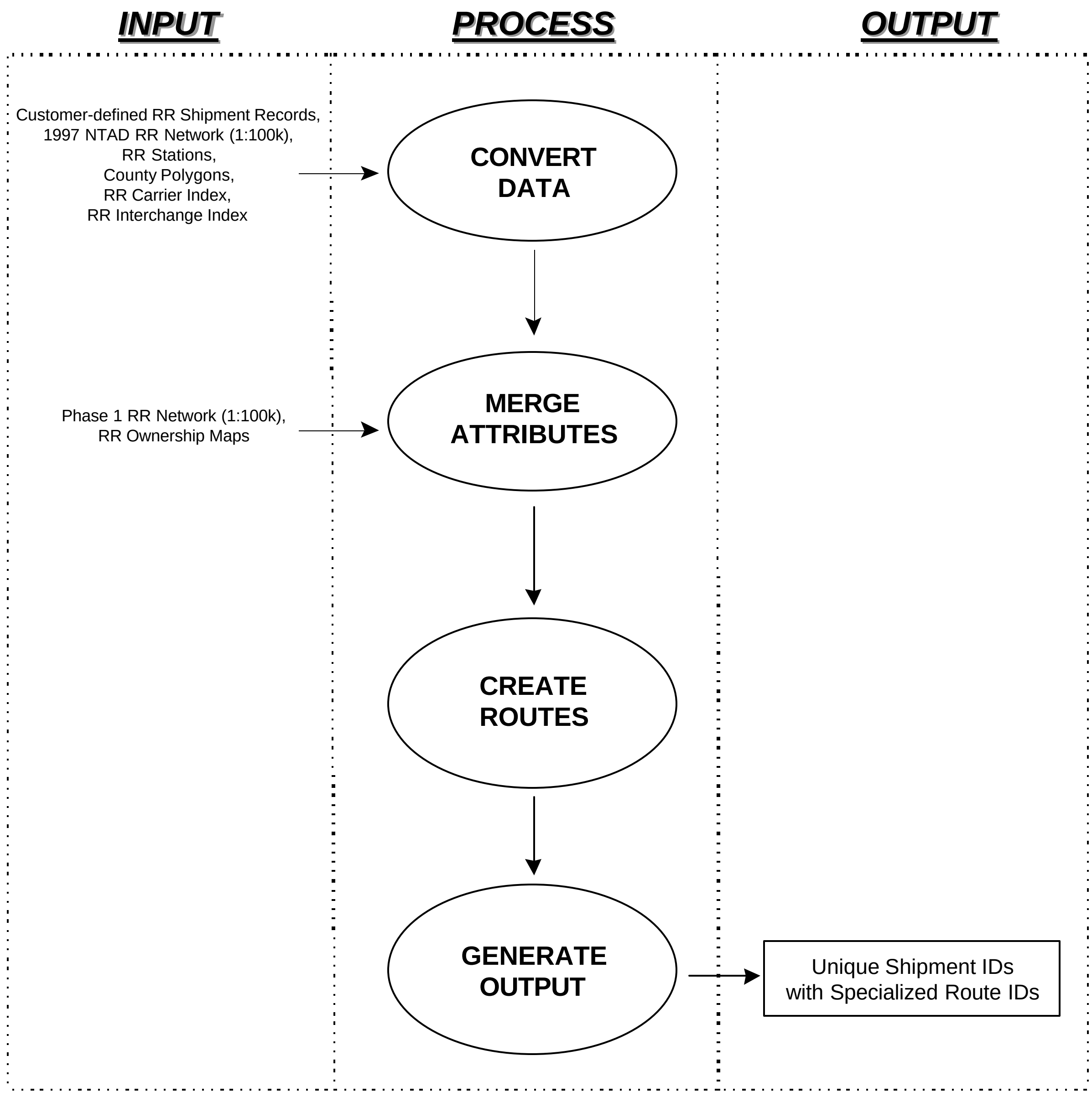

Figure 1. GIS Process Overview for Phase 2.

INPUT DATA

There were eight input data sets used for the project (as shown in Figure 1):

1). **Customer-defined railroad shipment records**. The customer originally sent about 500,000 shipment records to be routed. These records were generated from the 1995 Carload Waybill Sample and represented 2-3% of all railroad movements for that year. Since a separate record existed for each *type* of shipment (coal, corn, etc.), many of these shipment records had the same route (i.e., same origin, destination, and railroad owner). Therefore, after we discovered the large amount of time required to route so many shipments using Arc/Info, Dr. Burton combined duplicate shipment routes and generated a unique identifier for each group. The new, pared shipment data set contained about 75,000 records with the following attributes:

FIELD NAME	*DESCRIPTION*
UNIQUE	Unique Shipment Identifier Assigned by Dr. Mark Burton
OFSAC	Originating Station FSAC Code
ORR	Originating Railroad American Association of Railroads Number (AARNO)
INT1	First Interchange Location Alpha Code
RR2	Second Railroad American Association of Railroads Number
INT2	Second Interchange Location Alpha Code
RR3	Third Railroad American Association of Railroads Number
INT3	Third Interchange Location Alpha Code
RR4	Fourth Railroad American Association of Railroads Number
INT4	Fourth Interchange Location Alpha Code
TRR	Terminating Railroad American Association of Railroads Number
TFSAC	Terminating Station FSAC Code
NUMRR	Number of Shipment Segments
OFIP	Originating County FIPS Code
TFIP	Terminating County FIPS Code

2). **1997 NTAD 1:100,000 scale U. S. railroad network** (see website http://www.bts.gov). A pre-release version was acquired through the Department of Transportation's Bureau of Transportation Statistics and used as the underlying topology for the project. Refer to the rail100k.met metadata file on the 1997 NTAD compact disc for more details.

3). **Railroad station data** purchased from Alber Leland, Inc. A completed data set was not available at the beginning of the project, so a preliminary copy of the data was delivered in August 1997. An updated preliminary version was delivered again in October and used as the final data set. Station data contained the following coordinate information (from the RCOORUS file):

FIELD NAME	*DESCRIPTION*
STATION_ID	Unique Station Identifier
LATITUDE	Latitude of Railroad Station in Decimal Degrees
LONGITUDE	Longitude of Railroad Station in Decimal Degrees

and attribute information (from the RAILUS file):

FIELD NAME	*DESCRIPTION*
STATION_ID	Unique Station Identifier
STAT_NAME	Name of Railroad Station
STAT_STATE	State Name of Railroad Station
STAT_COUNT	County Name of Railroad Station

FSAC	Freight Station Accounting Code, *Corresponds with Shipment Record's* OFSAC, TFSAC *Attributes*
OPSL	Open and Prepaid Station List Number
SPLC	Standard Point Location Code
ZIPCODE	Rating Zip Code
SCAC	Serving Carrier Standard Carrier Alpha Code

4). County polygons. The county shapefiles on the "ESRI Data & Maps, Volume 1" compact disc provided with ESRI's ArcView 3.0 were used to provide county polygon data with the following information:

FIELD NAME	*DESCRIPTION*
NAME	Name of County
STATE_NAME	State Name of Residing County
FIPS	Full County FIPS Code, *Corresponds with Shipment Record's* OFIP, TFIP *Attributes*

5). Railroad carrier index provided by the Navigation Team. This index was created to provide a link between the customer's shipment records and the Alber Leland station records via the given carrier information. To do this, a list was first generated of all the American Association of Railroads numbers (AARNO) occurring in the shipment records (ORR, RR2, RR3, RR4, TRR). Carrier name alpha codes (ALPHA) were then added for each AARNO using the Official Railway Guide as a reference.

FIELD NAME	*DESCRIPTION*
ALPHA	Railroad Carrier Alpha Code (carrier name abbreviation), *Corresponds with Station List's* SCAC *Attribute*
CARRIER_NAME	Full Name of Railroad Carrier
AARNO	American Association of Railroads Number, *Corresponds with Shipment Record's* ORR, RR2, RR3, RR4, TRR *Attributes*

6). Railroad interchange index provided by the Navigation Team. This index was created to provide a link between the customer's shipment records and the Alber Leland station records for interchange points. First, a list was generated of all the interchange codes (INT_CODE) occurring in the shipment records (INT1, INT2, INT3, INT4). Corresponding interchange names and state names (INTERCHANGE, INT_STATE) were then added using the Open and Prepaid Station List as a reference.

FIELD NAME	*DESCRIPTION*
INT_CODE	Interchange Alpha Code (interchange name abbreviation), *Corresponds with Shipment Record's* INT1, INT2, INT3, INT4 *Attributes*
INTERCHANGE	Interchange Full Name, *Corresponds with Station List's* STAT_NAME *Attribute*
INT_STATE	State Name of Residing Interchange, *Corresponds with Station List's* STAT_STATE *Attribute*

7). Specialized 1995 NTAD railroad network (1:100,000 scale) with Phase 1 attributes. The specialized route identification numbers (ROUTEID field) and railroad ownership attributes from the Phase 1 network were reused in Phase 2. Ownership attributes from Phase 1 included the OWNER field from the 1995 NTAD railroad network (1:100,000 scale), and the RROWN1, RROWN2, RROWN3 fields from 1996 NTAD railroad network (1:2,000,000 scale). Refer to the Phase 1 documentation (May 1997) for a more detailed description of the Phase 1 attribute data.

8). Ownership information. Various paper maps produced by individual railroad carriers were used to add ownership attributes when necessary.

PROCESS OVERVIEW

Phase 2 of the GIS railroad line-haul capacity project was conducted using Arc/Info 7.0.4 and ArcView 3.0 running on a network of Sun workstations and Pentium PCs. The following sections describe how the input data were converted, attributes were merged, routes were created, and output was generated.

CONVERT DATA

1). Railroad shipment records were converted from an ASCII columnar format to INFO database format using an AML macro. The macro used the Tables module *DEFINE*[30] command, and the Info module *SEL* command and *GET* command (with the *COPY* and *ASCII* options). The *CHANGE* command from the Tables module of Arc/Info was then used to strip trailing blanks from the interchange fields (INT1, INT2, INT3, INT4).

2). The 1997 NTAD 1:100,000 scale railroad network was converted using the BTS bts2arc.aml conversion macro (see website http://www.bts.gov/gis/ntatlas/btsarc.aml).

3). The railroad station coordinate data purchased from Alber Leland, Inc. was converted by using the Arc/Info *GENERATE* command. The **station attribute data** was received with double quotes around each item, so all data were imported into Info as character fields, then the FSAC field was converted to integer and divided by 100.

4). U.S. county polygon shapefiles from the "ESRI Data & Maps, Volume 1" compact disc were copied to a UNIX hard drive and converted to an Arc/Info coverage using the following commands: *SHAPEARC*, *CLEAN*, *REGIONPOLY*.

5). The railroad carrier index provided by the Navigation Team was exported from MicroSoft Excel into dBASE IV format and copied to a UNIX hard drive. The data were then converted to Info format using the *DBASEINFO* command.

[30] Arc/Info commands are capitalized and italicized in this document.

6). **The railroad interchange** index provided by the Navigation Team was exported from MicroSoft Excel into dBASE IV format and copied to a UNIX hard drive. The *DBASEINFO* command was used to convert the data to Info format.

7). No conversion was necessary for the **Phase 1 network**.

8). No conversion was necessary for using the paper **ownership maps**.

MERGE ATTRIBUTES

Assemble Network Attributes

Attributes from the railroad network used in Phase 1 of this project were transferred to the new Phase 2 network (1997 NTAD 1:100,000 scale) using the *NEAR* and *JOINITEM* Arc/Info commands. A visual check of the network was made along with any necessary manual corrections, especially for the Phase 1 specialized route numbers (ROUTEID field). Only the ROUTEID, ownership, and state FIPS attributes were preserved on the new network. Therefore, the new network attributes were:

FIELD NAME	*DESCRIPTION*
STFIPS	State FIPS Code
RROWNER	1997 NTAD 1:100k Railroad Owner Name Abbreviation
ROUTEID	Dr. Mark Burton's Specialized Route Identification Number
OWNER	1995 NTAD 1:100k Railroad Owner Name Abbreviation
RROWN1	1996 NTAD 1:2mill First Railroad Owner Name Abbreviation
RROWN2	1996 NTAD 1:2mill Second Railroad Owner Name Abbreviation
RROWN3	1996 NTAD 1:2mill Third Railroad Owner Name Abbreviation

The 1997 NTAD 1:100,000 scale network did not have adequate ownership information, so ownership information from the Phase 1 network was combined with it to produce a new data field: COMBO_OWN, and the other ownership fields were dropped. Ownership was assigned in the following priority to emulate actual 1995 ownership as close as possible:

1.) 1996 NTAD 1:2,000,000 scale ownership attributes (RROWN1, RROWN2, RROWN3),
2.) 1995 NTAD 1:100,000 scale ownership attributes (OWNER), then
3.) 1997 NTAD 1:100,000 scale attributes (RROWNER).

Even after combining all ownership fields, only about 60% of the arcs had ownership attributes. So, the network was transferred to the Navigation Team GIS specialist and intern who used various paper maps produced by individual railroad carriers to manually enter additional ownership information. To save time during the editing process, the Phase 2 railroad network was divided into 2 parts (eastern and western U.S.) and worked on simultaneously. The western portion was *EXPORT*ed and FTPed to the Navigation Team UNIX workstation and edited with Arc/Info. The eastern portion was converted via *ARCSHAPE*[31] and transferred to their PC and edited with ArcView 3.0a. Upon completion of their manual edits, the network was transferred back to the Norris GIS Team. The eastern network was converted back to a UNIX coverage using *SHAPEARC*, and the western network was *IMPORT*ed. After *APPEND*ing the eastern and western portions back together, the network was spot checked for topological and attribute errors. Two more data fields were then added for calculating and displaying routes. Therefore, the final railroad network contained the following arc attributes:

[31] It was later discovered that this caused a problem with the route identification numbers. The ROUTEID field from the Phase 1 network was defined as a Numeric field with an internal width of 4. The *ARCSHAPE* command forced a decimal point in the output text file, therefore truncating all numbers to three digits. Although the routes had to be processed again, it provided an opportunity to make enhancements to the whole process and its final products.

FIELD NAME	*DESCRIPTION*
STFIPS	State FIPS Code
ROUTEID	Dr. Mark Burton’s Route Identification Number
COMBO_OWN	Ownership Alpha Code - compiled from multiple sources
IMPEDE	Impedance value for calculating a route
IMPEDESYM	Arc/Info drawing symbol code

Assemble Station Attributes

After the Alber Leland, Inc. railroad station coordinate data was converted to an Arc/Info point coverage, the station attribute data was converted and joined to it via the *JOINITEM* command using the unique station identification numbers as the key field (depicted below).

STATION COORDINATES
STATION ID
STATION LATITUDE
STATION LONGITUDE

JOIN

STATION ATTRIBUTES
STATION ID
STATION NAME
STATION STATE
STATION COUNTY
FSAC
OPSL
SPLC
ZIP CODE
SCAC

The carrier index was then joined to the station data via railroad alpha codes as shown below.

STATION ATTRIBUTES
STATION ID STATION LATITUDE
STATION LONGITUDE
STATION NAME
STATION STATE
STATION COUNTY
FSAC
OPSL
SPLC
ZIP CODE
SCAC

JOIN

RR CARRIER INDEX
ALPHA
CARRIER NAME
AARNO

Next, the *REDEFINE* and *JOINITEM* commands were used to join the interchange index to the station data. The interchange name and state fields were joined with the station name and state fields via a double join as depicted below.

STATION ATTRIBUTES
STATION ID
STATION LATITUDE
STATION LONGITUDE
STATION NAME
STATION STATE
STATION COUNTY
FSAC
OPSL
SPLC
ZIP CODE
SCAC
CARRIER NAME
AARNO

DOUBLE JOIN

RR INTERCHANGE INDEX
INTERCHANGE CODE
INTERCHANGE NAME
INTERCHANGE STATE

A link was then created between the station data and the railroad network data. Each station was assigned the internal address of the nearest node on the railroad network using the following Arc/Info commands:

BUILD - to create node topology for the rail network,

NEAR - to assign each station the nearest railroad network internal node number (PAREDRAIL#) and the distance between nodes (DISTANCE),

JOINITEM - to join the railroad network node attribute table to obtain the railroad node's user identification number (PAREDRAIL-ID) to be used by the routing program. This also included the railroad network arc the node is associated with (ARC#).

The attributes of the final station data are listed below.

FIELD NAME	*DESCRIPTION*
STATION_ID	Unique Station Identifier
LATITUDE	Station's Latitude in Decimal Degrees
LONGITUDE	Station's Longitude in Decimal Degrees
STAT_NAME	Name of Station
STAT_STATE	State Name of Station
STAT_COUNT	County Name of Station
FSAC	Freight Station Accounting Code, *Corresponds with Shipment Record's* OFSAC, TFSAC *Attributes*
OPSL	Open and Prepaid Station List Number
SPLC	Standard Point Location Code
ZIPCODE	Rating Zip Code
SCAC	Serving Carrier Standard Carrier Alpha Code
CARRIER_NAME	Name of Railroad Carrier
AARNO	American Association of Railroads Number, *Corresponds with Shipment Record's* ORR, RR2, RR3, RR4, TRR *Attributes*
INT_CODE	Alpha Code (interchange name abbreviation), *Corresponds with Shipment Record's* INT1, INT2, INT3, INT4 *Attributes*
PAREDRAIL#	Link to Nearest Railroad Network Node
DISTANCE	Distance to Nearest Railroad Node
ARC#	Internal Identification Number of Associated Railroad Arc
PAREDRAIL-ID	User Identification Number of Nearest Node

Assemble Alternate Station Point Attributes

It was necessary to create an alternate data set to use when a railroad station point was not found in the Alber Leland data set. Therefore, an Arc/Info point data layer was created from railroad network nodes. County FIPS and ownership attributes were added so that origin and destination points could be selected via the customer's shipment record data (ORR, OFIP, TRR, TFIP). The following is a list of main commands used to create the alternate data layer:

NODEPOINT - to create a new point coverage from the nodes in the railroad network,
RELATE - to copy the ARC# values from the rail network nodes, and COMBO_OWN values from the rail network arcs to the new point coverage,
JOINITEM - to join the carrier index attributes to the new point coverage,
IDENTITY - to join the county attributes to the new point coverage,
ALTER - to change field descriptions.

The final alternate data set attributes were:

FIELD NAME	*DESCRIPTION*
RAILPOINTS-ID	Arc/Info User Point Identification Number
Alternate Field Name:	PAREDRAIL-ID
ARC#	Internal Identification Number of Associated Railroad Arc
COMBO_OWN	Ownership Alpha Code - compiled from multiple sources
AARNO	American Association of Railroads Number, *Corresponds with Shipment Record's* ORR, RR2, RR3, RR4, TRR *Attributes*
COUNTY_NAME	Name of County where Point is Located
Previous Field Name:	NAME
STATE_NAME	Name of State where Point is Located
FIPS	Full County FIPS Code, *Corresponds with Shipment Record's* OFIP, TFIP *Attributes*

CREATE ROUTES

Once the data were prepared, the next step was to create the shipment routes. Three AML macros were produced to accomplish this. The main macro (AutoRoute.AML) was created to loop through the shipment records, call the necessary routines to process them (including the external routines ImpedeMany.AML and RouteBills.AML), and create the output files. Each AML is discussed further below.

Computer processing time was extensive due to the tremendous amount of data and the complexity of calculations. Therefore, the GIS Team divided the shipment records into batches and used as many central processing units and hard drives as possible in parallel. Originally, 12 CPUs were used with 14 different hard drives, but the maximum number of Arc/Info Network module licenses was 5, so the number of batches running simultaneously were reduced. Only 5 to 7 of the Sun Ultra workstations were used at one time on as many local hard drives as possible. Even after much of the GIS Team's computer network was upgraded to 100 megabyte Ethernet lines and two 9 megabyte hard drives were purchased by the Navigation Team, the final round of processing took approximately 4 weeks to process the 75,000 shipment records.

Main AML

The main AML macro used CURSOR commands to loop through the customer's shipment records, one shipment leg at a time. For each leg of a shipment, an attempt was made to find an originating and terminating node based on the following logic.

If the shipment route does not have any interchange points (only one leg):

- Use the shipment record originating and terminating FSAC codes and railroad owner AAR numbers (OFSAC, ORR, TFSAC and TRR fields) to find matching origin and destination points in the railroad station file (via the FSAC and AARNO fields). Store the identification number of the nearest nodes on the railroad network (PAREDRAIL-ID fields) in two variables, namely *from_node* and *to_node*, to pass on to the routing AML.
- If an origin or destination point cannot be found, use the shipment record county FIPS code (OFIP or TFIP) to find a matching point in the alternate station file for the current owner (ORR or TRR).
- If an origin or destination point still cannot be found, then use the shipment record county FIPS code (OFIP or TFIP) to find a point on the network within the county (via the alternate station file), regardless of the owner.
- If no match can be established[32], write the shipment record number to an error file.

If the shipment route has interchange points:

[32] Canadian legs of shipment routes were not processed.

- For the first leg of the route, use the shipment record originating FSAC code and railroad owner abbreviation (OFSAC, ORR fields) to find a matching origin point in the railroad station file. If no match was found in the station file, then use the alternate station file as stated above. If no match can be established, write the shipment record number and leg number to an error file. Otherwise, store the identification number of the nearest node on the railroad network (PAREDRAIL-ID field) in a variable (*from_node*) to pass on to the routing AML.
- Find an interchange point by matching the shipment record interchange code and railroad owner AAR number (for example, INT1 and RR2 fields) to a point in the railroad station file (via the INT_CODE and AARNO fields). If an interchange point cannot be found for that owner, then find a matching point with the same interchange abbreviation, regardless of the owner. If no match can be established, write the shipment record number and leg number to an error file. Otherwise, store the node identification number in the *to_node* variable.
- For each subsequent leg, copy the *to_node* value to the *from_node* variable and find the next interchange point (such as INT2, RR3) until reaching the last leg.
- For the last leg of the route, use the shipment record terminating FSAC code (TFSAC) and railroad owner abbreviation (TRR) to find a matching destination point in the railroad station file. If no match was found in the station file, then use the alternate station file as stated above. If no match can be established, write the shipment record number and leg number to an error file. Otherwise, store the identification number in the *to_node* variable to pass on to the routing AML.

Once the *to_node* and *from_node* variables were established, and were not equal to eachother, then the impedance values for the current owner were set on the network by calling the external impedance routine (only if the ownership had changed since the previous shipment leg). Afterward, the route was created for that leg via the external routing routine, and output was generated.

Impedance AML

The impedance AML macro set impedance values on the railroad network by assigning numbers to each arc's IMPEDE field via Arc/Info's Tables module. Since the routing algorithm used the shortest path method, impedance values were based on arc length (i.e., travel distance). The higher the number, the more difficult it was to travel across the arc (i.e., portion of track). The *SELECT*, *CALCULATE*, *RESELECT*, and *ASELECT* commands were used to:

- Select the arcs belonging to the current owner, **or** if the current owner was associated with a group of owners that share tracks, then select the arcs belonging to the whole group. (Only the six most important routing partnerships were used). Set the IMPEDE field of each selected arc to its arc length.
- Select the arcs of all the other owners. Set the impedance value of each selected arc to twice the length of the arc.
- Select all unknown owners' arcs. Set the impedance value of each selected arc to three times the length of the arc.

The impedance values were set so that the routing algorithm would first choose railroad tracks of the current owner or group of owners, then choose tracks from the other owners, and finally, choose tracks of unknown ownership. Therefore, abandoned tracks were the least likely to be used.

Routing AML

The routing AML macro created shipment routes by using Arc/Info's Network commands via the ArcPlot module. The following commands were used:

NETCOVER	- to specify the PAREDRAIL network file to be used by the Network commands to create and store the route system tables,
IMPEDANCE	- to specify the IMPEDE field to be used by the Network commands for network impedance values,
PATH	- to find the minimum path between the *from_node* and the *to_node* for each leg of a shipment.

The AML also contained ArcPlot drawing commands (*MAPEXTENT, ARCLINES, ROUTELINES*) for visually checking the route systems as they were created. Since the drawing time slowed the processing time, only the first few routes were verified for each batch, then the drawing commands were turned off until deemed necessary again.

GENERATE OUTPUT

After calling the routing AML, the main AML used the Tables *SELECT* command with the AML *SHOW* function to check if the route had indeed been created. If so, the route attribute table (RAT) and associated section (SEC) files were *EXPORT*ed via the *INFO* option[33]. If not, a message was written to an error file.

The *FREQUENCY* command was then used to create a non-duplicate list of all the route identification numbers (ROUTEID values) of arcs that the shipment leg had traveled across. The Tables *SELECT, RESELECT,* and *UNLOAD* commands were used to write out all nonzero ROUTEIDs with their associated UNIQUE number into a text file in columnar format. The *DROPFEATURES* command was then used to delete the RAT and SEC files because of the Arc/Info limit on the number of Info files[34]. Therefore, an output text file was created for every leg of a shipment that contained nonzero ROUTEIDs.

Multiple error files and status reports were also created while processing the shipment records. Information from these files was used to re-process shipment legs when possible.

After all the records were processed, UNIX 'cat' commands were used to concatenate all of the ROUTEID output files into one large file. It was *LOAD*ed back into Tables and *SORT*ed by UNIQUE number, and *UNLOAD*ed again to a text file and shipped to the customer.

CONCLUSION

The initial objective of this phase of the railroad capacity project was to develop a GIS application to simulate routing railroad shipments and produce a list of specialized route identification numbers for the customer in less than two months. The GIS Team accepted the proposed project with the mutual understanding that this was a high risk research and development project. (It was not known at the onset if the desired product was feasible.) However, the initial GIS application was developed in less than two months, and the project would have been completed on schedule had it not been for the large amounts of time necessary to process the data. In spite of this, the end product was achieved and the process also pioneered the development of other beneficial products.

The following output files were created for Phase 2 of the railroad capacity project:

1). Text file containing attribute information for arcs considered important for calculating the line-haul capacity of selected railways:

FIELD NAME	*DESCRIPTION*
UNIQUE	Unique Shipment Identifier Assigned by Dr. Mark Burton from the customer shipment records
ROUTEID	Dr. Mark Burton's Route Identification Number from the railroad network arcs

2). Exported Arc/Info route system files

3). Error text files

4). Status reports

[33] It was later discovered that the exported route systems were viewable in ArcPlot, but not ArcView, since they were no longer attached to the original railroad network file.

[34] It was later discovered that this could be avoided by using the *NETCOVER* and *PATH* commands differently.

Other products created for this project were:

1). 1:100,000 scale railroad network with specialized attributes in Arc/Info format
2). Railroad stations in Arc/Info format
3). AML software for routing railroad shipments
4). Color plots of routes deemed to be within the top 100 rail capacity indicators

In conclusion, similar future projects should be given ample time and funding for developing and implementing more efficient routing methods, as well as consulting experts in the GIS Transportation business.

Appendix 4

RAILROAD CONSTRUCTION COSTING

The railroad construction model is designed to predict costs for construction of various classes of railroad track on existing rights-of-way or from scratch on a new right-of-way (R-O-W). The costs are based upon estimates produced for four categories of track construction. These are further classified according to three terrain types. This paper describes the structure of the model.

INDEPENDENT VARIABLES

The model considers a number of independent variables. These include:
- R-O-W status,
- Terrain type,
- Track construction standards, and
- Control system.

These variables are described below.

R-O-W Status

Two types of R-O-W status are defined: existing and new. If the R-O-W is existing, the model considers that no land acquisition costs are incurred for adding track. Earthwork is limited to widening existing cuts and fills to accommodate the additional track. In the case of new R-O-W, construction of complete cuts and fills for the track are costed, as is the price of land acquisition. Naturally the cost of complete new construction is higher than the cost of adding track incrementally.

Terrain

The model considers three types of terrain: flat, rolling, and mountainous. The type of terrain governs the extent of earthwork needed to support the track structure, and the associated construction costs.

Flat terrain requires relatively little earthwork and supporting structures for the track. This, it represents the cheapest from a construction standpoint. The base cost case is developed for flat terrain.

Rolling terrain requires excavation of earth as well as the construction of embankments to provide a suitable track profile. As used in this model, rolling terrain requires approximately equally quantities of cut and fill for each mile of track construction. The average height of embankments and depth of fills is 20'. The soil consists of earth which can be easily excavated and placed using conventional construction equipment.

Mountainous terrain is underlain by rock which must be removed by blasting. The model assumes that mountainous terrain has approximately equally lengths of cut and fill for each mile of track construction. Because of the properties of rock, the amount of fill is greater than the volume of cut, and additional material must be brought to the site to build the embankments. The average height of embankments and depth of fills is 30'.

None of the terrain cases makes any assumption, or includes any costs, about required structures (bridges, box culverts) and the average cost of their construction per mile of track.

Track Construction Standards

The model provides costs for four different track construction standards: a mainline siding, a light density track, a medium density track, and a high density track. The mainline siding case uses relay rail to lower costs, a practice typically employed by the railroad industry; the other three cases employ all new materials. The density classes of the new construction classes represent different construction standards geared towards various traffic volumes and loadings.

For each track class, the cost of track construction (subballast, ballast, ties, rail, and other track materials) is provided on a unit length basis.

The cost for a pair of turnouts of appropriate construction is included for each track type. It is assumed for any track construction, a pair of turnouts will be required to connect the new track to existing tracks. Users may choose to include the turnout cost as a fixed component of a cost scenario.

Control System

Track construction costs in the model do not include the cost of signal and control systems. The base costs assume unsignalled, or "dark" territory. The approximate costs of adding signals, power operated switches, and logic circuitry for two dispatcher controlled turnouts are provided. These costs do not reflect the costs of additional automatic block signals which may be installed along the track.

MODEL STRUCTURE

The costs may be employed in an equation of the following form:

$$P = d_T(T_i + C_i d_C) + L(G_i + R_{j,k})$$

Where:	P	=	Total project cost, dollars;	
	T_i	=	Cost of installing turnout pair in track type i;	
	d_T	=	Decision variable set	0 if no turnouts installed,
				1 if turnouts installed;
	C_i	=	Cost of installing control system for turnouts in track type i;	
	d_C	=	Decision variable set	0 if no control system installed,
				1 if control system installed;
	L	=	Length of project, miles;	
	G_i	=	Unit cost of constructing track type i; and	
	$R_{j,k}$	=	Cost of construction in terrain type j for R-O-W status k.	
			$i \in$ {siding, light density, medium density, high density}	
			$j \in$ {flat, rolling, mountainous}	
			$k \in$ {existing, new}	

The model form essentially includes a term representing fixed costs and a term representing costs which vary with project size.

Using the model, the following scenarios may be evaluated in a straightforward manner:

- New track construction on existing R-O-W for a specified track type and terrain combination; and
- New track construction on new R-O-W for a specified track type and terrain combination.

Upgrading of track from one class to another may be handled using the following assumptions:

- Existing track components are replaced out-of-face;
- Salvage value of removed components is offset by some percentage of the removal cost; and
- The higher class track is constructed.

COST ELEMENT DERIVATION

The costs employed in the model are derived using standard engineering estimating techniques. Of course, actual project costs would be expected to have a high degree of variation based upon materials and design practices; construction practices; site specific factors such as soil conditions, drainage requirements, and ground cover; labor costs, and other factors. The costs derived in the estimates represent specific general scenarios. For these, the costs should be defensible. If necessary, the spreadsheets used to produce the numbers can be updated for specific conditions.

APPENDIX A

This appendix describes the construction details of the various track cases used in the costing model. The cases are a mainline siding, a light density track, a medium density track, and a high density track. The mainline siding case uses relay rail to lower costs, a practice typically employed by the railroad industry. The other three cases employ all new materials. The user of the model may price a siding using the mainline siding unit costs or the costs for new construction in the appropriate category.

The density classes of the new construction classes represent three different construction standards geared towards various traffic volumes and loadings.

The light density class is representative of track constructed for access to a major industrial facility, such as a power plant or mine, or for a railroad branchline. Such trackage would be capable of withstanding modern freight cars with a capacity of 100-tons, but typical annual tonnages would be less than 5 million gross tons/mile on an annual basis.

The medium density class is representative of mainline track on most major railroads outside of the highest density corridors. Track in this class would typically handle between 5 and 40 million gross tons/mile annually. The track structure would accommodate freight
cars up to 110-tons, and could handle 125-ton capacity cars.

The high density class represents track constructed for heavy tonnage corridors using a state-of-the-art structure including concrete crossties (grade and turnout), direct fixation fasteners, heavy rail sections, and deeper ballast/subballast sections. Such track is fully capable of handling freight cars having 125-ton payload capacities at relatively high speeds. Typical annual tonnages on such a line might range upward from 40 million gross tons/mile.

Track Case 1: Mainline Siding
Design for 100-ton capacity car
Rail:
  132# RE continuous welded relay rail
Ties:
  Hardwood, 7”x9”x8-1/2’ @22” C-C
  Fully plated and anchored
Ballast:
  Crushed rock
  12” below base of tie, 6” shoulders
  Subballast 6”

Light-moderate density main track
Design for 100-ton capacity car
Rail:
  115# RE welded new
Ties:
  Hardwood, 7”x8”x8-1/2’ @22” C-C
  Fully plated and anchored
Ballast:
  Crushed rock
  12” below base of tie, 6” shoulders
    6” subballast

Medium-high density main track
Design for 100-ton capacity car
Rail:

132# RE welded new
Ties:
Hardwood, 7”x9”x8-1/2’ @ 20” C-C
Fully plated and anchored
Ballast:
Crushed rock
15” below base of tie, 6” shoulders
12” subballast

High density main track
Design for 125-ton capacity car
Rail:
136# RE welded new
Ties:
Concrete @ 24” C-C
Direct fixation fasteners
Ballast:
Crushed rock
24” below base of tie, 12” shoulders
18” subballast