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Experiments with a Large Freight Network Model: Costs vs. Rates and the Effects of Network Aggregation

*by Michael S. Bronzini**

ABSTRACT

A NATIONAL MULTIMODAL freight transportation network model, developed primarily for energy transportation analysis, normally allocates interregional freight movements to modes and routes on the basis of average cost. A run of the model was made in which statistically estimated unit train coal rates and marginal costs for other commodities were used in place of average costs. Only small differences in modal traffic shares and network flow patterns were observed, indicating that costs can be used in lieu of rates for predicting modal shares, service levels, and energy use with this model. In a second experiment, the model was exercised with two different versions of the national railroad network, one with 3,091 links and one with 1,401 links obtained by aggregating the first one. The more detailed network, with its more direct routings and additional capacity, allowed rail to capture slightly more traffic, but the overall routing patterns obtained in the model runs were very similar. Hence the more aggregate network provides a representation of the underlying system which is sufficiently accurate for most analyses.

INTRODUCTION

Transportation costs are an important determinant of energy supply cost. Consequently the Electric Power Research Institute (EPRI) Energy Supply Program sponsored research to examine the relationships among energy demand, transportation supply, and energy supply in order to accomplish the following:

1. To analyze the capacity of the existing and currently planned national transportation network to handle projected regional and nationwide coal movements from supply to demand regions; and
2. To provide tools for forecasting the costs of transporting coal from the coal supply regions to the coal demand regions of the United States.

This research effort focused on routing anticipated movements of both fuels and other (non-energy) commodities over a computerized representation of the nation's multimodal intercity freight transportation network. A relatively detailed multimodal network is used because the various modes of transportation, and the various facilities and routes within transport modes, compete for the freight traffic offered by shippers. All commodities are included in the analysis because shippers are in competition for the use of the available transportation capacity. The network models developed consider both of these types of competition in arriving at predictions of the mode and route selections of each individual freight movement and the resulting network flow pattern.

As part of this research, several experimental analyses were conducted to test the validity and sensitivity of some key network model elements. These included a test of the effect of using simulated rates in the model, rather than transportation costs, and a test of the effects of network aggregation on model results. These experiments are summarized in this paper.

TRANSPORTATION NETWORK DATA AND MODELS

The background, features, and structure of the national transportation network model and data base used in this research have been presented in an earlier paper published in the Transportation Research Forum Proceedings.[1] The current version of the model and all results achieved are documented in the EPRI final report.[2] Hence, only a brief overview of the model and data base is provided here.

The national freight network data base developed for EPRI includes seven transportation modes—rail, highway, inland waterway, domestic deep draft (coastal) shipping, crude petroleum pipelines, petroleum products pipelines, and coal slurry pipelines. Facilities for transferring between modes are also included. The

**Associate Director, Transportation Center, The University of Tennessee, Knoxville, Tennessee; and Senior Consultant, CACI, Inc., Arlington, Virginia.*

total network contains 2,175 nodes and 3,939 links, and depicts nearly 302,000 miles of intercity transportation corridors. Links represent intercity linehaul transportation facilities, such as rail mainlines, interstate and primary highways, petrolum trunklines, and so on. A single link in the model often represents the combined capacity of several individual linehaul facilities serving the same interregional corridor. Nodes represent intersections and junctions of linehaul facilities and corridors, and also transportation facilities such as rail yards, waterway locks, pipeline pumping stations, and so forth.

For some analyses, it is either necessary or desirable to obtain detailed railroad routings over the trackage of individual railroads. For such applications a detailed rail network of 3,091 links (versus 1,401 rail links in the corridor level network described above) was defined. The effect of network detail on model results is examined in a later section of this paper.

Two different network routing models were developed for use with the two different levels of network detail. The **Transportation Network Model** (TNM) is used with the corridor level network to allocate total origin-destination traffic to transport modes and corridor routings. The **Railroad Routing Model** (RRM) is used with the detailed rail network to allocate rail traffic to specific railroads and their trackage. In both of these models, modes and routes are selected on the basis of transportation cost and travel time, and the relative importance of each to the shippers of various commodities. The costs used are input for each node and link in the network as short run average costs and are adjusted in the model to account for scale effects, congestion effects, and commodity differentials. Costs are used rather than rates because of the difficulty of generating and maintaining a comprehensive tariff data base. The effectiveness of this procedure is investigated in the next section of this paper.

Much of the data required for this project was available from previous research. The recent government sponsored National Energy Transportation Study (NETS)[3] provided considerable network data, as well as information on likely future network additions and upgrades. Commodity flow forecasts were obtained from NETS and also from the recent work of the National Transportation Policy Study Commission.[4] EPRI provided forecasts of coal flows, from other prior and ongoing research projects.

The TNM was first used to simulate a baseline scenario, consisting of the expected network structure and anticipated commodity flows for the years 1980, 1990, and 2000. These results, which are not described further here, serve as the base against which to measure the effects of the factors varied in the sensitivity tests.

TRANSPORTATION COSTS VS. RATES

The relative merits of using costs or rates in transportation analyses have been debated by economists for many years. In general, it is agreed that the prices paid by shippers, i.e., rates, should be used to predict choice of mode, but that the total costs incurred by carriers and shippers are better measures of societal resources devoted to transportation. Furthermore, many analysts favor the use of costs for all purposes, since costs are more amenable to modeling and prediction than rates are. The hope is that predictive equations relating rates to costs may be found.

The variance between costs and rates and their relative advantages for various purposes creates somewhat of a dilemma. The present version of the TNM allows for only a single expenditure variable, referred to as "transportation cost," which is used both to determine mode choice and to account for societal resource utilization. The basic modeling strategy adopted is to use short run average cost for this purpose, on the assumption that relative intermodal cost advantages would generate similar (but not necessarily equal) rate advantages. That is, it is assumed that rate-based modal split predictions would be the same as cost-based modal split predictions. This assumption was tested, as described below. Also tested was the feasibility of predicting rates from the model's cost predictions.

Estimating Rates from Costs

Many considerations go into determining the rates charged by railroads for coal movements. Theoretically, rates are established so that each traffic movement recoups at least variable cost and, to the maximum extent possible, contributes to recovery of fixed costs accrued by the railroad. The rates charged, therefore, are not necessarily based on fully allocated costs but rather depend to some degree on the bargaining position of the railroad.

This analysis only deals with rate-cost differentials with respect to unit train compatible coal. Cost data used for comparison were produced by the TNM.

These costs include both fixed and variable cost elements, as expressed in the cost functions provided to the model.[2] In other words, the attempt here is to relate rates to modeled costs, since the latter are readily available and are used throughout the rest of the study rather than to costs reported elsewhere, such as to the Interstate Commerce Commission (ICC).

ICC economists provided recent rate hearings reports and rates for western coal unit-train movements. Most of the rates for the East and South were identified through proprietary rate studies prepared by a major energy producer with interests in coal production. The Edison Electric Institute provided a recent coal unit train rate study prepared by its consultant, G. W. Fauth and Associates, Inc. This study confirmed the accuracy of most of the western rates already collected and identified other eastern rates. January 1980 was selected as the base date and all rates were adjusted to that date using ICC ex-parte rate increases and escalation clauses for contracted rates.

Linear regression was used to express coal unit train rates as functions of costs. The final statistical analysis compared western, eastern, and southern rates per ton to model costs per ton. The following results were obtained:

	Sample Size	Correlation Coefficient	Regression Equation
EAST	22	0.680	Rate = \$3.09 + (0.95) Cost
SOUTH	23	0.937	Rate = \$0.57 + (1.33) Cost
WEST	45	0.959	Rate = \$0.74 + (1.13) Cost

The eastern rates are the most difficult to predict, as shown by the correlation coefficient of 0.68. The regression was more successful for western and southern rates. The western data points and regression lines are plotted in Figure 1.

The equations produced by this rate-versus-cost analysis could be used to predict future unit train coal rates as a function of future model costs. However, the equations will produce a more reliable prediction of any given western or southern rate than any eastern rate. The accuracy of any specific origin-destination pair rate would not be as reliable as the average rate for a region as a whole.

It must be emphasized that this analysis is only a small beginning in the attempt to predict rates from costs. At best, the result can be labeled promising. This investigation merely shows that it is possible to derive meaningful rate equations using modeled costs. Further, as would be expected, such efforts are likely to be more successful where market segments can be isolated.

Using Rates and Marginal Costs in the Network Model

A special 1980 TNM run was constructed in which the above regression equations were used to estimate coal unit train rates, and in which short run marginal costs (SMC) were used to simulate transportation prices for other commodities. These marginal costs replaced the short run average costs (SAC) used for the 1980 base case and were defined as the change in total cost resulting from a one unit increase in traffic volume. To obtain these costs, the model was instructed to determine marginal cost per ton as the derivative of the total cost function.

In the absence of any additional information with respect to rates, marginal cost pricing is often assumed. This assumption is correct for competitive situations. For noncompetitive markets, short run marginal costs represent a floor on rates (assuming the absence of predatory pricing or significant internal cross subsidization). The marginal cost pricing concept was therefore judged to be an acceptable technique to use for simulating prices for the purposes of experimenting with synthetic rates in the TNM.

The main treatment of interest in this experiment was the use of the estimated coal unit train rates. Marginal costs were used to simulate a possible set of rates for the other commodities to avoid running the TNM with unit train coal routed on the basis of rates while everything else was routed on an average cost basis. Admittedly, the test conducted was less than ideal. It would be preferable to run the TNM with either estimated or actual rates for all commodities. The comprehensive national level rate data base needed to conduct such an experiment does not eixst. Thus, the compromise procedure reported here was used. Note that this experiment does not require an assumption that rates equal modeled marginal costs. The experiment consists only of using a combination of estimated

PLOT OF RATE PER TON VERSUS COST PER TON, WESTERN REGION

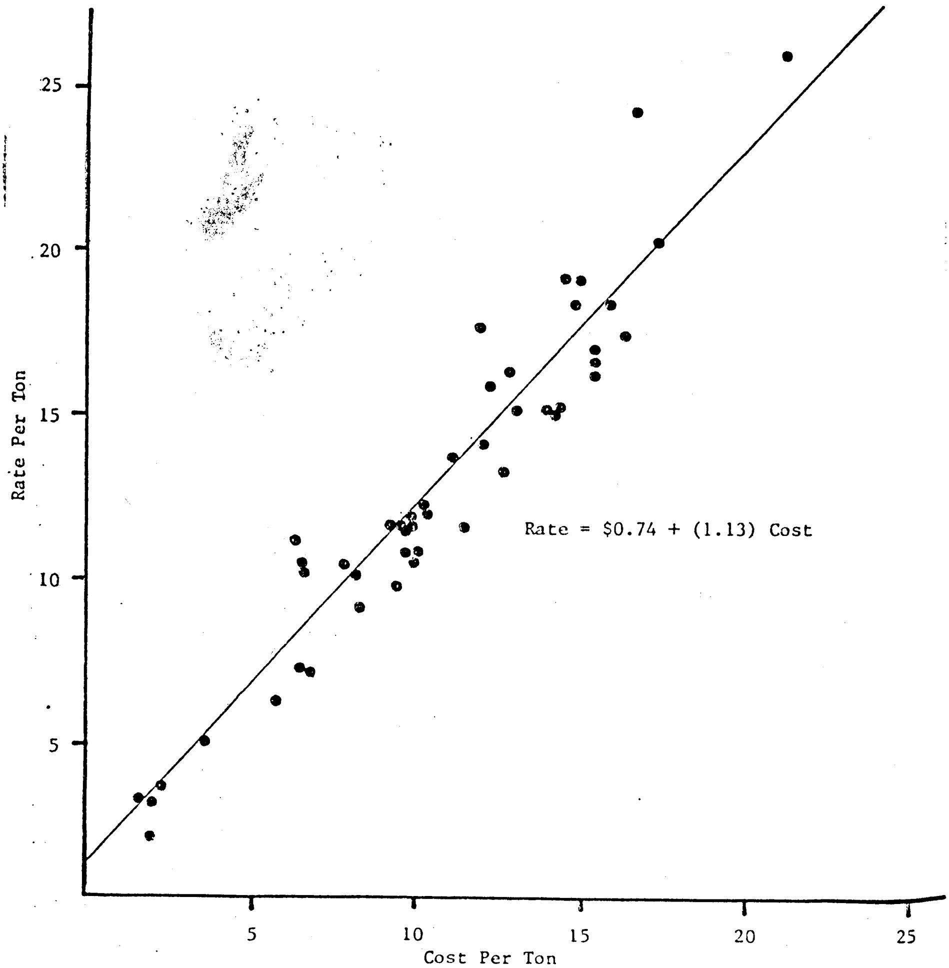

FIGURE 1

rates and marginal costs, both based on modeled average costs, in the TNM and then observing the results.

In summary, in this special 1980 scenario marginal costs were used to simulate transportation prices for all commodities other than unit train coal. Estimated prices for unit train compatible coal transportation were determined with the rate-cost regression equations developed previously. The results obtained using marginal cost pricing and statistically simulated unit train prices were compared with the 1980 base case to determine the effects of rate-cost and SMC-SAC differentials on model behavior.

Shipments moving under simulated SMC prices were transported at a total cost of $64.3 billion. The cost for these same movements (SAC) was $60.7 billion, a total difference of $3.6 billion. Thus, prices in the aggregate exceeded costs by 5.9 percent. In the other key areas, aggregate kiloton days varied by only 2.2 percent and energy use varied by only 1.4 percent from corresponding totals in the cost-based 1980 TNM run.

Table 1 depicts the differences between the two model runs in terms of dollars,

TABLE 1

NETWORK TOTALS FOR UNIT TRAIN COMPATIBLE COAL (COST RUN VS. PRICE RUN)

	Estimated Costs	Estimated Prices	Percentage Difference
Dollars (Billions)	1.65	2.02	+22.4
Ton Days (Billions)	.69	.73	+ 5.8
BTUs (Trillions)	73.44	76.04	+ 3.5

time, and energy use for unit train compatible coal. As expected, total simulated price exceeds total simulated cost, in this case by 22.4 percent. Total time and energy use display less substantial increases.

Table 2 displays the percentage of market tonnage for each mode of transportation. All traffic is included and the results are given for both the "cost" run and the "price" run. The table reveals that there is not much difference in the modal splits. Multimodal transport and rail capture a bit more of the market, while highway and waterway shares decrease somewhat. The cost efficiencies associated with long distance rail transportation continue to attract the largest share of the traffic.

Comparing outputs of the network model for both rates and costs, it is apparent that similar results were achieved. The modal share of tonnage is the best indicator of the relevant model behavior, and Figure 2 illustrates the experimental findings. It can readily be seen that the majority of the commodity modal share predictions are clustered around the forty five degree line of perfect correlation between the two runs.

Effect of Modeling Rates

It can be concluded that little difference occurred in determining modal split based on simulated price or cost. Therefore, costs can be used in lieu of prices when predicting modal shares, service levels, and energy use with the TNM. This is a fortunate result, since estimating transportation prices is a difficult and expensive process, to be avoided if possible.

This experimental analysis basically confirmed the approach adopted for data and model development. Using simulated rates in the TNM produced a pattern of modal traffic shares and network routings which was virtually indistinguishable from that obtained using transportation costs. This means that results obtained by basing shipper decisions in the model on transportation cost advantages can be accepted as a reasonable approxi-

TABLE 2

MODAL TRAFFIC SHARES: COST VS. RATE

Mode	% Tonnage Cost Run	% Tonnage Price Run	Difference
Rail	35.4	36.3	+0.9
Highway	22.3	20.0	−2.3
Waterway	11.5	10.9	−0.6
Deep Draft	3.2	3.2	0.0
Crude Pipeline	7.6	7.7	+0.1
Products Pipeline	12.8	12.8	0.0
Coal Slurry Pipeline	0.1	0.1	0.0
Multimodal	7.1	9.0	+1.9

SIMULATED RATES VS. SIMULATED COSTS MODAL SHARE OF COMMODITY TONNAGE

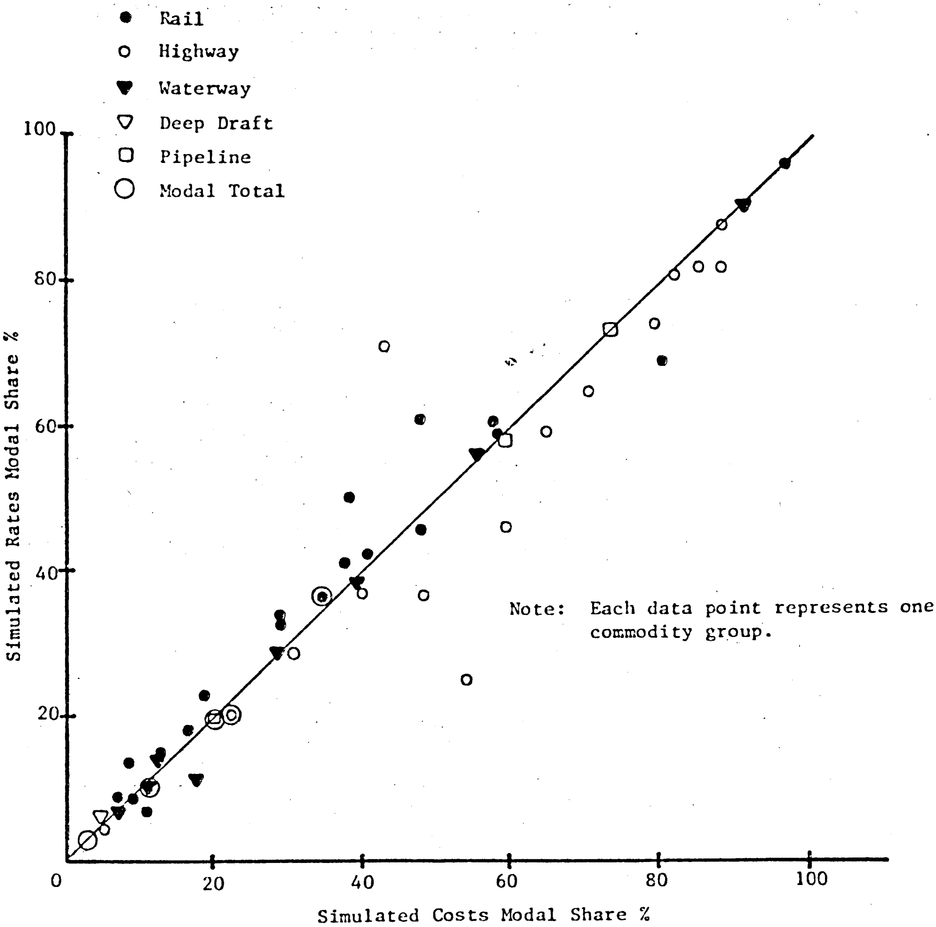

FIGURE 2

mation of price-based transportation market behavior.

EFFECTS OF NETWORK AGGREGATION

Considerable aggregation of links and nodes was needed to arrive at the network size cited earlier. The primary reason for this aggregation is analytical tractability. Working with networks with many thousands of nodes and links makes it very difficult to trace relationships and achieve any worthwhile analysis. Also, it is inappropriate and misleading to use a highly detailed network in combination with commodity origin destination data with considerably less geographic resolution. That is, the network scale must be commensurate with the regionalization scheme to produce useful analyses. Finally, it is wasteful of resources to process unnecessarily large networks on the computer. For all of these reasons, the networks described here, which originated as much larger networks created by federal agencies and others over the past 15 years, were winnowed down to their present sizes using a variety of manual and automated techniques. Much of this aggregation work was accomplished in previous projects.[5,6] In the case of the rail network, however, significant new aggregation work was performed. This portion of the research addressed the questions of the compatibility of the two levels of rail network aggregation that will be used most often, and the effects of aggregation on the model's outputs.

Aggregation Levels

The various levels of network aggregation created previously are summarized in Table 3. The railroad network of level 1 was originally developed by the Federal Railroad Administration.[7] For the reasons discussed above, CACI aggregated this network to a more manageable size[8] by deleting branch lines and other elements of superfluous detail. During this aggregation process, two important rail line attributes were eliminated. These were the type of signal system, which is a determinant of capacity, and the identity of the railroads which either own the line or have trackage rights, which affects routing. It was deemed essential for the EPRI work to restore these attributes, to enable greater accuracy in analyzing railroad routings, costs, and capacities.

The most recent rail network data set which contained the desired attributes corresponded to level 6 in Table 2. This network was retrieved and the data were manually checked to correct any errors and to bring the data into conformance with the current (1980) rail network structure. The resulting network is a highly faithful representation of the N.S. mainline intercity railroad network, but one which is still aggregated enough to permit meaningful and relatively convenient analysis. This network, with 1,479 nodes and 3,088 links, is referred to as the "railroad routing level" rail network.

Previous CACI studies[5,6] had indicated that networks could be considerably less detailed when the primary analysis concerns were modal traffic allocation and the intermodal effects of changes to one mode. For such applications, it is sufficient to have a network which preserves the general route, operating characteristics, and total capacity of interregional transportation corridors containing one or more major linehaul facilities. Hence, following previous techniques,[8] the railroad routing level rail network was aggregated to 863 nodes and 1,401 links. Railroad ownership codes are not included, but signal system data are preserved. This network is referred to as the "corridor level" rail network.

The primary connection between the two new rail networks developed for EPRI is through the nodes. Every node in the corridor level network is also a node in the railroad routing level network. This allows node-to-node flow data to be referenced to either network without change or ambiguity. Also, the data formats for the two networks are very similar. These two features make it relatively easy to use both networks for various facets of an analysis with minimal inconvenience.

Figure 3 shows the way in which the two rail networks and their related models, the TNM and RRM, can be used in an integrated fashion. Total interregional commodity flows are presented to the TNM which loads them onto the corridor level multimodal network. The node-to-node rail traffic generated in this run, which is available in a modal traffic file output by the TNM, is then input to the RRM which loads this traffic on the detailed rail network. Since the two net-

TABLE 3

LEVELS OF NETWORK AGGREGATION

	Rail		Highway		Water	
	Nodes	Links	Nodes	Links	Nodes	Links
Level 1	16,341	19,476	3,041	4,528	857	860
Level 2	13,826	16,961	2,478	3,592	416	421
Level 3	4,221	7,356	1,547	2,661		
Level 4	3,236	6,369	1,390	2,504		
Level 5	1,591	3,863	597	1,549		
Level 6	1,591	3,198	585	1,297		
Level 7	895	1,752				

works are compatible, this analysis sequence produces comparable TNM and RPM result for the rail mode.

Analysis of Aggregation Effects

The sensitivity of the model to network aggregation was tested by conducting a special 1990 run in which the railroad routing level rail network replaced the corridor level rail network. In the latter network, all rail links are upgraded to centralized traffic control (CTC), to recognize the added capacity and operational flexibility afforded by aggregating parallel routes into corridors. In the more detailed network, all links have either CTC or automatic block signal (ABS) control in the network's 1990 configuration. These link reclassifications result in an increase in average link capacity from 69 million net tons per year in the rail routing network to 90 million net tons per year in the corridor network. All other data and the input commodity shipments were the same as in the 1990 baseline run.

Computer runs for the year 1990, rather than some past year with recorded operating results, were used because these runs were needed for other purposes. The effect of network aggregation can be observed directly by comparing two model runs differing only in network detail. Thus, the year simulated is irrelevant, as long as all conditions are substantially the same for both runs.

Table 4 presents the major results observed. Rail ton-miles decreased when using the more detailed network. Average haul distance decreased by four percent. This change in total traffic is caused by the availability of more direct routes between origin and destination points. As a result fewer transfers are involved, and the other modes' shares of the market totals are reduced. The availability of a more detailed mode (rail) relative to the other modal networks in the multimodal network system gives that mode a heavier share of market shipments. With respect to costs, average rail ton-mile costs, including the rail portion of joint movements, varied by less than five percent, or 0.64 mills per ton-mile, between the two runs. Transit time remained approximately the same, and energy per ton-mile varied by only 2.8 percent due to the increased congestion found on the more detailed network. Overall, costs decline as long-distance truck, water, and multimodal movements are diverted to rail. With respect to coal, all major statistical indicators varied by less than 6.3 percent.

In summary, ton-miles were slightly lower in the more detailed network due to the availability of more direct routings for rail shipments. The added rail capacity and coverage of the detailed network, in combination with the more direct routings, allowed the rail mode to capture a few percent more traffic. This indicates that the corridor level network should always be used in conjunction with corridor level representation of the other modes, to avoid favoring the rail mode, even though the bias generated with the detailed network is not too severe. The relatively close agreement of the results of the two runs also indicate that the corridor level rail network provides a representation of the underlying system which is sufficiently accurate for modal split and corridor level routing analyses, and for transportation cost estimation.

MULTISTAGE MODELING STRATEGY

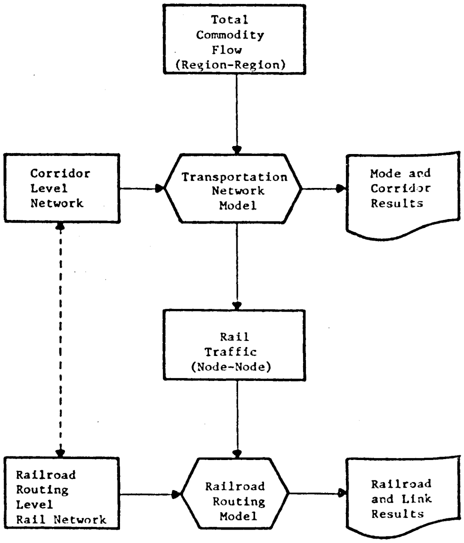

FIGURE 3

FINDINGS AND CONCLUSIONS

The network model experiments basically confirmed the approach adopted for data and model development. Using simulated rates in the TNM produced a pattern of modal traffic shares and network routings which was virtually indistinguishable from that obtained using transportation costs. This means that results obtained by basing shipper decisions in the model on transportation cost advantages can be accepted as a reasonable approximation of price-based transportation market behavior. In the second

TABLE 4

TRANSPORTATION NETWORK PERFORMANCE WITH DIFFERENT LEVELS OF RAIL NETWORK AGGREGATION

		Base Case	1990 Detailed Rail Case	Difference Quantity	Difference Percent
Ton (millions)		1,400	1,400	0	0
Ton-miles (billions)		889	855	34	—3.9
Costs ($ millions)		18,291	17,144	1,147	—6.3
Mills/ton-mile		20.6	20.1	0.5	—2.4
$/Ton		13.07	12.25	0.82	—6.3
		Coal Modal Split Percentages			
Tons					
Coal: Non-unit train compatible					
Rail	(%)	79.5	83.1	+3.6	
Water	(%)	15.8	13.6	—2.2	
Multimodal	(%)	4.7	3.3	—1.4	
Coal: Unit-train compatible					
Rail	(%)	93.0	94.3	+1.3	
Water	(%)	0.7	0.0	—0.7	
Slurry Pipeline	(%)	1.1	1.1	0.0	
Multimodal	(%)	5.2	4.6	—0.6	
Ton-Miles					
Coal: Non-unit train compatible					
Rail	(%)	82.7	86.0	—3.3	
Water	(%)	12.1	10.5	—1.6	
Multimodal	(%)	5.3	3.5	—1.8	
Coal: Unit-train compatible					
Rail	(%)	93.6	96.0	+2.4	
Water	(%)	0.4	0.0	—0.4	
Slurry Pipeline	(%)	0.3	0.4	+0.1	
Multimodal	(%)	5.7	3.6	—2.1	

experiment, a 1990 TNM run was made using the detailed rail network in place of the corridor level rail network. The added rail capacity and more direct routings available in the detailed rail network attracted a few percent more traffic, as expected, but no major distortions of network behavior were evident. This confirms that wisdom of keeping all modal networks at comparable levels of aggregation, and also shows that the aggregated networks developed for EPRI tend to produce flow patterns which are good approximations of the underlying detailed flow patterns.

REFERENCES

1. Bronzini, M. S., "Evolution of a Multimodal Freight Transportation Network Model," *Proceedings — Transportation Research Forum,* Vol. 21, No. 1, 1980, pp. 475-485.
2. CACI, Inc., *Transportation Network Models for Energy Supply Analysis,* Final Report, Research Project 1219-3, Electric Power Research Institute, Palo Alto, CA, January 1981.
3. *National Energy Transportation Study,* A Preliminary Report to the

President by the Secretary of Transportation and the Secretary of Energy, Washington, D.C., July 1980.
4. National Transportation Policy Study Commission, *National Transportation Policies Through the Year 2000*, Washington, D.C., June 1979.
5. CACI, Inc., *Transportation Flow Analysis: National Energy Transportation Study*, Report Nos. DOT-OST-P-10-29 to 32, Office of the Secretary of Transportation, Washington, D.C., January 1980.
6. Bronzini, M. S., *Freight Transportation Energy Use*, Report No. DOT-TSC-OST-79-1 (I-IV), Transportation Systems Center, Cambridge, MA, October, 1978.
7. Federal Railroad Administration, *FRA Network Zone Maps*, U.S. Department of Transportation, Washington, D.C., April 1976.
8. Kistler, R., Rahrer, M., and Bronzini, M., *Aggregation of FRA Railroad Network*, CACI, Inc., Arlington, VA, November 1976.

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