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Proceedings of Coal Transportation Modeling Workshop

December 3-4, 1981

Palo Alto, California

Center for Transportation Research

Energy and Environmental Systems Division
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Kenneth M. Bertram and Marc P. Kaplan

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EXECUTIVE SUMMARY

Projections of major increases in U.S. coal production and use have raised concern about the ability of the U.S. transportation industry to handle these increases. To address this concern, the Electric Power Research Institute (EPRI) and the U.S. Department of Energy (U.S. DOE) sponsored this workshop to bring together the builders of major coal transportation models and analyze the problems of modeling the transportation of coal for use by domestic utilities and for export. The workshop was conducted for EPRI and U.S. DOE by Argonne National Laboratory (ANL) Energy and Environmental Systems Division, Center for Transportation Research.

At the workshop, papers on the models were presented by their authors; they were followed by the presentation of a summarizing paper comparing and contrasting the models. The models presented included two coal transport cost models; a model of county-level coal supply and demand; a non-network-based model of interregional coal supply, demand, and price; three network-based coal-flow assignment models; five comprehensive models of transportation interactions in the domestic coal industry; and a model of international coal flows. Following the presentation of papers, participants separated into two discussion groups, one dealing with the modeling problems of domestic utility transportation and one discussing coal export transportation modeling. Both groups used the summary paper as a springboard for discussion of current and future problems in their specific areas and in the area of generic modeling.

Major findings of the utility group meeting included identifying the following needs:

- To explain the relationship between transportation costs and rates,
- To appropriately transfer either the ability to use models or the information obtained from models to the utilities,
- To establish a means for developing and sharing an improved data base for coal transportation, and
- To engage in more extensive sensitivity analysis and validation of existing models.

At the coal export group meeting, the major identified need was for new models to aid the following:

- U.S. seaports in setting user charges to recover dredging costs,
- U.S. seaports in combining with railroads and coal companies to set prices to compete with other seaports, and
- The U.S. government in establishing coal export strategies. These new models pertaining to these strategies might deal with world coal supply and demand and national ports and shipping. The supply-demand model would have to include both political and economic variables. The port-ocean

shipping model would require the flexibility to (1) incorporate new shipping technologies, (2) address issues concerning port dredging, and (3) provide quantified cost/benefit analysis information where possible. The port-ocean shipping model would be used to help define the best U.S. port and ocean-shipping system for satisfying world coal transport demands.

1 WORKSHOP DESCRIPTION

1.1 BACKGROUND

Total U.S. coal production is projected to increase from about 805 million tons in 1981 to approximately 2.2 billion tons in 1995.[1,2] Domestic utilities are forecast to increase their use of coal from 580 million tons in 1980 to 880 million tons in 1990.[3] U.S. coal exports are projected to increase from approximately 95 million tons in 1981 to an estimated 250 million tons in 1995.[1,4] Coal availability and production technology to satisfy these increases are not considered to be problems, but the transport of these quantities of coal has been identified as a major challenge facing the U.S. transportation system.

As a step in planning for these forecast increases in coal movements, the Energy Analysis and Environment Division of the Electric Power Research Institute (EPRI) and the Office of Energy Supply Transportation and Coal Exports of the U.S. Department of Energy (U.S. DOE) jointly sponsored a Coal Transportation Modeling Workshop. The Argonne National Laboratory (ANL) Energy and Environmental Systems Division, Center for Transportation Research, conducted the workshop, at which the authors of major coal transportation models were invited to present papers about their models. Other coal transport researchers and representatives from electric utilities and relevant government agencies were also invited. Appendix A is a list of the workshop participants.

Prior to the workshop, ANL sent questionnaires to each speaker requesting summary information concerning his/her model. In addition, each modeler was interviewed by telephone by Marc P. Kaplan of the Center for Transportation Research, who used the summary and interview information to write a paper comparing and contrasting the models presented. Kaplan's paper was designed to provide a focal point for discussion of the various models and increase the productivity of the workshop discussions.

The workshop was held at the EPRI facilities in Palo Alto, California, on December 3 and 4, 1981.

1.2 FORMAT

The workshop agenda (see Appendix B) began with presentations describing models, scheduled in ascending order by degree of model comprehensiveness. Kaplan's summary paper comparing and contrasting the models concluded the paper presentation section of the workshop.

Two separate group discussions, one dealing with the coal transportation problems of domestic utilities and one considering U.S. coal export transportation, were then held simultaneously. These discussions provided an opportunity for participants to discuss the current and future transportation situations facing either domestic utilities or U.S. coal export companies, modeling needs relating to these situations, and generic modeling problems. Before the workshop was adjourned, presentations of discussion results were made to the entire group.

The next two chapters of these Proceedings contain summaries of the utility and coal export group discussions and the papers presented at the workshop.

1.3 REFERENCES

1. *NCA Predicts Record 1982 Levels*, Coal Outlook, pp. 1-2 (Dec. 28, 1981).

2. *DOE Ups Its Coal Production Goals*, Coal Outlook, p. 5 (Feb. 16, 1981).

3. Vincent, B., Engineering Analyst for North American Electric Reliability Council, as quoted by S. Glasser in *Effect of "Reaganomics" Unclear on Electric Utilities Coal Use*, Journal of Commerce, pp. 1C, 7C (Nov. 16, 1981).

4. U.S. Interagency Coal Export Task Force, *Interim Report of the Interagency Coal Export Task Force* (draft for public comment), U.S. Department of Energy, pp. 4, 102 (Jan. 1981).

2 WORKSHOP GROUP SUMMARIES

2.1 UTILITY WORKSHOP GROUP SUMMARY

Participants discussed the role of coal transportation modeling in helping to solve utility problems. The basic problem areas identified included the following:

- Rate litigation,
- Rate negotiation,
- Plant location planning,
- Fuel source procurement, and
- National planning and national policy development.

Coal transportation cost models as aids to rate litigation and negotiation were considered of most value to utilities that had a history of dependence on coal. Utilities facing fuel conversion or having a wide range of expansion options, although valuing the cost models, also had long-range-planning concerns that are more directly addressed by comprehensive coal transportation models.

Several problem areas were identified as limiting the application of utility-oriented models:

- Lack of an adequate understanding of the relationship between costs and rates,
- Complexity of assembling input data and operating the models, and
- Limited availability of current, accurate, and complete data about the flow, prices, and routing of coal.

The participants expressed different opinions about the resolution of these problems.

- Some viewed the problem of explaining the cost vs. rate relationship as basically impossible to solve; others thought that examining the next least cost alternative would provide some insight.
- Some thought that the models should be made more user oriented and actually be available to the end users; others thought that only the model developers could take full advantage of the models and therefore modelers should function as information rather than model providers.

- All participants believed that data availability should be improved; however, it was recognized that barriers exist to universal data sharing. For example, the individual utilities know what rates they are paying but may not wish to make that information available to the modelers, who also may work for carriers with which the utilities may later be negotiating.

The participants also agreed that more sensitivity analysis and model validation would help to establish the appropriateness of applying models to solve utility problems.

2.2 COAL EXPORT WORKSHOP GROUP SUMMARY

Participants discussed the realities of the coal export situation and concluded the following:

- A few major firms are dominant suppliers,
- European consortiums deal with these dominant suppliers and often frustrate small suppliers,
- Demand is based on both a diversity of suppliers and other political considerations,
- Many export variables cannot be precisely modeled due to major real-world uncertainties (e.g., the amount of time that will be required to accomplish dredging given uncertain funding sources and environmental delays),
- Europe and Japan should be modeled as separate markets, and
- Domestic rail charges and not ocean shipping charges are the driving factors for coal export.

Participants also identified and discussed the need for the following coal export models:

- A model for ports to use to set user charges to recover dredging costs.
- A model to aid individual ports to combine with railroads and coal companies to set prices to compete with other ports.
- Models to aid the U.S. government in establishing some kind of coal export strategies. This category of models might deal with world coal supply and demand and national ports and shipping. The supply-demand model would have to include political and economic variables. The port-ocean shipping model would require the flexibility to incorporate new shipping technologies, address questions concerning port dredging, and provide quantitative cost/benefit

analysis information where possible. It could be used to help define the best U.S. port and ocean-shipping system for satisfying world coal transport demands.

- A hierarchy of models for exports:

  Macro - dealing with basic questions,
  Mezzo - dealing with the majority of problems, and
  Micro - answering very specific questions for the shippers, ports, and transportation firms.

- An export coal model to be coupled to the EPRI model developed by CACI, Inc., or to the National Coal Model to better predict export impacts upon the domestic coal transport system.

In addition, participants discussed the following generic modeling problems and concluded the following:

- Modeling port and ocean shipping capacities for coal exports is not as difficult a problem as modeling railroad capacity.

- The need for model validation is often not satisfied. Model sponsors often do not stress validation because of costs and the inherent lack of precision of models. It was also noted that models can only be invalidated. The use of models only to gain insights was seen to reduce the need to validate by some. It was agreed that modelers should validate as many results as possible.

3 COAL TRANSPORTATION MODELING PAPERS

This chapter includes all of the papers presented at the workshop, plus additional ones describing relevant recent modeling efforts of the Federal Railroad Administration and TERA Consultants, Inc.* The first paper provides a perspective on how each of the models described fits into the overall framework of coal transportation modeling. The remaining papers are presented in ascending order of model comprehensiveness. All papers have been printed exactly as received from their authors.

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*The TERA paper was on the workshop agenda, but travel difficulties prevented the presenter from attending the workshop.

A REVIEW AND COMPARISON OF COAL TRANSPORTATION MODELS

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ABSTRACT

Forecasts of dramatic increases in the demand for coal over the next 20 years have raised concerns about ability of the United States transportation system to move these coal volumes. These dramatic increases in coal use may be limited by the capacity of the transportation system or by the cost of capital improvements needed to expand transport capacity. In addition, many other economic, social, and environmental issues have been raised regarding increased coal demand and transport. A variety of mathematical, computerized models have been developed to aid analysis of these issues. This paper reviews and contrasts a sample of 13 of these models that were presented at the Coal Transportation Modeling Workshop in Palo Alto, California, on December 3-4, 1981. Jointly sponsored by the Electric Power Research Institute and the U.S. Department of Energy, the workshop assembled prominent coal transportation modelers from private industry, government, and academia.

This paper was prepared as a summary and comparison of the models presented and served as a focal point for the workshop sessions that followed the paper presentations. The information presented here was obtained through (1) responses of the modelers to a one-page questionnaire, (2) personal conversations with the modelers, and (3) reading of the submitted papers. This paper first presents a schematic conceptual model of the overall coal supply/demand transportation system. This presentation is followed by a brief description of each model accompanied by the same schematic highlighting the interactions addressed by that particular model. Finally, a matrix that summarizes the salient features of each model is presented.

INTRODUCTION

The current level of domestic coal production is about 805 million tons, of which approximately 580 million tons are burned by electric-power utilities and 95 millions tons are exported.[1,2,3] By the year 1990, it is expected that 880 million tons of coal will be consumed annually by domestic electric utilities.[3] By 1995 coal exports are expected to increase to an estimated 260 million tons. Although resource availabililty for total coal production of 2.2 billion tons/yr by 1995 is not generally considered a problem,[4] the transport of this quantity has been identified as a major challenge.

Although long-term capital improvements to the transport system can be implemented to facilitate the growth in coal traffic, there exists much

uncertainty regarding the long-term dynamic impact on future coal demand of (1) short-term constraints and (2) large capital-expenditure allocations to coal shippers. Transport cost is already a major component of the delivered price of coal, accounting for as much as 50% in some cases. Therefore, expectations of future coal transport services play an ever increasing role in the long-term planning in major coal use industries, e.g., electric-power generation and export.

In the electric-power industry these expectations can significantly affect the choice between coal-fired generating plants and other power-generating alternatives. The location of future coal-fired plants will also be affected because transport costs greatly influence the decision to trade off electrotransmission for fuel transport costs. The demand for export coal will, of course, be affected by the supply price. Decisions related to the expansion and location of coal export facilities are, therefore, dependent on the delivered price of coal to those facilities.

In addition to these ever-important economic considerations, many social and environmental issues have been raised regarding the growth of coal demand and transport. Included among these are concerns about land erosion, water depletion and pollution, air pollution, and community disruptions. Furthermore, some government actions directly affect coal supply/demand activity patterns and transport costs. Notable among these are the Clean Air Act regulating removal of sulfur from coal burned within controlled regions, Interstate Commerce Commission (ICC) regulations on transport pricing, and recent Stagger's Act reductions in these ICC regulations. Because of these concerns, government agencies -- as well as private industry -- are interested in accurate and reliable estimates for quantities and costs of future coal extraction, transport, and use.

A variety of mathematical, computerized models have been developed and implemented as aids in preparing these estimates. These models, though simplified abstractions of a very complex system, are themselves complicated systems of mathematical expressions. The major advantage offered by the models is their ability to answer, in a consistent fashion, questions about what will likely happen if the coal supply/demand system is altered in various ways under different circumstances. The complex coal supply/transportation/demand system involves multiple suppliers and users connected by several shipping modes and routes that are competing with other commodities for available transport capacity. Forecasting these activities requires a systematic, explicitly stated, rigorous approach in order for consistency and accuracy to be maintained.

Unfortunately, the modeling of such a complex system leads to a dilemma. On the one hand, a model should be as simple as possible in order to be clearly understood and capture the structure of underlying causal relationships. However, simplicity can lead to an unrealistic representation of the modeled system. On the other hand, overcomplexity in the modeling system may muddle analysis by introducing yet another imponderable item. All modelers use subjective judgment to identify the appropriate balance of simplicity and realism -- a fact that helps to explain some of the differences among existing models.

Recognizing that a multitude of coal transportation models have been put forward, the Electric Power Research Institute (EPRI) and the U.S. Department of Energy (U.S. DOE) sponsored, with the assistance of Argonne National Laboratory, the Coal Transportation Modeling Workshop. The objectives of the workshop were to (1) establish the current level of understanding by professional modelers of the coal supply/demand system, (2) identify and assess the implications of underlying assumptions for coal transport modeling, (3) identify strengths and weaknesses in existing approaches, and (4) provide a forum for interaction that would be conducive to the synthesis of new and improved approaches.

A dozen coal transportation modelers representing private industry, government, and academia prepared papers for presentation at the workshop and for inclusion in these proceedings. This summary and comparison of the models was prepared to help focus discussion and maximize the productivity of the workshop. The information presented here was obtained through (1) responses of the modelers to a one-page questionnaire, (2) personal conversations with the modelers, and (3) reading of the submitted papers.

This paper first presents a schematic conceptual model of the overall coal supply/demand transportation system. This presentation is followed by a brief description of each individual model accompanied by the same schematic highlighting the interactions addressed by that particular model. Finally, a matrix that summarizes the salient features of all the models is presented.

CONCEPTUAL MODEL

In this section, a simple block diagram model of the coal supply/demand transportation system is presented to focus the following discussions. In this diagram (Figure 1) the boxes may be viewed as individual system components, each serving a distinct function. The arrows indicate the reliance of each component on others by showing required information flow. The many feedback loops are an indication of the degree of interrelation. The model is conceptual in that its purpose is only to identify important interactions. It is not operational because no functional relationships are defined. Indeed, there is intentionally no suggestion made of the form of the operational model, e.g., sequential, iterative processing, or simultaneous.

For simplicity, the model is limited by the assumption that the demand for electricity and all transportable commodities other than coal is given. Modeling these interactions goes beyond all existing operational models and is, therefore, excluded from consideration here.

The supply and demand for coal is affected by many variables. The demand, stratified by location and coal type, is a function of the demand for products, including electricity and steel. For example, the delivered price of coal in combination with other economic and regulatory considerations determines which electrical generation alternative (coal-fired vs. other) will be selected at any given time. Similarly, the supply of coal, stratified by location and coal type, is determined by such factors as the market price of coal, physical constraints of coal extraction, and regulations.

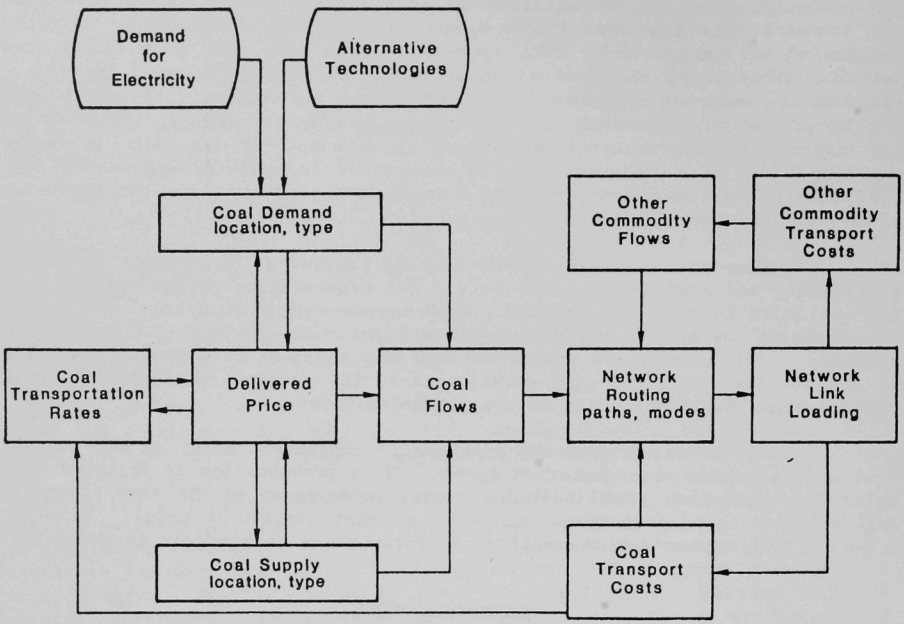

Fig. 1 Conceptual Model Coal Supply/Demand Transportation System

The delivered market price of coal is, in classic economic theory, determined by the equilibrium of supply and demand price. In addition to production cost, transport cost is an important component determining the supply cost function. Another very important component is profit. Because the system is geographically distributed, there are locational advantages enjoyed by various users, suppliers, and transport operators. These locational advantages can be quantified as an economic rent. In a purely competitive economic environment, this economic rent is ultimately shared equally by all participants. However, there are many reasons why this paradigm is not strictly applicable to the coal market. The relative strength of the participants determines their relative shares of the rent. Transport, primarily rail, sometimes holds the strongest position because of near monopolistic or market dominance advantages. Although transportation's share of the economic rent is often largest, in the absence of additional explicit constraints, its precise share remains indeterminate. This fact makes the transition from transport costs to transport rates one of the most difficult modeling problems.

The distribution of coal supplies and demands and the cost to the users (delivered price) provide the information required to specify both the objective function and system constraints used to determine the flow of coal from supply points to user points. All of the operational models presented at the workshop that addressed this component used a mathematical programming approach. However, two basic philosophies were represented: user optimum and system optimum. The user-optimized approach minimizes the acquisition cost for each demand point. The system-optimized approach minimizes total system costs. Under the most general of circumstances, these two approaches provide different results. The user-optimized solution is generally considered more representative of actual individual choice, whereas the system optimum is more prescriptive.

Appropriate paths, i.e., linked segments of the transportation system that may represent multiple modes, are identified for accommodating the coal flows. Identifying these paths (i.e., network routing) is accomplished by finding minimum cost paths. However, as traffic over the individual links and through individual nodes changes, the cost of transport changes. And, since it is not only coal traffic that affects link impedance, it is desirable to account for all commodity traffic. The interaction of network routing, loading, and costing has been operationally modeled by algorithms that seek out either user- or system-optimal equilibrium solutions.

In the conceptual model, the costs feed back to rates; hence delivered price, and coal flow would ideally define an overall system equilibrium encompassing the transportation network equilibria. Unfortunately, none of the existing operational models presented at the workshop was this comprehensive.

The following brief descriptions of each model are accompanied by a diagram of the conceptual model indicating the subset of interactions modeled. The following summaries are presented in ascending order by degree of model comprehensiveness. However, the judgment of relative value of the models should not be made on this criterion alone. The relative tradeoffs among comprehensiveness, simplicity, precision, and computational efficiency are very much application-specific and beyond the scope of this comparison.

DRI - COAL TRANSPORTATION COST MODEL[5]

More accurately described as an accounting procedure linked to an extensive data base, the DRI Coal Transportation Cost Model provides the user with an ICC-compatible estimate of rail and/or barge carrier costs for a particular shipment. The user specifies the type of origin, type of destination (e.g., deep mine, power plant), annual quantity shipped, number of shipments, cars per shipment, type of cars, round trip time, and distance by each carrier. Both variable cost (including embedded debt cost of capital) and fully allocated cost are estimated. Unless otherwise specified by the user, carrier-specific average costs per various transportation functions (e.g., yard switching, train switching, maintenance materials, and labor) are used as derived from the carrier's annual report to the ICC. Terminal and car costs are variable according to the number of cars per shipment.

Because the DRI Coal Transportation Model is ICC-Form A compatible, it is a valuable aid in rate negotiation and litigation. Its link with other DRI data bases and forecasting models provides estimates of future functional unit costs as input to future transport-cost estimates. The process does not directly identify a minimum-cost transportation route. Successive user inquiries can, however, quantify the costs for previously identified alternative routes.

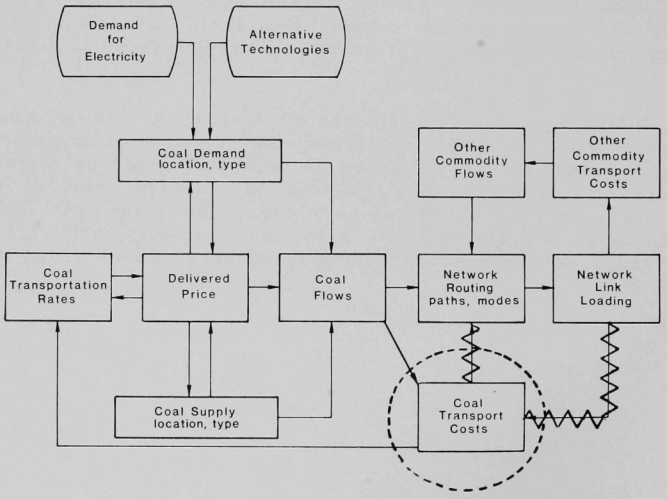

Fig. 2 DRI - Coal Transportation Cost Model

MANALYTICS - COAL TRANSPORTATION COST MODEL[6]

The Manalytics Coal Transportation Cost Model is a route-specific engineering-cost model of variable carrier costs. The user defines and describes the shipment routes, size, and configuration. Details of the route include curve and grade along segments, stop and idle points, helper locomotive stations, and crew changeover points. Although default values provide unit costs of fuel, labor, materials, and equipment, the user can override these values. User-specified inflation factors can be used to escalate these costs over the forecast period.

The model determines the power and locomotive requirements of the shipment and terrain-specific energy intensity. When train speed, as computed by the model, is reduced below a specified lower limit, the model prescribes helper engine support. Regulatory and union-required crew changes are also determined. Based on these operating parameters and unit costs, the total shipment cost is computed.

Although the Manalytics model is not an ICC-accepted computational technique and therefore not likely to be of value in litigation, it does provide additional unpublished route-specific information useful in rate negotiation. Like the DRI model, the Manalytics model does not directly identify a minimum-cost transportion route. Successive runs can, however, quantify the cost of previously identified alternative routes.

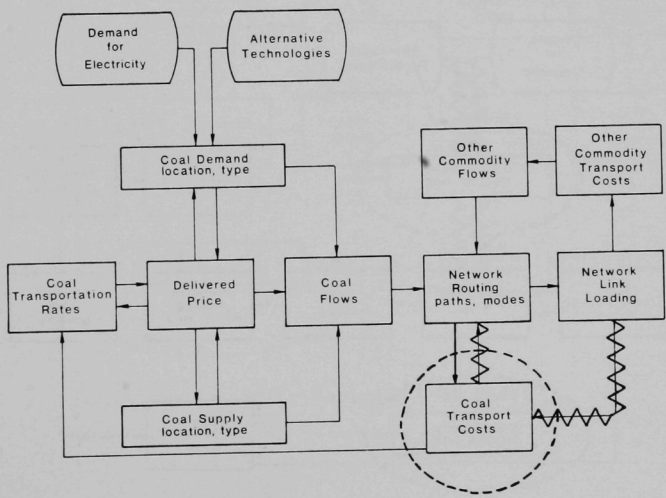

Fig. 3 Manalytics - Coal Transportation Cost Model

TERA - COAL SUPPLY AND DEMAND DISAGGREGATION METHODOLOGY[7]

Actually an input to coal transportation models, the TERA Coal Supply and Demand Disaggregating Methodology provides the capability to disaggregate highly aggregate regional commodity forecasts to a county level. The method can be used to generate input data for subregional analyses that require a finer level of geographic detail than is typically addressed by interregional models. The TERA methodology has been used to disaggregate DRI interregional (7 supply, 13 demand regions) coal forecasts and DOT freight forecasts of other commodities for use in a study of coal flows between Northern Appalachia and the Northeast resulting from the Fuel Use Act of 1978 (FUA).

Noncoal commodities are allocated to counties in proportion to the share of regional value added in manufacturing contributed by each county. Coal production is allocated to counties such that the weighted sum of deviations from historical production trends in quantity, sulfur content and price is minimized. The solution is constrained by limiting the amount of growth or decline in production. Coal demand disaggregation is performed separately for mandated coal conversion due to the FUA and non-FUA demand. Non-FUA demand is simply apportioned according to each county's historical share of regional demand. FUA coal demand is allocated directly to the counties where mandatory coal conversion has been dictated in amounts consistent with their coal-fired capacity. Coal export demands are similarly allocated.

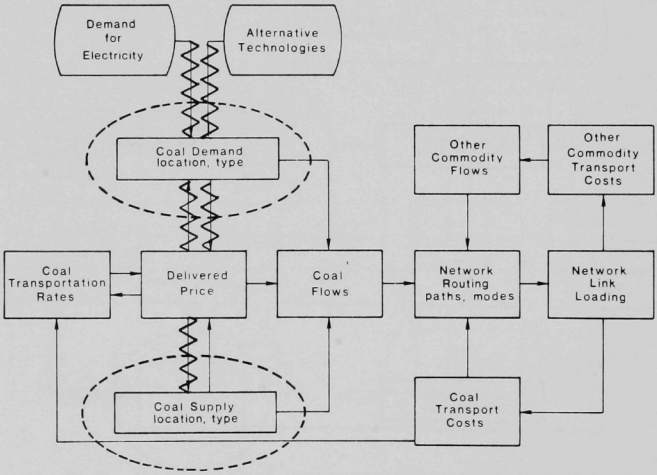

Fig. 4 TERA - Coal Supply and Demand Disaggregation

DOE - NATIONAL COAL MODEL[8]

The National Coal Model (NCM) estimates the flow of 18 types of coal from 32 coal-supply regions to 44 demand regions. The NCM uses a standard linear programming formulation to determine a system-optimized minimum-cost distribution of coal. The objective function of the NCM is the total cost of supplying coal energy to all the demand sectors. This cost includes the mine-mouth price of coal and the transport costs. The mine-mouth price of each coal type by supply region is described by a multistep function; the marginal cost of extraction increases as supplies reach depletion. The cost of transporting coal is simplistically defined in the NCM by four regionally specific per mile unit costs. The solution is constrained at both supply and demand regions. The supply of each coal type at a given price level is specified for each supply region. The energy requirements and limits on emissions are specified for each demand region. The NCM does not place any upper constraint on the amount of coal that can be shipped between regions; however, minimum levels that represent existing coal contracts are invoked.

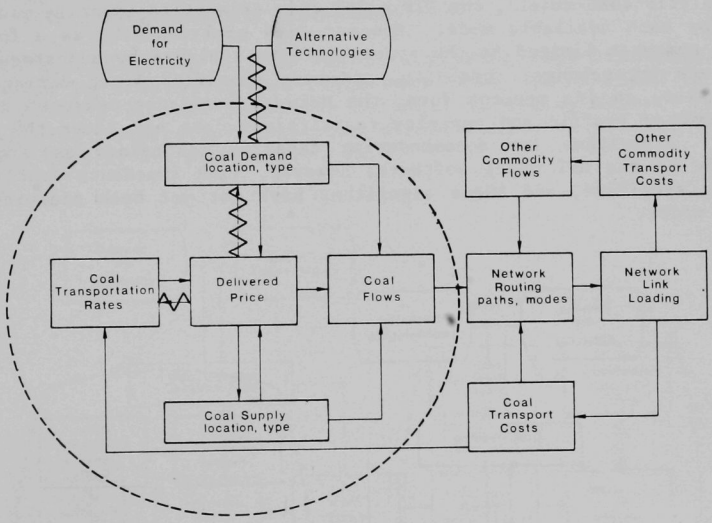

Fig. 5 DOE - National Coal Model

COMSIS - NATIONAL TRANSPORTATION PLANNING MODEL[9]

The National Transportation Planning Model (NTP) is a multimodal network routing and assignment (link-loading) model. Although the model is capable of assigning flows for 19 commodities, individual commodity types (e.g., coal) can be independently analyzed. Basic inputs to the NTP model are network descriptors and interregional commodity flows. Separate networks are defined for rail, highway, and waterways. Links in these networks are described by speed and length. Less-detailed "spiderweb" networks describe interregional connections by air and pipeline. Base year (1972) interregional flows among 173 Bureau of Economic Analysis (BEA) regions by commodity type and mode have been derived from various surveys.

Forecasting with the NTP model involves a three-step sequential process: (1) The base year flows are adjusted with growth factors that reflect future change in commodity production. (2) Interregional commodity flows are "split" by mode according to a mode-split model that is analagous to parallel resistance current split in electrical circuits. (3) Mode-specific interregional flows are assigned to their respective networks. Unlike the DRI and Manalytic cost models, the NTP model does attempt to identify minimum-cost routes by each available mode. However, its applicability as a forecasting tool is somewhat limited by the strong influence played by adjustment factors (which are interchange, commodity, and mode specific) fixed during calibration. Also, in its present form, the network impedance measures are fixed. The volume of traffic and capacity restrictions does not alter the impedance values. Algorithms for accommodating capacity restrained assignments are available to the NPT model software; however, link impedance functions have not been specified, and these algorithms have not yet been exercised within the NTP model.

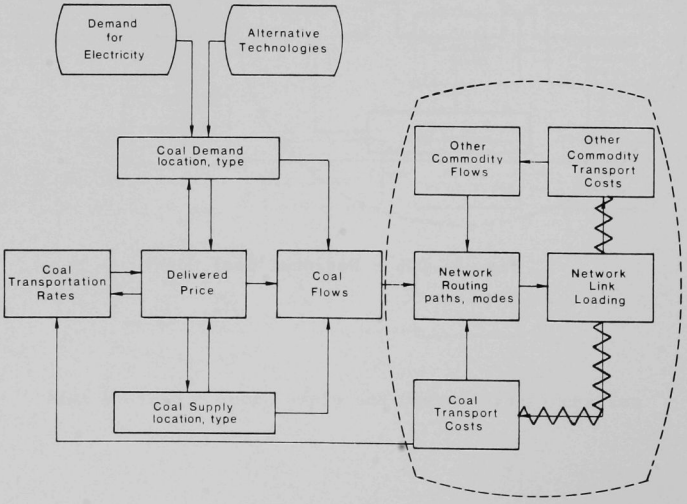

Fig. 6 COMSIS - National Transportation Planning Model

PRINCETON - RAILROAD NETWORK INFORMATION SYSTEM[10]

The Princeton Railroad Network (PRN) Information System evolved from the Princeton Rail Network Model. The original model was a rail network routing and assignment model. Like the COMSIS model, the original model ignored capacity feedbacks; however, the distinguishing feature of the Princeton model was its representation of rail interlining connections. Large "quantum" impedances were invoked where poor cooperation between two separate carriers could potentially exist. This feature provided the Princeton model the unique ability to analyze the effect of line mergers.

In order to more efficiently and effectively use the varied modeled outputs and large amounts of data, the Information System was developed. The data structure in the PRN is built around a link-node format. More than 22,000 links and 20,000 nodes are included in this data base. Link data includes distance, track class, ownership, trackage rights, grade, curve, and interlining impedances. Nodal data include longitude, latitude, state, county, ramp, and yard designations. The information system invokes efficient computer algorithms for graphical display, manipulation, and editing of the data base within an interactive environment.

The applicability of the PRN in analyzing coal transportation is demonstrated by displaying available data from the 1978 ICC 1% waybill sample and the 1979 coal utilities National Marketing Report. Measures of interlining cooperation, railroad market dominance, length of hauls, and traffic density are presented.

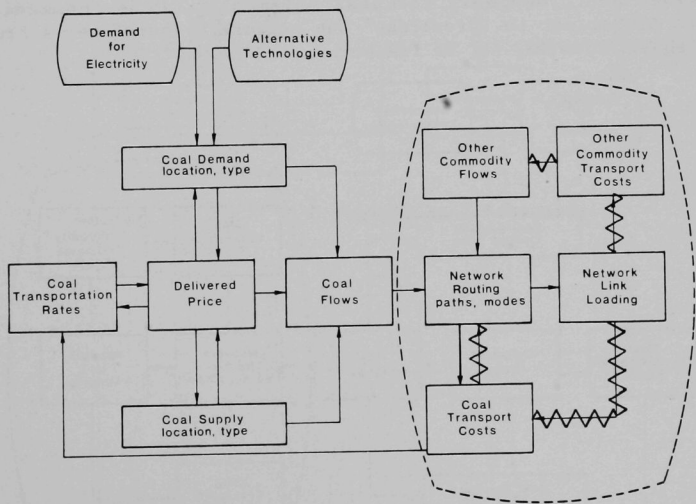

Fig. 7 PRINCETON - Railroad Network Information System

CACI - MULTIMODAL NETWORK MODEL FOR COAL TRANSPORTATION ANALYSIS[11]

The CACI Multimodal Network Model (MNM) is a multimodal network routing and assignment model. Two features distinguish it from the two other models of this type (COMSIS, Princeton). Recognizing both the competitive and cooperative relationship of alternative modes, the multimodal CACI model includes intermodal connection links where appropriate (for example, between rail and barge). Also recognizing the competition of commodities for available transportation capacity, the CACI model includes a capacity restraint feedback. The cost of transport is dependent on the volume of transport and the capacity of the transport facilities. While the principle application of the model is for coal transportation all commodity types are represented because all commodities shipped compete for available capacity.

Required inputs to the model include interregional flows for all commodities, network link and node descriptors, and functional parameters that determine the shape of the link impedance functions. External modal simulators are used to determine the shape of these functions for various classes of links within each mode. In general, these functions have a U shape. Initially, as volume increases, economies of scale reduce per unit costs. But, as volumes approach capacity, there are diminishing returns. The CACI model uses a minimum-path-finding algorithm similar to that used by the other network routing models, however, in the CACI model this algorithm is iteratively exercised. Between iterations the link impedances are redefined to agree with specified impedance functions. A quadratic programming technique is used to insure that final network equilibrium is reached. The equilibrium defines a shipper optimized solution: no shipper, acting alone can find a less costly path. However, as a computation expedient these iterations are sometimes performed only for coal movements. Other commodities are assigned at the outset to "prestress" the network. Therefore, a true multicommodity equilibrium may not be reached.

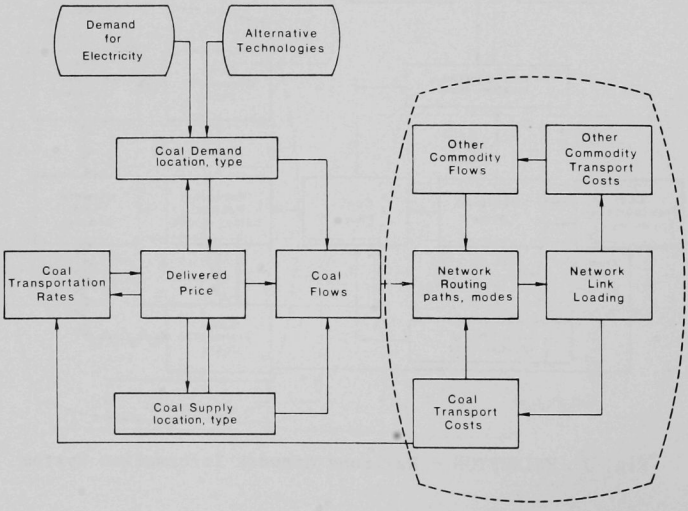

Fig. 8 CACI - Multimodal Network Model

FRA - 1990 FREIGHT RAIL FORECASTS[12]

The Federal Rail Administration has forecast traffic flows along national rail mainlines. The forecasting method consisted of a three-step sequential modeling process. First, the volume of 14 commodity types (coal included) originating and terminating within each of three railroad districts was developed. Next, forecast flows between 129 analysis regions (aggregates of BEA regions) were developed by factoring 1978 base year flows derived from a 1% waybill sample so as to satisfy the district forecasts. Finally, the forecast flows were assigned to links along minimum-distance paths along the aggregated mainline rail network. The assigned freight traffic flows were plotted on assignment maps that display the volume of traffic along each link.

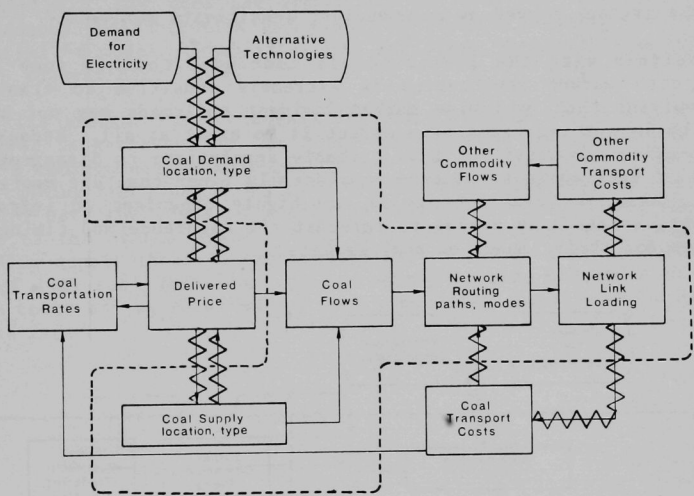

Fig. 9 FRA - 1990 Freight Rail Forecasts

CRA - MODEL OF COAL TRANSPORTATION INDUSTRY INTERACTIONS[13]

Charles River Associates (CRA), in a study of the implications of the Stagger's Act on coal transport, merged the National Coal Model (NCM) with an early version of the CACI Transportation Freight Model (TFM). The NCM generates interregional flows that are input to the CACI model. A shipment-specific Train Cost Model (TCM) is used to determine both total variable and fully allocated carrier costs. These costs are converted into allowable rates according to the Stagger's Act and input to the NCM. The process is repeated several times. In practice, this process did not converge to an equilibrium; because the two models each are based on different equilibrium assumptions, there is no a priori reason why their interaction would converge. However, in spite of the resulting model oscillations, it was concluded that it is important to simultaneously analyze both coal and transportation markets. Although the choice of models and their linkage may be imperfect, an analysis of the oscillations served as a convenient sensitivity analysis.

Analysis with the linked models concluded that in some instances regional coal market penetration is extremely sensitive to transportation price, implying that otherwise market-dominant railroads may not have great flexibility in setting rates if a market is to exist at all. Because of this transport price sensitivity, it is probably appropriate to disaggregate flows at levels of geographic resolution considerably finer than are represented in the NCM. Also, as transport costs are highly dependent on infrastructure improvement, research is needed to forecast the magnitude and timing of these investments and their impact on coal markets.

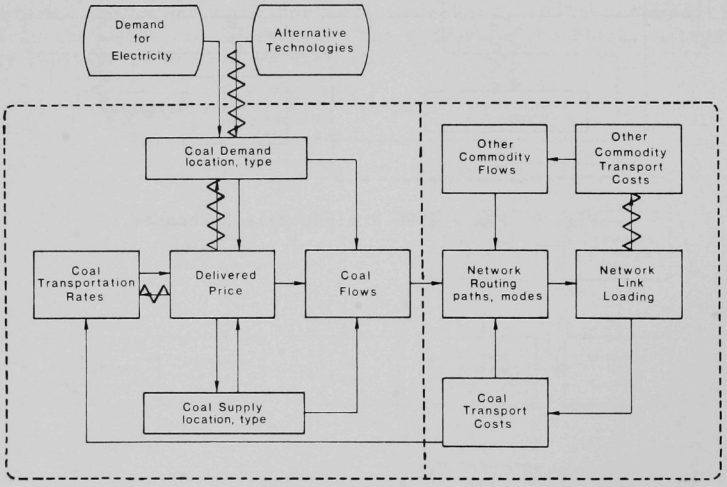

Fig. 10 CRA - Coal Transportation Industry Interactions

ANL/U. OF PENN. FREIGHT NETWORK EQUILIBRIUM MODEL[14]

The Freight Network Equilibrium Model (FNEM) is a multimodal, multi-commodity model of freight distribution and network assignment. The FNEM explicitly represents the behavior of both shippers and carriers by employing appropriate models for the different types of decisions made by each. The shippers are modeled as a set of competing interests, each independently seeking to minimize the delivered price of needed commodities. The resulting flows are assigned over individual carrier networks according to logic that seeks to minimize each carrier's cost. The user-optimized shipper model identifies a solution such that no shipper, acting alone, can find a less costly source of supplies. In this respect, the shipper perceived cost of transport is along all competing paths that are of equal minimum average cost. The system-optimized carrier model assigns flows such that the marginal cost on any path used does not exceed the marginal cost on any other path. By simultaneously distributing and assigning freight volumes, the FNEM avoids the potential of model instability that can arise when otherwise independent models are sequentially linked.

In its present form, the FNEM accepts commodity supply and demand at a county level as generated by the TERA supply/demand disaggregation methodology. As a consequence, both supplies and demands are strictly defined, thus overconstraining the final model results. A more attractive extension of the model would have the level of supply be dependent on the bid price and thus sensitive to the demand level. This extension is currently being developed by including supply links to the transportation system that have the familiar U shape of link cost functions; at low supply levels, economies of scale reduce unit costs and as supplies approach production capacity (mine depletion), unit costs rise.

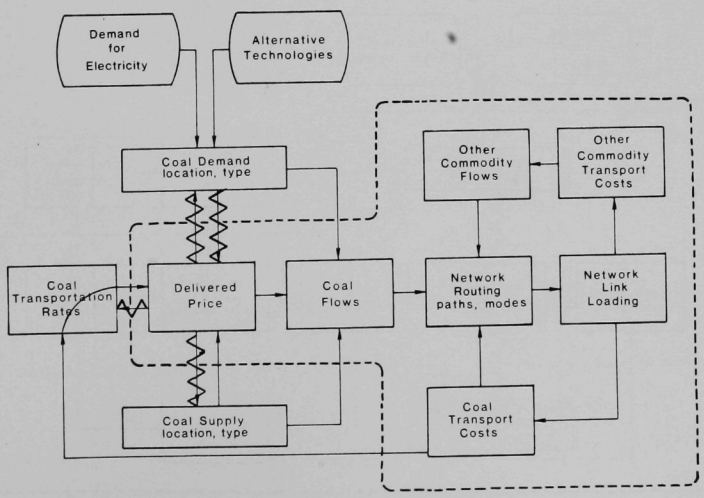

Fig. 11 ANL/U. of Penn. - Freight Network Equilibrium Model

EPA-USDA INTERREGIONAL COAL ANALYSIS MODEL[15]

The Interregional Coal Analysis Model (ICAM) is the central component in an integrated data storage, retrieval, and analysis system capable of characterizing and analyzing coal market interactions. The ICAM is a standard linear programming formulation that minimizes the purchase price, transportation cost, and energy conversion cost by determining the optimal flow of coal between production and demand counties. However, to date the ICAM has not been used to define these optimal flows. In an alternative mode of use, the ICAM has been used to simulate coal flow by heavily constraining the solution to replicate existing flow patterns. The basis for determining these intercounty flow constraints is a continuously updated data base that describes coal reserves, mining, cleaning, transportation, and utilization at the level of individual mines and power plants.

The ICAM is supported by three analysis modules that provide estimates of the unit cost of coal purchase, transportation, and conversion. Derived by linear regression, the mining module is an equation of mine mouth price as a function of Btu and sulfur content, quantity mined, forecast years, and union-contract renewal scheduling. Transportation costs are derived from the Transportation Analysis System (TAS). TAS is coal-flow-assignment model, developed by North Dakota State University, that simulates coal movements from mine to power plant over a combined network of rail, barge, and pipeline links. It uses capacity limitations for individual links while simultaneously building an engineering cost for the movement. The utilization module is an equation, also derived by linear regression, that relates the power plant's capacity factor to its heat ratio, nonfuel operating cost, generating capacity, and coal share of generation. This module provides an estimate of a plant's coal requirement given a forecast-required electric demand.

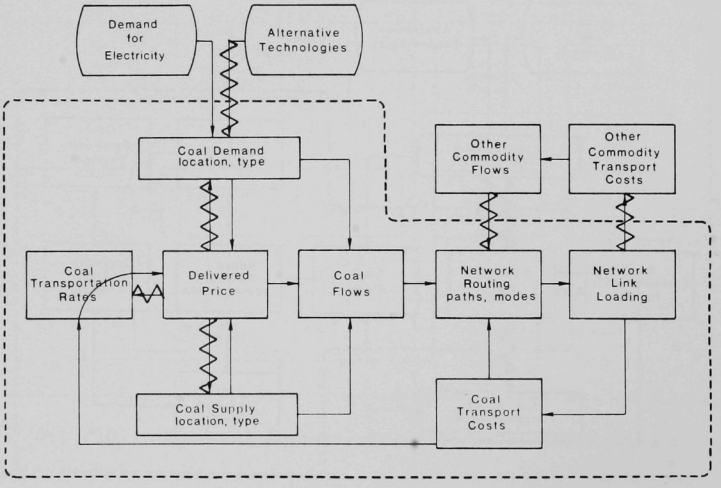

Fig. 12 EPA/USDA - Interregional Coal Analysis Model

BOSTON UNIVERSITY - PORT EXPANSION SYSTEM[16]

The Port Expansion System (PES) is a comprehensive coal transportation market model that focuses on the location and allocation of transshipment coal-handling facilities. PES is a mixed-integer, mathematical programming model that seeks to minimize total costs for the system of transporting coal to demand sites. The mixed-integer approach is used since the handling facilities are discrete improvements and are therefore represented as either available or not, e.g., zero-one integer variables. In actuality, PES is two linked models, one nested within the other. Aggregate coal flows from mine to power plant are estimated as continuous variables, through the traditional linear programming transportation problem formulation. The transportation costs are, however, dependent on the configuration of facilities at transshipment nodes. Within the transshipment nodes, the location/allocation of the handling facilities is optimized for the specific transshipment volume through the integer programming logic, which incorporates a relaxed linear programming representation with a "branch and bound" search routine.

Recognizing that cost minimization is but one design criterion, the PES has been exercised to investigate the tradeoffs of possible competing objectives such as minimizing transport delay and minimizing emission levels. Through this approach, the PES can generate information to construct a tradeoff frontier, which is useful in investigating the range of multiobjective optima under alternative decision-maker-scale weightings.

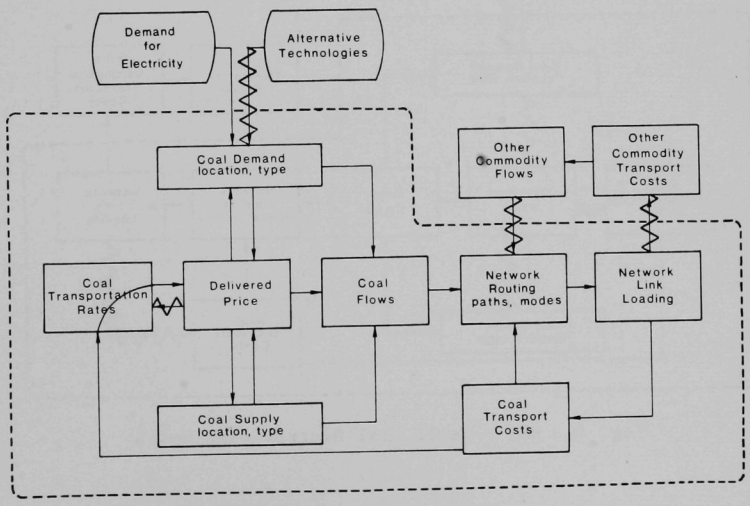

Fig. 13 Boston U. - Port Expansion System

DRI - WORLD COAL DISTRIBUTION MODEL[17]

The World Coal Distribution Model is a collection of 10 separate economic, energy, and transportation models that function together as a comprehensive model of world coal transportation market interactions. The main focus of the model is forecasting the distribution of coal between export and import countries. The analysis is, however, detailed enough to examine flows from a particular mine, along specific routes (rail and barge) to a specific export facility on a specified type of ship to the import country and, finally, to a specific end user.

The component models that constitute the World Coal Distribution Model are processed sequentially. First, a set of international macroeconomic models forecast demand for energy by production sector in all major industrialized nations. An econometric dynamic disequilibrium model identifies the fuel mix and associated fuel prices that will satisfy the energy demand. An analysis of exportable reserves in all major coal-producing countries, a qualitative risk analysis considering numerous political considerations, and an analysis of transportation rates and capacity limits are used to determine the international coal flows.

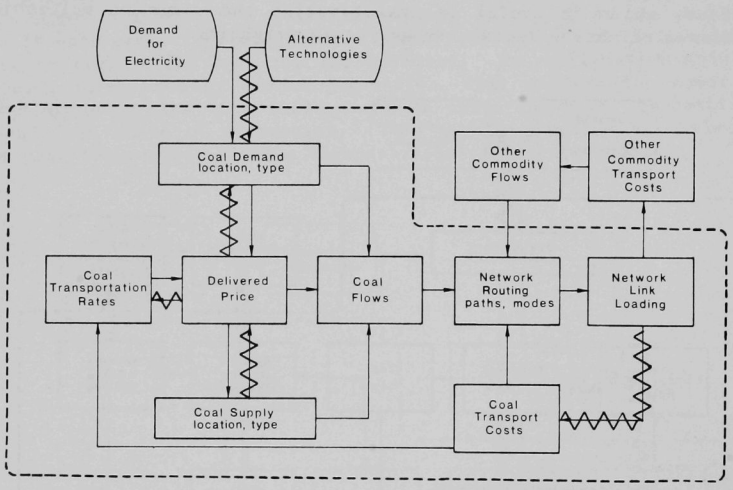

Fig. 14 DRI - World Coal Distribution Model

SUMMARY MATRIX

Table 1 is the matrix summarizing the salient features of the individual models as they have been presented in the preceding descriptions.

Table 1 Matrix of Coal Transportation Model Features

Model	Function*	Methods	Scope	Aggregation	Comments
DRI - Coal Transportation Cost Model	C	Econometric, accounting	Multimodal, multi-commodity, present - 1995, national	Rail and barge, shipment specific, variable and fully allocated cost estimates	ICC Form A compatible; user specifies shipment routing information
Manalytics - Coal Transportation Cost Model	C	Engineering cost	Multimodal, current, long range, national or corridor	Rail and barge, shipment	User specifies routing
TERA - Coal Supply/Demand Disaggregation Method	S,D	Historical trends, proportional allocation, differential minimization	Regional, national 1978, 1990 interpolation for intermediate years	County level, utility and export sectors	Requires aggregate inter-regional flows, county economic activity, historic supply and energy use
DOE - National Coal Model	S,D,P,F	System optimized linear programming with multi-step minemouth prices	National, through 1995	18 coal types 32 supply regions 44 demand regions	Assumes very crude regional per ton mile transport cost estimates
COMSIS - National Transportation Planning Model	N,L	Sequential mode split and minipath assignment	National, multi-commodity, multimodal	2600 rail nodes 2600 hwy nodes 1300 water nodes 20 commodity groups	Separate networks, no intermodal representation; uses U.S. DOT/UMTA-UTPS software, can be extended to address capacity equilibrium
PRINCETON - Rail Network Information System	N,L	Sequential unconstrained minipath assignments, interactive graphics	National, corridor, present to near (5 yr) term	22,000 rail node, links by carrier ownership	Explicit treatment of rail interlining and merger impacts; very sophisticated data display
CACI - Multimodal Network Model	C,N,L	User optimized minimum cost multimodal assignment	National, multi-commodity multimodal	2200 nodes 3900 links with inter-modal connections	Ordinarily (at user option) network is "prestressed" with other commodity flows and coal is loaded last -- capacity constrained by external cost functions

Table 1 (Cont'd)

Model	Function*	Methods	Scope	Aggregation	Comments
FRA - 1990 Rail Forecast	S,D,F,N,L	Base year growth factoring, unconstrained minipath	National, ten years (1990) multicommodity	15 commodity types, 129 regions, aggregated corridor links	Minipath based on average distance along aggregate links
CRA - Coal Transportation Industry Interactions	R,S,D,P, F,N,L,C	Iterative application of the DOE-NCM and CACI network model	National, multimodal, 1990	18 coal types 32 S/44D regions 22,000 rail nodes	Sensitivity analysis of extreme rate vs. cost; model iterations did not close - flows sensitive to rates
ANL/U of PENN Freight Network Equilibrium Model	F,N,L,C	Simultaneous flow and user optimized assignment followed by system optimized assignment within each carrier network	National regional multimodal, multicommodity, short and long range	Intercounty flows, detailed multimodal network (in northeast, 2258 nodes, 9799 links)	Currently uses fixed county supply and demand, extension to represent supply function under investigation
EPA/USDA Interregional Coal Analysis Model	S,D,P,F, N,L,C	Regression for S,D,P system optimized LP for flows, minipath assignment	National, simulates present, not yet used to forecast	Individual firm or county, only coal, multimodal	Continuously updated, detailed and complete flow data base; prescribes additional transportation capacity where needed.
BOSTON U. Port Expansion System	S,D,P,F, N,L,C	System optimized nested LP with integer variables to represent coal handling facilities, minipath assignment	Regional, rail-water intermodalism, near term	Individual mine and power plant flows, 9 coal types, 8 coal handling components	Prescribes location and allocation of coal handling equipment at ports; uses multiobjective function approach for competing objectives
DRI - World Coal Distribution Model	S,D,P,F, N,L,C	Macroeconomics, econometric dynamic disequilibrium, transportation network model	International, long range (20 yrs)	Capable of analyzing individual shipments along specified routes	Models applied sequentially, limited capacity feedback

*S - Supply, D - Demand, P - Price, F - Flows, N - Network Routing, L - Link Loading, C - Transport Cost, R - Transportation Rate.

REFERENCES

1. *NCA Predicts Record 1982 Levels*, Coal Outlook, pp. 1-2 (Dec. 28, 1981).

2. *DOE Ups Its Coal Production Goals*, Coal Outlook, p. 5 (Feb. 16, 1981).

3. Vincent, B., Engineering Analyst for North America Electric Reliability Council, as quoted by Glasser, Samuel, *Effect of "Reagonomics" Unclear on Electric Utilities Coal Use*, pp. 1C, 7C, Journal of Commerce (Nov. 16, 1981).

4. U.S. Interagency Coal Export Task Force, *Interim Report of the Interagency Coal Export Task Force* (Draft for Public Comment), published by U.S. Department of Energy, pp. 4, 102 (Jan. 1981).

5. Anderson, D.L., and T.J. Biggins, *Coal Transportation Cost and Rate Modeling*, these proceedings, pp. 29-47.

6. Rifas, B.E., *Manalytics Coal Transportation Cost Model*, these proceedings, pp. 48-67.

7. Brooks, R.E., *Freight Network Equilibrium Model Supply and Demand Disaggregation Metholology*, these proceedings, pp. 68-77.

8. Orchard-Hays, W., *Components of the National Coal Model and Use of An Auxiliary Transportation Model*, these proceedings, pp. 78-85.

9. Rubin, D., and M. Roskin, *The National Transportation Planning Model and Its Use for Coal Transportation Forecasting*, these proceedings, pp. 86-98.

10. Kornhauser, A.L., *A Preliminary View of U.S. Coal Transportation Using the Princeton Railroad Network Information System*, these proceedings, pp. 99-124.

11. Bronzini, M.S., *Multimodal Network Model for Coal Transportation Analysis*, these proceedings, pp. 125-149.

12. Kedar, R., *Rail Freight Forecasts - 1990*, these proceedings, pp. 150-157.

13. Egan, T.P., *The Modeling of Coal and Transport Industry Interaction*, these proceedings, pp. 158-185.

14. Friez, T.L., R.L. Tobin, and J.A. Gottfried, *A New Model and Efficient Computational Procedure for Determining Multimodal Freight Network Equilibrium*, these proceedings, pp. 186-199.

15. Green, J.W., and J.P. Haskins, *The USDA-EPA Economic Impacts of Coal Development on Natural Resources Project*, these proceedings, pp. 200-207.

16. Ratick, S.J., and J.P. Osleeb, *The Port Expansion System: Applications and Extensions*, these proceedings, pp. 208-222.

17. Anderson, D.L., *World Coal Distribution Analysis*, these proceedings, pp. 223-236.

COAL TRANSPORTATION COST AND RATE MODELING

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ABSTRACT

The paper describes a set of accounting and econometric models that determine both current and forecast coal transportation costs for rail and barge for specific movements (e.g., mine to consuming plant) by individual carrier. Single car, multiple car, trainload, and unit train costs are available for railroads, while both non-dedicated and unit tows can be analyzed for barge. The models generate individual railroad costs for both single carrier and interline movements of coal as well as multi-mode flows involving any combination of rail, barge, and truck flows.

After describing the rationale for and general features of the models, a detailed description of the rail costing, rail unit train, and barge costing models is presented. Next, procedures for modeling rail and barge rates are discussed. Finally, a complete listing of inputs to and outputs from the unit train costing model is presented.

OVERVIEW

Data Resources, Inc. (DRI) and Kearney: Management Consultants (Kearney) have developed a service designed to meet the modal cost informational and forecasting needs of transportation professionals in the 1980s. The next decade promises to be one of constant turmoil in the transportation industry, with carriers adjusting to deregulation, and renewed competitive pressures that alter historical cost structures for shipments.

Although carrier costs have always been of interest to shippers, rate bureaus, and regulatory agencies, recent deregulation legislation has resulted in increased demand for accurate and detailed carrier cost information.

As a result of deregulation, published rate dockets will give way to individually-negotiated charges for transportation services. Those companies able to negotiate lower transportation rates will profit. In order to negotiate effectively in this new environment, transportation managers will require detailed information on carrier costs. Failure to know and understand a carrier's cost structure could potentially lead to unfavorable rate levels and higher transportation costs.

The Transportation Costing Service provides quick access to individual carrier costs. The costing models represent the current "state-of-the-art" in carrier costing and are accepted as prima facie evidence by the Interstate Commerce Commission.

The models also incorporate the latest technological changes in costing data and methodology. This is evidenced by the work currently being performed by Kearney for the Interstate Commerce Commission. In its work for the

Commission, Kearney is developing the 1979 Rail Form A cost data as well as jointly developing the data base for the Uniform Rail Costing System (URCS). This new costing system, although still in the experimental stage, is already mounted on the DRI computer system and will be made accessible to users once the new procedure is approved by the ICC.

GENERAL FEATURES

One of the most important features of the rail and barge costing models is the ability to generate carrier-specific costs in a matter of minutes. Specific point-to-point modal costs are accessed by users at their place of work by typing into the DRI timesharing computer via a local telephone number. The cost models and forecasts are maintained on DRI's multiprocessing Burroughs B7700/B7800 systems, which represent one of the world's largest commercially-available timesharing systems. The system is available for use 24 hours per day throughout the year.

No programming knowledge is required on the part of the user in accessing carrier cost information. The quick access, easy-to-use models can be used by staff with little or no knowledge of computers.

It is also important to note that if a user does not know the specific answer to any of the optional questions, such as switching minutes, the computer will automatically use the carrier's average. Help memos are also provided.

The models have been developed by the largest team of transportation cost analysts ever formed to support the development and ongoing management of such an undertaking. This group ensures that the costing methodology in the service is high quality and state-of-the-art. A critical portion of their assignment is to monitor industry developments and incorporate these in the cost models, bringing users the very best information there is to offer.

The Transportation Costing Models enable users to develop costs for various modes. Individual carrier costs can be developed for single car, multiple car, trainload, and unit train movements. In addition, barge non-dedicated and unit tow costing models are available.

Currently, the Transportation Costing Service maintains the latest approved cost information for 39 Class I railroads and over 240 regular route motor common carriers. The irregular route model will have the capability of accessing up to 750 individual carriers. This ability to access individual carrier information allows the user to develop highly-specific shipment cost estimates which are of significant value in rate negotiation sessions.

In addition to developing the total cost for specific point-to-point movements, the variable cost can be broken down into its operational components by carrier (i.e., freight train car costs, switching costs, clerical costs, etc.). This feature facilitates rate negotiations by enabling both parties to identify where they differ in their individual cost estimates.

The costs are updated quarterly to reflect interim cost increases and can be forecast for a 10-year period by accessing DRI's projections of the labor, fuel, and materials price increases. These forecasts are revised

monthly and are based on a detailed analysis of individual modal cost components. Railroad costs include both variable operating expenses (fuels, lubricants, wages and supplements, other materials and supplies) and new capital expenditures (new rail, ties, ballast, locomotives, railcars, and other transportation equipment).

This capability allows the user to project transportation costs for planning purposes and to evaluate which mode or transportation contract would be most economic in the long run.

The models allow maximum flexibility in determining costs based on the particular operating characteristics of the shipment. Costs can be easily adjusted to reflect different car costs, re-load economics, and switching operations which illustrate just a few of the system's sensitivity capabilities.

In all, there are over 49 different questions which the user can answer in determining specific rail carrier costs. The ability to quickly change any one of these answers allows a client to re-run costs for different levels of service or operations.

Since the models are intended to provide negotiation assistance for the shipper, outputs are formatted to provide analysis of critical negotiating points. These include escalation analysis graphics, cost recovery analysis, and alternative rate of return analysis. These analyses are most useful in justifying possible rate changes to a carrier, based on alternative operational or contract conditions.

In addition to assisting in negotiating better transportation rates, the models have a number of other applications including:

- forecasting a company's future transportation bill,
- evaluating the costs of various levels of carrier service,
- identifying which locales are better situated for establishing new facilities because of low transportation costs,
- negotiating favorable escalation agreements,
- evaluating private fleet operations,
- conducting competitive mode/routing analyses,
- identifying those moves whose revenue/cost ratio exceed the various thresholds established by the Staggers Act, and
- regulatory proceeding support.

DESCRIPTION OF RAIL COSTING METHODOLOGY

Costs utilized in the Kearney/DRI proprietary rail computer costing model are developed on the basis of an application of the Interstate Commerce Commission's Rail Form A, ICC Statement No. IFI-73, Formula For Use in

Determining Rail Freight Service Costs, to the expenses and statistics of individual Class I linehaul railroads. Costs are also developed by applying Rail Form A to the expenses and statistics of all Class I linehaul railroads assigned to the seven designated regional territories according to the Interstate Commerce Commission's Statement No. ICI-77, Rail Carload Cost Scales - 1977.

Rail Form A (RFA) is a costing procedure which apportions the basic inputs of operating expenses and cost of capital among various transportation functions such as yard switching, train switching, running, station, special service, and general overhead. However, for costing purposes, Rail Form A also separates those transportation functions into 45 cost service functions.

The principal source of the "basic inputs" to Rail Form A is the individual carrier's annual reports to the Interstate Commerce Commission. Other inputs are developed on the basis of special studies and/or from carrier operating statistics.

Costs utilized in the Kearney/DRI model are developed on both the variable cost basis, reflecting embedded debt cost of capital, and the fully allocated basis. The fully allocated costs are developed using the dollar (ratio) basis as well as the ton/ton-mile basis to allocate constant costs to the movements at issue.

Variable costs represent those expenses which, over the long-term, vary with the volume of traffic handled. Specifically, variable costs consist of the variable portions of freight operating expenses, rents and taxes, and the variable portion of the "cost of capital," excluding Federal income taxes.

When developing the fully allocated cost for a given movement, the variable cost is calculated first and to this cost there is added an allocation of the constant costs. To develop the constant costs per ton and per ton-mile, the tons originated and terminated and the ton-miles are used for the respective terminal and linehaul elements. The constant unit costs per ton and per ton-mile are then applied to the respective tons and ton-miles generated by a particular movement. The allocated constant costs thus obtained are added to the variable cost per net ton to produce the fully allocated cost per net ton. For the dollar basis an allocation ratio is developed for each individual railroad and designated regional territory by dividing the individual carrier or regional total costs (variable plus constant) by that carrier's or region's total variable cost. The variable cost per net ton for a given movement is then multiplied by the applicable carrier or regional ratio to produce the fully allocated cost per net ton.

The aforementioned Rail Form A costs are updated to various wage and price levels based on the Interstate Commerce Commission's update procedures described in ICC Statement No. 1E3-78, Explanation of Rail Cost Update Procedures. This update process was applied specifically to the operating expenses, rents, and taxes, excluding Federal income taxes, incurred by each participant in the movements at issue, and incurred by the group of carriers assigned to the designated regional territories.

The costing procedures employed in the Kearney/DRI model follow the basic costing methodology specified in the ICC's Rail Carload Cost Scales and

further incorporates the cost methods employed by the Commission in Ex Parte No. 270, Investigation of Freight Rate Structure of Railroads. These procedures have been accepted by the Interstate Commerce Commission in numerous proceedings as providing reasonable estimates of rail carrier costs. Specifically, the variable costs reflect adjustments to recognize certain transportation characteristics indicated in the movements at issue, including the actual route of movement miles, actual lading weights, and car ownership, whether privately owned or railroad owned. Where the car is other than carrier owned, the car ownership costs are removed from variable and fully allocated costs. Costs for each movement at issue are based on the specific type of car used; and "way" and "through" costs are applied to single- and multiple-car movements, and only "through" costs to trainload movements. The basic adjustments made to the single-car, multiple-car, and trainload movements are as follows:

Single-car movements - where the actual routing of the movement is shown, linehaul costs are adjusted by removing the interchange costs included on a loaded car-mile basis and substituting therefore the interchange cost per car interchanged, using the actual number of interchanges from the routing shown. This is done for both variable and constant costs.

Multiple-car movements - of five or more cars, terminal costs are adjusted by reducing switching costs per carload on the basis of a sliding scale adopted from the "Improved Regulatory Costing Methodology for Railroads," published November 1977. Variable freight train car costs per carload are reduced by 25 percent at origin and destination. Similarly, station clerical costs per carload are reduced by assuming 75 percent of the cost as being associated with the car and 25 percent as being associated with the shipment. Linehaul costs are also adjusted to reflect actual interchange costs where the actual routing of the movement is shown.

Trainload movements - of 50 cars or more, terminal costs are adjusted by reducing switching costs per carload by 75 percent at origin and destination. Variable freight train car costs per carload are reduced by 50 percent at origin and destination. Furthermore, station clerical costs per carload are reduced by assuming 75 percent of the cost as being associated with the car and 25 percent as being associated with the shipment. Linehaul costs are adjusted to reflect actual interchange costs where the actual routing of the movement is shown. Further, intertrain and intratrain switching costs per loaded car-mile are eliminated.

In addition to the adjustments indicated above, the following adjustments are also incorporated when specified.

1. Actual Way Train Miles
2. Mileage Allowances
3. Actual Hourly and Mileage Per Diem
4. Actual Empty Return
5. Assigned Cars
6. Actual Car Tare Weight
7. Actual Inter/Intratrain Switches
8. Actual Switching Minutes (Origin and Destination)
9. Actual Switching Days
10. Actual Loading/Unloading Days

11. Transit Movement
12. Inspection
13. Grain Doors
14. Switching Minutes at Interchange
15. Actual Loss and Damage

DESCRIPTION OF UNIT TRAIN COSTING METHODOLOGY

The Kearney/DRI Unit Train Cost Model is designed to provide estimates of the cost incurred by the railroad in providing unit train service. The methodology draws heavily on the Rail Form A methodology described elsewhere (ICC Statement No. IFI-73). However, the methodology incorporates engineering estimates of the known impacts of unit trains on rail cost structure. Thus, the model can be properly described as a hybrid between the accounting and engineering approaches to rail costing. In this manner, the Unit Train Costing Model emulates the railroad's own managerial cost estimates for unit trains.

The term "unit train" refers to a specific type of operation. Unit train operation is defined as service provided by use of an integral trainset of identical cars moving between a single origin point and a single destination. In this operation, the only switching performed is usually to cut out cars for maintenance. Generally, loading and unloading operations will be performed within 12 hours or less.

The most important criterion in determining the applicability of the Unit Train Model to a specific movement is the handling of the cars at origin and destination. The model is only applicable if the set of cars in each trainset is returned for another load immediately upon being emptied. In other words, trainload movements which are essentially one way, where the cars are nondedicated and are released for other service immediately upon being unloaded, should not be costed with this model. The Kearney/DRI Rail Cost Model should be used for these movements. It is assumed that unit trains will not be classified en route nor will they be subject to any interchange switching. Other than this limitation, the model can be adapted to a wide variety of unit train operations.

Cost analysis for unit train operation is useful for a variety of situations. In each one there will be different approaches to the use of the model. Several common applications are discussed below together with comments as to how to use the model for each.

General Planning. There are many situations where approximate rail costs are required as a basis for forecasting rail rates in planning projects. Examples of such projects would include: analysis of alternate coal or oil sources, feasibility of bulk terminal locations, grain or coal marketing studies, and projections of fuel price escalation on probable rail rate levels. Such studies are more dependent on consistency of assumptions from case to case than they are on the precision of the costs relative to actual operations. In fact, detailed operational parameters are often unavailable at this state of analysis.

The Kearney/DRI Unit Train Model may be used in this type of study since it can be run with fairly generalized operational inputs. For example,

average car costs will be used if specific costs are not available. Also, if specific carriers have not been identified, regional average rail unit costs may be employed.

Operational Analysis. Costs of unit train operation can vary substantially as operating parameters are changed. Different train sizes, numbers of locomotives, trips per year, turnaround times, and car types can yield costs which vary plus or minus 30% or more around an average. Often, the analyst is called upon to determine the most economical set of operating parameters. The Kearney/DRI Unit Train Model is ideally suited to analyze such a problem.

Contract Rate Negotiations. An operational analysis is often a preliminary to preparation of a contract rate proposal. In addition it is frequently important to determine the cost impact of varying volume levels on a given operational pattern. Other decisions in contract development relate to escalation formulas and establishment of a reasonable base rate. The Kearney/DRI Unit Train Cost Model is an indispensable tool for such analysis.

Beyond its capability to test various operational and volume variations, the model provides highly-detailed cost outputs. Costs are broken down into the following major categories:

1. Labor
2. Fuel
3. Materials
4. Car Ownership
5. Locomotive Ownership
6. Fixed Plant Investment
7. General and Administrative
8. Allocated Constant Costs

With this breakdown, highly-refined cost escalation methodologies can be developed and tested before actual carrier negotiations.

DESCRIPTION OF BARGE COSTING METHODOLOGY

The DRI Transportation Service Towboat and Barge Cost Model analyzes variable costs and fixed costs for towboats and barges which operate on the inland waterway system. Historical data on barge and towboat operating expenses are provided by the Army Corps of Engineers. This data contains cost items for 11 types of towboats and 15 types of barges. A total of 9 cost items are included for each towboat type, while 5 items are included for each barge type. Equipment annuity (return on investment) is the major expense category for barges, accounting for approximately 70% of total barge costs, while wages and fuel are the major expense items for a towboat, accounting for approximately 60% of total towboat costs.

The models can be used to cost out point-to-point movements of commodities among any two specific points on the U.S. navigable river system. Operating costs are provided by river segment allowing analysis at the most detailed level of operations. In addition, the individual movement costs are also projected, using historical weights for each cost category to develop a

movement-specific forecast. The user may also specify a towboat/barge configuration for a specific cost index forecast.

In all, 11 towboats and 15 barge types can be used to construct tow configurations that correspond to actual movements on the U.S. waterways system:

Towboats

Description	
Towboat - Harbor	400-600 HP
Towboat - Line Haul	800-1200 HP
Line Haul	1400-1600 HP
Line Haul	1800-2000 HP
Line Haul	2800-3400 HP
Line Haul	4000-4400 HP
Line Haul	5000-6000 HP
Line Haul	6100-7000 HP
Line Haul	7100-8000 HP
Line Haul	8100-9000 HP
Line Haul	10,000 HP

Barges

Description

Deck 130' x 35'
Deck 175' x 26'
Open Hopper 175' x 26'
Open Hopper 195' x 35'
Covered Hopper 175' x 26'
Covered Hopper 195' x 35'
Double Skin Tank, Coiled, Lined 195' x 35'
Cylindrical Tank, Pressure 195' x 35'
Cylindrical Refrigerated 280' x 50'
Tank, Single Skin 195' x 35'
Tank, Single Skin 240' x 50'
Tank, Single Skin 290' x 50'
Tank, Double Skin with Coils 195' x 35'
Tank, Double Skin with Coils 240' x 50'
Tank, Double Skin with Coils 290' x 50'

Nine cost concepts are analyzed for each towboat type. They are:

Fixed Costs

ROI	Return on Investment (Equipment Annuity)
Admin	Administration and Supervision

Variable Cost

Wages	Wages and Fringe Benefits
Fuel	Fuel
Maint	Maintenance and Repairs
Supp	Supplies
Subsist	Subsistence
Ins	Insurance
Other	Other Expenses

Five cost concepts are analyzed for each barge type. They are:

Fixed Cost

ROI	Return on Investment (Equipment Annuity)
Admin	Administration and Supervision

Variable Cost

Maint	Maintenance and Repair
Ins	Insurance
Supp	Supplies

The barge cost model is used to develop coal transportation costs by movement (both current and forecast) for either all waterway or multi-mode flows. The basic methodology involves use of both accounting and econometric relationships to determine barge costs. The procedures can be modified to deal with fleeting, unit tow, changing tow configuration, and other issues.

The models are used to plan new distribution systems involving waterways transportation. Full consideration of existing and planned waterway user charges is included in the barge costing analysis.

MODELING RAIL AND BARGE TRANSPORTATION RATES

Deregulation of the U.S. rail industry will introduce an entirely new set of relationships between modal rates and costs over the next 10 years. An avowed purpose of the Staggers Rail Act is to make rail transportation rates more closely aligned with movement costs over the long term. Thus, analysis of current and future relationships between rail coal rates and costs requires two different procedures: one reflecting current (and transitional) conditions and the second emulating long-term expectations. At present, DRI regards 1985 as the division point between these two regimes, with rates in the post-1985 period more directly related to underlying movement cost structures.

Forecasting rail coal rates for the pre-1985 period involves looking at the following factors: rail costs, commodity market conditions, modal dominance issues, and escalation agreements. Rail costs are a primary, if not dominant, factor in rate forecasting, often accounting for as much as 60% of the variation in rates over time. Whether markets served by the railroads in the commodity movements are strong or weak also has an influence on rates. For example, the high demand for export coal has resulted in rapid increases in some rail export coal rates, changes that have little to do with movement

costs. The degree of modal competition associated with the movement (whether other railroads, barge, or truck) also influence rail rates. Direct relations exist between high levels of competition for a movement and a lower rate, compared to similar moves, with little competition. Finally, certain rail coal contracts have built-in escalation clauses for rates that specifically state procedures (e.g., rates escalate at 80% of the Association of American Railroads' rail cost index) that must be considered in the analysis. As a result, a customized rail rate escalation procedure must be developed for each rate under analysis. No general rail rate determination procedures can be used, given the wide discrepancy in factors that may influence a particular rate.

For the post-1985 period, rail rates are generally escalated in accordance with expected cost increases, which are corrected for rail productivity increases (not done for the pre-1985 rates). The specific assumptions that rail productivity gains (a) will occur after deregulation and (b) should be shared with shippers is perhaps controversial but is realistic when long-term forecasts have to be made. DRI assumes that more sophisticated shippers who modify their operations to make physical distribution less expensive for a railroad will want to share in these benefits via lower rail rates.

Corrections for shipper- versus carrier-owned equipment must also be made. The actual procedure is to escalate the rates based on costs using current equipment, with higher cost escalators in the period after new equipment must be purchased for the move.

In sum, rail rate determination and forecasting is a complex process that rquires not only a detailed analysis of current factors influencing rates but a multi-stage forecasting procedure that accounts for expected structural changes in rate-making during the 1980s. Each movement must be analyzed separately, and a rate escalation procedure devised that best fits future expectations.

For barge, rate determination will also become more complex in the 1980s due to the imposition of waterway user charges. At present, DRI estimates barge rates by adding an appropriate rate of return on investment to barge operating costs. Some analysis of barge availability is also done if short-term market conditions indicate that this is an important factor.

In the long term, the principal issue is how barge operations will include user charges in rates. DRI is currently using different levels of user charge impacts on rates, depending on the potential divertability (to other modes) of the movement over time.

APPENDIX

UNIT TRAIN COSTING MODEL OUTPUT

```
?E*EPS

*********
*  EPS  *  11/9/81  14:50   VERSION 11/5/81   SC
*********
FRACTIONFORMs, WRITE function, enhancements to graphics.  Type NEWS.

?LOAD @TCS/UNITTRAIN
LOADING @TCS/UNITTRAIN AS TCS/UNITTRAIN

###  A.T. KEARNEY / DRI  UNIT-TRAIN COSTING MODEL

###  PLEASE NOTE:  THE COST ESTIMATES PRODUCED BY THIS UNIT-TRAIN
###  MODEL ARE FOR PLANNING PURPOSES ONLY, AND ARE NOT SUITABLE
###  FOR REGULATORY PROCEEDINGS, CRITICAL NEGOTIATIONS, OR FINAL
###  OPERATIONAL OPTIMIZATION.  TYPE 'SEE DISCLAIMER' FOR MORE DETAIL.

###  TYPE 'DO COSTING', TO RUN THE UNIT-TRAIN COSTING MODEL.

?DO COSTING

###  ENTERING UNIT-TRAIN COSTING MODEL --
###  TYPE 'GENHELP' FOR A LIST OF GENERAL RESPONSES (E.G. 'STOP',
###  'CORRECT 5'), OR TYPE 'HELP' FOR QUESTION-SPECIFIC ASSISTANCE.

###  INPUT SECTION:

1. What prompting verbosity do you want (LONG or SHORT)?
LONG

2. Enter origin point name:
DEEP MINE

3. Enter the destination point name:
POWER PLANT

4. Enter first 2 to 5 digits of STCC code:
11

5. Enter tons per year:
1600000

6. Enter trips per train set per year:
160

7. Enter the number of train sets:
1

8. Enter the number of cars per train:
100
```

9. Enter the type of car or code for specified car data:
HELP
TYPE OF CAR

Eight standard car types are provided by the model. Specifying the car type dictates the cost of the car (replacement cost), the empty weight and the weight of the lading. The eight standard types are listed below:

		COST	CAR WEIGHT	LADING WEIGHT
1.	Standard High Side Gondola	36500	30.5	100.0
2.	High Capacity Gondola	36000	26.3	102.0
3.	Rapid Discharge Hopper	43000	33.0	98.0
4.	Tank Train Car	58000	39.3	85.0
5.	Covered Hopper	39000	30.8	100.0
6.	RR Purch. Open Hopper - East	37000	29.8	100.0
7.	RR Purch. Open Hopper - West	38500	30.7	100.0
8.	RR Purch. Open Hopper - Special	39500	31.3	100.0

If a car of a different specification is being considered, specify car type 9 and answer the questions asked by the system.

9. Enter the type of car or code for specified car data:
3

10. Enter the total round trip time(hours):
48

11. For each movement leg, enter the carrier initials, a comma, and the mileage (e.g., 'ATSF,1215'). FIRST LEG:
SP,600

SECOND LEG (OR <CR> IF DONE):
ATSF,400

THIRD LEG (OR <CR> IF DONE):

12. Enter the number of locomotives:
5

13. Enter the car status (P=private, C=carrier owned [non-dedicated], D= carrier owned [dedicated])
C

14. Do you want to skip optional input questions?
NO

15. Enter cost of car (dollars):
36500

16. Enter the lading weight (tons)
100

17. Enter weight of car (tons):
30.5

18. Enter cost of locomotive: (R=replacement value,H=historical cost,or
    dollar value)
750000

19. Enter the locomotive status (D=dedicated,N=non-dedicated
D

20. Enter cost of capital:
18

21. Enter loss and damage (dollars per net ton):

Do you wish to see a table of your inputs?
NO

Do you wish to make any corrections?
NO

11/9/81

KEARNEY/DRI TRANSPORTATION COSTING SERVICE
UNIT TRAIN COSTS - LEVEL B.0 INDIVIDUAL

---------- BASIC DATA ----------

	CAR TYPE:	RAPID DSCHRG HPPR	
ORIGIN:	DEEP MINE	DESTINATION:	POWER PLANT
STCC CODE:	11000	TONS PER YEAR:	1600000
TRIPS/TRAINSET/YR:	160	TRAIN SETS:	1
CARS PER TRAIN:	100	ROUND TRIP TIME:	48
LOCOMOTIVES:	5	CAR STATUS:	CARRIER (NON-DED.)

---------- MOVEMENT CHARACTERISTICS ----------

COST OF CAR:	$36500	LADING WEIGHT:	100
WEIGHT OF CAR:	30.5	LOCOMOTIVE COST:	$750000
LOCOMOTIVE STATUS:	[NON-DED.]	COST OF CAPITAL:	[18%]
LOSS & DAMAGE:	0		

MOVEMENT BREAKDOWN

FIRST LEG:	SP, 600	SECOND LEG:	ATSF, 400

---------- VARIABLE COSTS ($/TON) ----------

LABOR	4.909
MATERIALS	1.476
FUEL	3.100
MISC. EXPENSES	1.559
EQUIP OWNERSHIP	0.946
LOSS AND DAMAGE	0.030
TOTAL VARIABLE COSTS	12.020

---------- FIXED COSTS ($/TON) ----------

	DOLLAR RATIO METHOD	TON AND TON-MILE METHOD
OPERATIONS	3.169	3.357
ROAD INVESTMENT	2.367	2.937
MISC INVESTMENT	0.365	0.436
TOTAL	5.901	6.730

---------- COST SUMMARY ($/TON)----------

	DOLLAR RATIO	TON AND TON-MILE
TOTAL VARIABLE COSTS	12.0	12.020
TOTAL FIXED COST	5.901	6.730
FULLY ALLOCATED COSTS	17.9	18.751

Page 1

Do you wish to see a detail cost summary?
YES

11/9/81

COST DETAIL FOR SP RAILROAD

VARIABLE COSTS ($/TON)	LABOR	MATERIALS AND FUEL	MISC. EXPENSES	TOTAL
MAINTENANCE OF WAY	0.788	0.364	0.430	1.582
LOCOMOTIVE OPERATIONS	0.476	0.295	0.033	0.804
FUEL	0.000	1.798	0.000	1.798
TRAIN OPERATIONS	0.224	0.064	0.110	0.398
CREW COSTS	1.031	0.003	0.030	1.064
CAR OPERATIONS	0.238	0.135	0.214	0.586
STATION EXPENSES	0.172	0.005	0.027	0.205
MISC. MAINTENANCE	0.000	0.000	0.000	0.000
GEN. AND ADMIN.	0.290	0.014	0.332	0.636
SUBTOTALS	3.220	2.677	1.175	7.072
LOSS AND DAMAGE				0.018
LOCOMOTIVE OWNERSHIP				0.506
CAR OWNERSHIP				0.432
CABOOSE OWNERSHIP				0.007
TOTAL VARIABLE COSTS				8.036

FIXED COSTS ($/TON)	DOLLAR RATIO	TON AND TON-MILE
OPERATIONS	1.962	1.971
ROAD INVESTMENT	1.595	1.816
MISC INVESTMENT	0.299	0.340
TOTAL FIXED COSTS	3.857	4.127

FULLY ALLOCATED COSTS ($/TON)	DOLLAR RATIO	TON AND TON-MILE
TOTAL VARIABLE COSTS	8.048	8.048
TOTAL FIXED COSTS	3.857	4.127
FULLY ALLOCATED COSTS	11.904	12.175

COST DETAIL FOR ATSF RAILROAD

VARIABLE COSTS ($/TON)	LABOR	MATERIALS AND FUEL	MISC. EXPENSES	TOTAL
MAINTENANCE OF WAY	0.611	0.404	0.179	1.194
LOCOMOTIVE OPERATIONS	0.213	0.177	0.021	0.411
FUEL	0.000	1.302	-0.022	1.281
TRAIN OPERATIONS	0.091	0.009	0.036	0.136
CREW COSTS	0.517	0.000	-0.005	0.513
CAR OPERATIONS	0.021	0.000	0.006	0.028
STATION EXPENSES	0.065	0.002	0.011	0.078
MISC. MAINTENANCE	0.000	0.000	0.000	0.000
GEN. AND ADMIN.	0.170	0.005	0.158	0.333
SUBTOTALS	1.689	1.900	0.384	3.972
LOSS AND DAMAGE				0.012
LOCOMOTIVE OWNERSHIP				0.000
TOTAL VARIABLE COSTS				3.985

FIXED COSTS ($/TON)	DOLLAR RATIO	TON AND TON-MILE
OPERATIONS	1.207	1.386
ROAD INVESTMENT	0.771	1.122
MISC INVESTMENT	0.066	0.096
TOTAL FIXED COSTS	2.044	2.604

FULLY ALLOCATED COSTS ($/TON)	DOLLAR RATIO	TON AND TON-MILE
TOTAL VARIABLE COSTS	3.972	3.972
TOTAL FIXED COSTS	2.044	2.604
FULLY ALLOCATED COSTS	6.017	6.576

Do you wish to see a cost forecast?
YES

ENTER STARTDATE FOR OPERATIONS AS 'YEAR:QUARTER' (E.G. 83:2)
81:4

11/9/81

QUARTERLY

	1981:2	1981:3	*1981:4	1982:1	1982:2
VARIABLE COST	12.020	12.456	12.599	12.965	13.132
% CHANGE YEAR AGO	13.7	12.3	13.0	11.3	9.3
FULLY ALLOCATED - DOLLAR	17.921	18.560	18.800	19.332	19.670
% CHANGE YEAR AGO	13.6	13.0	12.9	10.8	9.8
FULLY ALLOCATED - TON MILE	18.751	19.416	19.675	20.226	20.595
% CHANGE YEAR AGO	13.7	13.2	13.0	10.7	9.8

	1982:3	1982:4	1983	1984	1985
VARIABLE COST	13.501	13.712	14.588	16.009	17.717
% CHANGE YEAR AGO	8.4	8.8	9.5	9.7	10.7
FULLY ALLOCATED - DOLLAR	20.278	20.659	21.911	24.030	26.429
% CHANGE YEAR AGO	9.3	9.9	9.6	9.7	10.0
FULLY ALLOCATED - TON MILE	21.239	21.652	22.951	25.171	27.664
% CHANGE YEAR AGO	9.4	10.0	9.7	9.7	9.9

ANNUAL

	1986	1987	1988	1989	1990
VARIABLE COST	19.629	21.665	23.870	26.325	29.035
% CHANGE YEAR AGO	10.8	10.4	10.2	10.3	10.3
FULLY ALLOCATED - DOLLAR	29.053	31.859	34.906	38.252	41.918
% CHANGE YEAR AGO	9.9	9.7	9.6	9.6	9.6
FULLY ALLOCATED - TON MILE	30.378	33.282	36.438	39.896	43.684
% CHANGE YEAR AGO	9.8	9.6	9.5	9.5	9.5

	1991	1992	1993	1994	1995
VARIABLE COST	31.844	34.725	37.874	41.254	44.884
% CHANGE YEAR AGO	9.7	9.0	9.1	8.9	8 8
FULLY ALLOCATED - DOLLAR	45.676	49.510	53.655	58.047	62.751
% CHANGE YEAR AGO	9.0	8.4	8.4	8.2	8.1
FULLY ALLOCATED - TON MILE	47.556	51.502	55.762	60 268	65.089
% CHANGE YEAR AGO	8.9	8.3	8.3	8.1	8.0

Do you wish to save your inputs to rerun COSTING at a later time?
NO

Do you wish to modify your inputs and rerun program?
NO

?DN

MANALYTICS COAL TRANSPORTATION COST MODEL

Bertram E. Rifas
Vice President
Manalytics

ABSTRACT

The Manalytics model focusses on developing the costs for a PARTICULAR shipment, defined in terms of the route followed, the equipment used, the time frame for the costs, the trip operations required, the terminal operations required, and the intermodal transfer operations required.

The model is set up and applicable to rail, barge, lake vessel, and coastal vessel modes, and to origin, destinations, and intermediate coal transfers.

The description of the model, the default parameters, the original Fortran program statements, and sample output pages are given in two volumes published by EPRI, Report EA 675 and Report EA 675-Appendix 1. A proprietary improved Fortran program is not published.

The paper read at the seminar was an overview of the material presented in the EPRI reports, augmented with references to current examples of applications of the model for proprietary clients.

The research needed to facilitate widespread use of the model includes a study of the detailed route characteristics of the coal carrying railroads, and of the applicable detailed unit costs for coal trains. The following is a reprint of the summary of the rail cost model from EPRI report EA 675.

SUMMARY

BACKGROUND

In 1976, the Electric Power Research Institute published a preliminary appraisal of the ability of the domestic transportation infrastructure to move significantly increased amounts of coal.* The study found that some portions of the rail and waterways networks could become congested if the projections of greatly increased consumption of coal by utilities were realized, and if the capacity of the transportation system remained at its present level.

Subsequently, EPRI authorized a second study, to develop a set of computerized transportation cost models; to verify the earlier identification of potentially constrained rail and water links, using refined measures of capacity; and to estimate the variable coal transportation costs that would be added by the diversion of excess coal traffic from the constrained routes to alternative, unconstrained routes (all-land, land-water, or all-water). The costs added by rerouting were assumed to be a measure of the economic value of expanding capacity on the congested routes.

The study covered interregional movements of coal. It did not assess local collection and distribution capabilities or the demands that might be placed on those capabilities in future. In computing the capacities of origin/destination routes, we did not consider the existence of deteriorated roadbeds or of weight limitations or other constraints imposed by local communities or states. Nor did we consider institutional impediments to the free movement of unit trains from one carrier's line to another, such as inter-carrier competition, differing work rules, non-compensating revenue splits, and incompatible freight rates. All of these factors can reduce the capacity of a route and thus increase the rail congestion and the costs attributable thereto.

Because the great majority of utility coal shipments move by rail, the study emphasizes that mode. The waterways systems will, however, continue to be used as an alternative to rail transport in interregional movements not considered in this study (because the rail routes were unconstrained), and will be used even more in intraregional movements. To the extent that water carriers are used for such interregional moves, the demands on the rail system will, of course, be lessened.

THE COST MODELS

The cost models provide a basis for computing the variable operating costs associated with moving coal from mines to power plants (fuel, labor, equipment, and maintenance). Given the large amounts of coal moved by

*Coal Transportation Capability of the Existing Rail and Barge Network, 1985 and Beyond, prepared for the Electric Power Research Institute by Manalytics, Inc., 1976 (EPRI, EA-237); available through Research Report Center, P.O. Box 10090, Palo Alto, California 94303.

utilities, even shifts of a few cents per ton in these costs can mean hundreds of thousands of dollars in freight charges annually. The models can also be used in conjunction with other data for selection of coal sources and plant sites.

Three computerized coal transportation cost models were developed: one for rail; one for inland river, Great Lakes, and coastal ocean waterways; and one for origin/destination loading/unloading and for transfer of coal between rail and barge at intermodal transshipment points. The models calculate the costs of owning, maintaining, and operating transportation and related equipment, including: propulsion equipment (locomotives or tugboats), load-carrying equipment (hopper cars or barges), crew costs, fuel costs, maintenance costs, other operating costs, and the cost of capital. They offer a variety of operating options, involving unit trains or through trains; towboats dedicated to a set of barges or towboats that swap barges at one or both ends of a trip; train or flotilla size; trip distances; rail terrain; rail regions for wage-rate distinctions; barge trips over open water, over pools behind locks, and through locks; intermodal transfer; and (for deepwater transportation) self-propelled or towed vessels, vessel size and draft, and trip distance.

The models use basic technical performance and cost values developed for our analyses (the default values). Other users, however, can override the default values with their own measures of technical performance and cost. The default values are variable costs, which account neither for overhead nor for profit, although other users may assign overhead or profit to the parameters as needed. The exclusion of overhead and profit from the default parameters means that income tax effects, such as investment credits, are not included in the calculated costs. Furthermore, because the cost relationships developed in the study are based on the assumption that trains (and barges) return empty, the actual rates offered utilities may differ significantly from these average costs, even after allowing for overhead and profit. Such factors as track maintenance allowance, availability of backhaul cargo, interchange agreements, and noncoal traffic can have substantial impacts on costs, and hence on rates. Consequently, it is important that costs derived from using the default values be construed neither as full costs nor as suggested rates, especially as the default values are industrywide averages, which may not reflect local conditions.

The rail model calculates train speeds and fuel consumption from track grade and curvature, locomotive power, and number and weight of railcars. Running times are calculated from the result. Running times, added to line-haul and terminal delays, yield operating turn times. Unit-cost parameters for labor and equipment, applied to the operating turn times and then added to the fuel cost, yield the total round-trip cost.

The waterways and transfer models calculate costs much as the rail model does; that is, operating turn times are calculated from technical parameters (such as flotilla size, towboat power, and loading rates) and then applied to unit-cost parameters.

THE CAPACITY ANALYSES

General rail link capacities were derived as a function of signaling system, track configuration, and train speed. We first developed formulas for estimating the maximum capacity on five combinations of track configuration and signal system, assuming ideal conditions. We then reduced those maximums to a practical operational level that allowed for coordinating and scheduling trains so that interference delays were manageable and acceptable.

The capacity estimates, developed as they were from normative operating procedures, must be qualified as follows for a given length of track: waiting time may differ where managements are willing to bear the added expense of periodic high congestion through crowded links in order to achieve greater throughput. Longer trains would reduce the number of trains needed to transport a given amount of cargo and could thus effectively increase the net tonnage capacity of a line. If trains have unequal priority (as they have not in this analysis), passing would degrade some lines; if more down time is required for track maintenance (wear is a particularly severe problem where heavy coal trains run), the capacity of the link will be reduced proportionately.

The measures of capacity used for the inland waterways were based on actual experience. The principal constraints on waterways capacity are locks; as the facilities become congested and the flotillas must wait to lock through. River operators consider that a lock has reached its practical capacity when the average waiting time at a lock exceeds six hours per flotilla.

Transfer facility capacities were not considered as a critical constraint on the coal transportation network in this study because, with rerouting, the rail network by itself has the capacity to transport the projected interregional coal traffic, even without intermodal routing. In reality, the capacity of existing transfer facilities is insufficient to handle projected intermodal coal traffic, with the increasing volumes and changing coal flow patterns. As the increases in utility coal traffic materialize, however, construction of transfer facilities, as well as loading facilities at mines and unloading facilities at power plants, can be expected to respond to demand. Large intermodal transfer facilities are already expected to respond to demand. Large intermodal transfer facilities are already being built on the lower Mississippi River, the lower Ohio River, and Lake Superior.

CALCULATING THE COSTS OF CONGESTION

All rail links identified as constrained in the preliminary study were reexamined to determine more precisely whether those links and their connections would be sufficient for greatly increased loads.

We applied the practical track capacity formulas to the 1974 rail link data obtained from United States Transportation Zone Maps.* On the few links where projected traffic flows exceeded the capacity estimates, we identified alternate routes with excess capacity sufficient to handle the excess traffic on the constrained route. We then used the cost models to calculate the marginal (per ton) and total annual added costs associated with the supplemental routings.

In the 1976 report, the direct, short-line route was defined as the most economical route. We refined our treatment in this analysis by calculating actual train turn times and fuel consumption over these routes. In some cases, an alternative, longer route over flat land, for example, was found to have lower cost than a direct route with high curvatures and severe grades. Therefore, we identified the rail route with the lowest operating cost as the primary rail route and used the higher-cost routes as supplementary alternatives in calculating the costs added by congestion.

We considered water transportation as an alternate to land transport wherever it could provide a viable large-scale means of interregional coal transportation. In presenting waterways alternatives, however, we are not projecting modal splits for long-haul coal transport but are merely examining practical options.

The refined capacity measures and the cost models were used to evaluate:

- the marginal cost per ton of using the lowest-cost unconstrained land route to supplement each constrained route for the coal tonnage the constrained route could not carry;
- the marginal costs of substituting water routes, with or without intermodal transfers, for constrained land routes;
- The total annual added costs of using supplementary least-cost unconstrained all-land, land-water, or all-water routes;
- the comparative annual costs on identified routes where all-water or land-water transportation provides a lower delivered cost to the consignee than all-land transportation.

From these evaluations, we determined the potential impacts of constrained rail links on coal transportation costs for the electric power industry, in sum or by region, as illustrated in Figures 1 and 2. The identified overloads are symptoms of conditions that can be corrected through such remedies as rerouting or improvement of the rail system. (Indeed, certain railroads are already implementing expansion plans.)

The marginal transport costs depicted in Figure 1 show the least-cost route in the example accommodating approximately 50,000,000 tons (at $4.60 per ton) before it becomes congested. Movements between 50,000,000 and 120,000,000 tons are diverted to the next least-cost alternate route, at an increase of $0.20 per ton ($4.80). In

*U.S. Department of Transportation, Federal Railroad Administration, Office of Policy and Program Development, 1975 (Washington, D.C.: Government Printing Office, 050-005-00012-7).

this example, six increasingly costly alternate routes are required in order to move 320,000,000 tons between the mining and consuming regions.

As long as coal traffic is less than 50,000,000 tons, there will be no congestion and therefore no added annual variable transport costs (Figure 2). Above 50,000,000 tons, the added variable costs would increase fairly uniformly, to $93,000,000 per year if the coal movements totaled a high maximum of 320,000,000 tons.

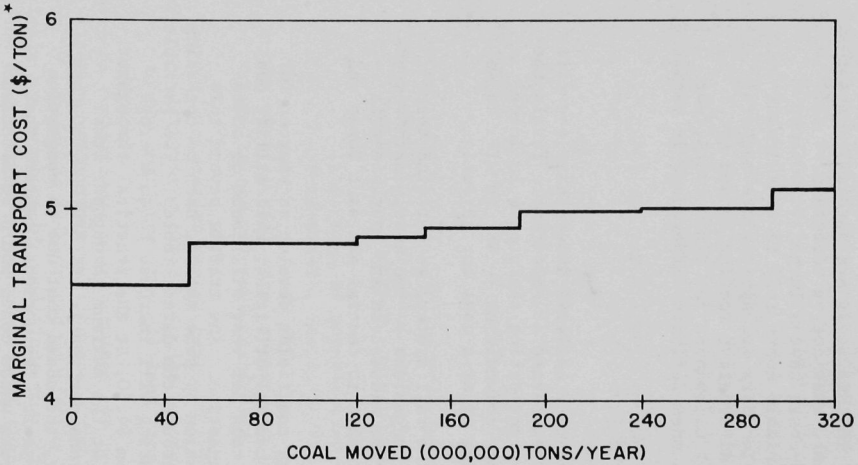
The variable costs developed in this study are naturally less than carrier rates and, as stated earlier, must not be construed as full costs or rates. (Because railroad costs have a larger fixed-cost component than waterways costs, variable costs tend to be a lesser proportion of rail rates.) Variable costs are appropriate measures for comparing the consequences of alternative routing caused by congestion because the inclusion of allowances for fixed costs, not wholly dependent on routing, would mask definite differences in variable, out-of-pocket costs.

CONCLUSIONS

Our capacity reassessment and cost analysis showed that the rail network (assuming the trackage is maintained at serviceable levels for heavy, unit trains) is capable of transporting the projected interregional movements of coal and other commodities -- but it will do so only with an investment in upgrading or at a cost for rerouting.

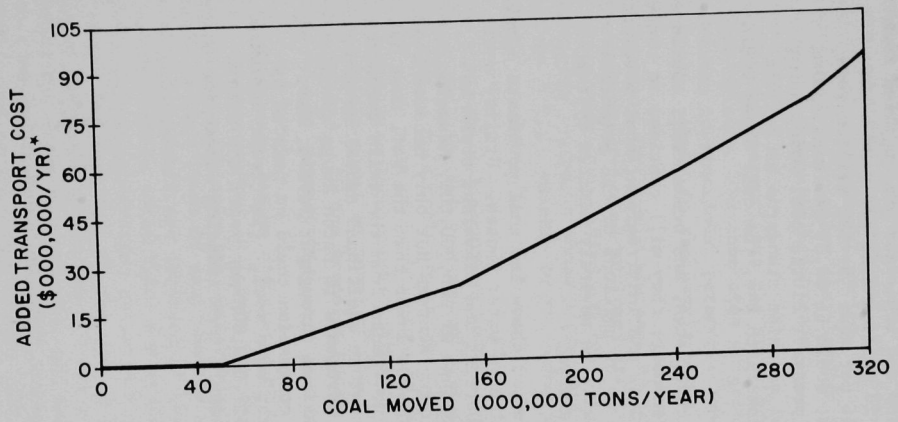
By testing the capacity of the rail system, we detected three networks susceptible to potential congestion -- two involving movements from the Rocky Mountain states to the midwestern and south central states, and one from western Appalachia to central and east Texas and Louisiana:

- If the Montana and Wyoming coalfields develop as sources for the midwestern and south central utilities, rail utility coal traffic up to 50,000,000 tons per year will incur no added variable costs due to congestion. Any traffic beyond this amount will require expansion by some method, such as upgrading the system or rerouting around the direct routes. The variable transport costs for rerouting will increase to an average variable unit cost of from $4.60, at the practical throughput level, to $5.10 per ton, at the maximum throughput level considered (320,000,000 tons per year). If 320,000,000 tons did in fact move annually, the added cost due to congestion would be $93,000,000 per year. The notional centers that represent power supply areas whose costs would be affected by rerouting are Pierre, Denver, Omaha, Des Moines, Topeka, Kansas City, Milwaukee, Chicago, Detroit, Cleveland, Springfield, St. Louis, Oklahoma City, Dallas, Baton Route, and New Orleans.



*$ 1975

Figure I MARGINAL TRANSPORT COSTS FOR COAL
(regional illustration – see text)



*$ 1975

Figure 2 ADDED TRANSPORT COSTS CAUSED BY CONGESTION
(regional illustration – see text)

- If New Mexico coal becomes the energy source for the power supply areas represented by Lubbock and Houston, Texas, up to 26,000,000 tons per year could move along the direct route at an average of $3.73 per ton. At the maximum throughput considered (40,000,000 tons annually), variable transport costs would rise to $5.03 per ton, at an added cost of $11,000,000 per year.

- If central and eastern Texas and Louisiana are supplied from western Appalachia, up to 28 million tons per year could move at an average of $3.16 per ton. By 120 million tons the variable transport cost would be $4.36 per ton, adding $63,000,000 to costs. At present, little coal moves among those areas; should federal emission standards be relaxed or scrubber technologies come into use, the coal flows could increase substantially.

- The waterways systems (inland, lakes, and ocean) will continue to be important in coal transport; they will continue to compete successfully for intraregional and interregional coal movements. Their ability to alleviate major portions of the potential rail congestion, however, will be severely limited by the congestion on critical waterways.

Two of the rail networks discussed above had coal movements completely or partially susceptible to diversion to water routes. Utility coal movements from Montana/Wyoming to Detroit and Cleveland could be diverted at Duluth, at an annual savings of $26,000,000, assuming maximum throughput levels. This saving accrues not only because the annual variable water cost is $9,000,000 lower than the rail cost but also because the diversion of coal movements from the rails decreases the congestion on the rail network for an additional annual savings of $17,000,000. The Kentucky rail movements to Baton Rouge are also amenable to water transport. At maximum throughput levels, the $63,000,000 per year added by rail congestion could be reduced by $29,000,000 if alternate water routes were used. (The lower variable water cost, by itself, amounts to $12,000,000 per year; the other $17,000,000 saving per year would result from reducing congestion on the rail network.)

THE COST MODELS

One of the three computerized models developed in this study calculates variable railroad transportation costs; another calculates variable waterways transportation costs; and the third calculates the variable costs of origin/destination loading/unloading and of transferring coal between transport modes. The railroad and waterways models assess the ownership, maintenance, and operating costs of transportation equipment during operational cycles. The transfer model does the same for facilities that transfer coal between a stockpile and a transport mode and between transportation modes.

This discussion outlines the structure of the models and summarizes the default values. The annotated programs (written in FORTRAN IV), with operating instructions, parameter labels, sequence of steps, and default logic, appear in the user's manual (a separate volume).

In general, the models are used as represented in Figure 3. They provide deterministic cost analyses for coal movements over the land and/or water routes specified by the user. The user either selects transportation equipment whose parameters are already stored in the models (the default values) or furnishes parameter values for other equipment.

For the rail and waterways models, the user must provide data describing the physical features of the route, link by link. In the railroad model, this includes grade, curvature, length, and speed limits for each link of track, along with stopping points, crew change points, and helper locomotive changes on the route. Links are specified in the waterways model in terms of running speeds, delay times, currents, and speed limits. In the transfer model, the user selects equipment from the default parameters.

The cost calculation structures of the three models are similar, overall, as represented in Figure 4. In the first stage, technical parameters are combined with operating-option parameters to calculate the cycle or turn times of equipment in a delivery cycle. Fuel consumption and crew requirements are included at this stage in the waterways and rail models. These cycle times for equipment are then increased by availability and utilization parameters to allow for time lost to maintenance and repairs. By the end of this stage, the models have simulated equipment activities for every phase of the delivery cycle, including the empty return hauls, and have calculated equipment cycle times, crew requirements, and fuel consumption. These results are applied in the second stage to cost parameters, inflated as necessary from the base year to any year specified by the user, to yield a cost per equipment cycle. The equipment cycle cost applied to the amount of coal transferred per cycle yields a cost per ton of coal. Default cost parameters are based on 1975 costs--that is, for operations that began in 1975. Equipment costs are based on costs of equipment delivered during 1975, so the equipment prices are given at a level negotiated before 1975. The models print both base-year and inflated cost parameter values, along with the technical parameters, so users can verify the values used.

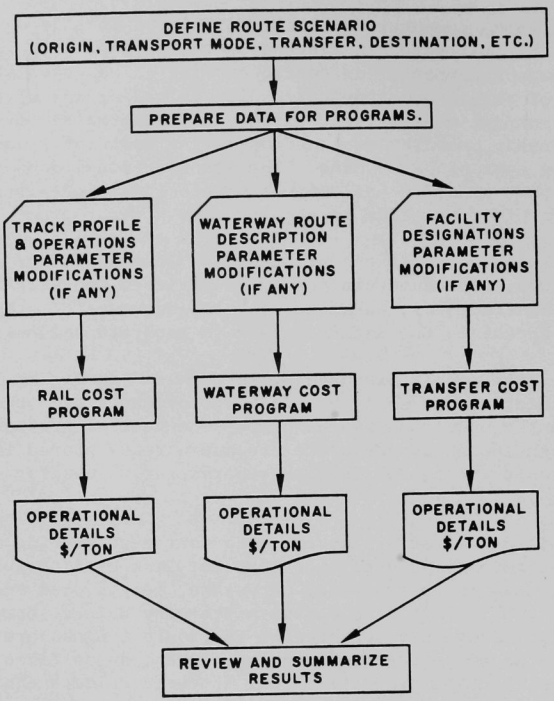


Figure 3 —GENERAL STEPS FOR DETERMINING ORIGIN-TO-DESTINATION TRANSPORTATION COSTS

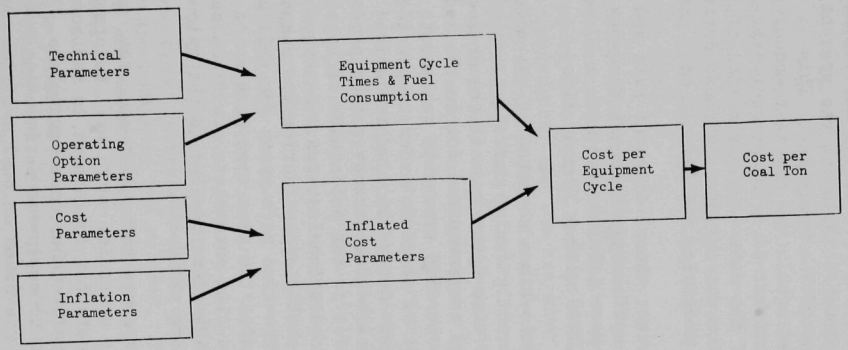


Figure 4
COST CALCULATION STRUCTURE OF MODELS

The three models calculate leveled costs, not dynamic cash flows. For example, the acquisition costs of capital assets (plus interest) are leveled over the life of the equipment, using a simple capital-recovery approach--that is, a constant proportion of the initial cost (plus interest) is charged to each year of operation. This proportion is the recovery factor, and the annual charge is the annual ownership cost.

The recovery factors used in determining the default cost parameters were derived so that the discounted present value of the annual ownership cost over the life of the equipment, including the present salvage value, would equal the initial cost of the equipment. This is equivalent to saying the annual ownership cost equals the constant annual payment, which covers both principal and interest of a 100 percent debt-financing arrangement, where the term of the debt equals the life of the equipment. Income tax effects were not included in these derivations, but users can accommodate them by modifying the default cost parameters.

All three models use a 10 percent annual discount rate and a 20 percent salvage value. These assumptions yield annual recovery factors of 0.1252 for equipment with a 15-year life, 0.1140 with a 20-year life, 0.1082 with a 25-year life, and 0.1049 with a 30-year life.

The practical, operational cycle times computed by the models include delays that would occur normally during operating cycles. They do not include repair time or time spent by railcars or locomotives in idle backup status. These times are accounted for in the model by expanding operational time to an ownership time that represents the total amount of time equipment must be owned in order to provide the particular operational service time. Ownership time is derived by dividing operational time by an active-time parameter (the product of utilization and availability factors) or the proportion of total ownership time that equipment is in an operational status. A towboat, for example, is normally in operating status except during its annual dry-dock work. In comparison, active-time parameters for railcars must include not only repair time, but also the time some cars spend idle in backup pools. Values for active-time parameters are discussed later in this chapter. Ownership cost parameters applied to the calculated ownership time yield ownerships costs per cycle.

In general, the models produce costs for equipment, crew, maintenance and repair, fuel, and miscellaneous operating supplies. Maintenance and repair involves some capital costs for investment in replacement parts, which are leveled into the maintenance cost parameters. Miscellaneous costs not otherwise coupled to equipment performance are included as auxiliary costs, which are based on coal traffic. An example of an auxiliary cost in the transfer model would be the cost of delivering coal by truck to the loading point. The special characteristics of the individual models, their performance parameters, and default values are discussed below.

As stated earlier, the default values are industry averages and include neither profits nor overhead, although these and tax factors can be specified by users. Costs derived from the default values must therefore not be mistaken as full costs or tariff projections.

THE RAILROAD COST MODEL

This model uses the input route description to simulate the round-trip performance of the train and then applies cost parameters to produce the coal transportation cost over that route. At a minimum, the route description must include length, grade, and curvature of the track sections on the route. When appropriate, users can also supply minimum and maximum speed limits on sections of track and can specify points where crews are to be changed, helper locomotives are to be added or removed, and trains are to stop and wait (at a siding, for example). Users can change any default cost or performance parameter value. The general steps for preparing input data for the model are diagramed in Figure 5.

The model simulates the behavior of the loaded train over the route. Speed is determined by comparing the physical resistance of the train (calculated by taking into account rolling, aerodynamic, grade, and curvature resistance) and the tractive forces of the locomotive consist. Fuel consumption is derived from the effective physical work performed by the locomotives. Helper locomotives are automatically added to trains to accommodate steep grades, unless specified otherwise by the user. Fuel consumption and passage times are tabulated for use in the cost calculations. Equipment times associated with the loading and discharging at origin and destination are included. The trip times over the route, which include the impact of acceleration, deceleration, and intermediate stops, are estimated for both the loaded and the empty direction. The model essentially calculates fuel consumption and equipment hours over each section of the route; it then accumulates the equipment hours, fuel consumption, crew work days, and crew overtime and excess mileage costs that occur during the line hauls in both directions. The activities that take place along the route are printed.

The model then applies cost parameters to the equipment to compute line-haul costs. Costs per train cycle, per coal ton, and per coal ton-mile are estimated and printed. Finally, the values of both the input and the unchanged default parameters are printed for verification by the user.

Costs produced by the model are classified as line-haul costs and terminal costs. The former are incurred by the train between origin and destination; the latter are incurred when the equipment is being turned around at origin and destination. The model calculates these costs for either a unit train or a through train. In the unit-train option, the rolling stock is dedicated full time through train. In the unit-train option, the rolling stock is dedicated full time (allowing for maintenance and repairs) to the service of hauling coal from an origin to a destination and returning empty. In the through-train option, rolling stock is assembled to form a coal train upon

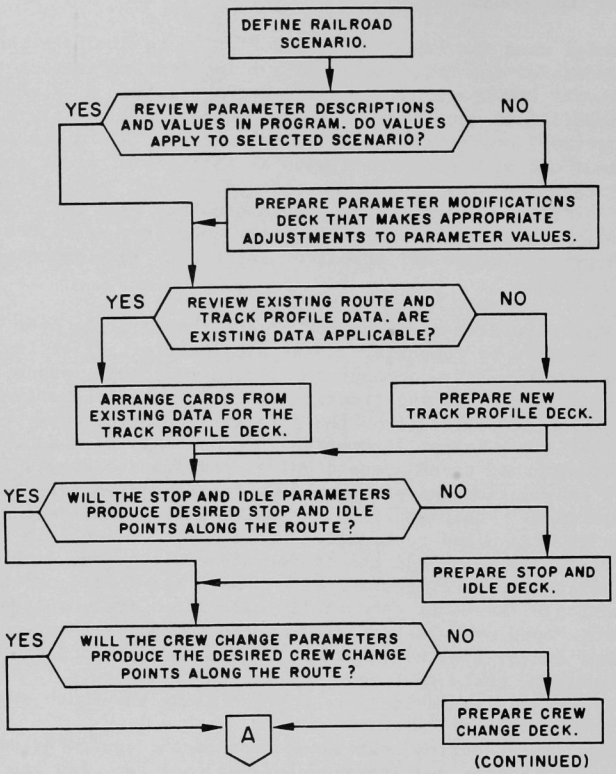
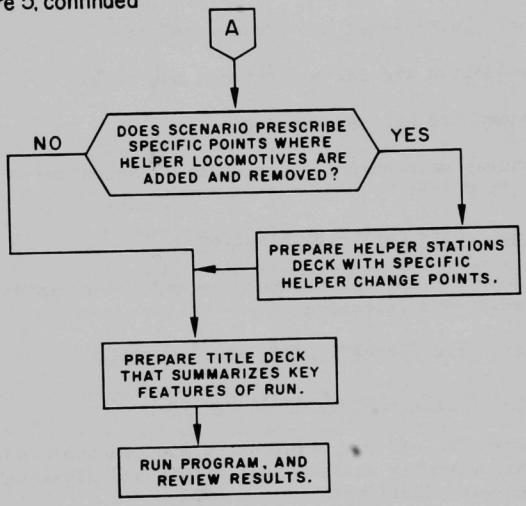


Figure 5 —APPLICATION STEPS
TRAIN COST SIMULATION PROGRAM

Figure 5, continued



demand. (Cars are picked up from loading stations and assembled into a train at the line-haul origin; the train moves to the line-haul destination; the train is broken up and the cars distributed to unloading stations; the train, reassembled, returns empty to the loading stations.)

Line-haul and terminal output costs (produced from the cost parameters as indicated in Figures 6 and 7) can be categorized as follows for the two options:

1) Line-haul costs, unit-train and through-train options

- o train crew, including supervision and fringe benefits
- o fuel, lubricants, and train supplies
- o locomotive and car maintenance and repair
- o locomotive and car ownership
- o roadway maintenance, incrementally dependent on the train weight

2a) Terminal costs, unit-train option

- o locomotive and car maintenance and ownership during loading and unloading
- o train crew during loading and unloading

2b) Terminal costs, through-train option

- o locomotive and car maintenance and ownership during train assmebly at line-haul origin and disassembly at line-haul destination
- o train crew during assembly and disassembly at line-haul origin and destination
- o auxiliary car pickup and delivery from and to loading and unloading stations

The total dollar value in a cost category is the sum of the relevant cost parameters multiplied by the activity bases computed in the simulated operation. Each cost parameter is intrinsically related to an activity base, as indicated by the terms used to describe the cost parameters. In an obvious example, the parameter "distance-based car maintenance cost ($/car-mile)" uses car-miles as a base and is itself used to produce maintenance costs.

COST PARAMETERS	COST CATEGORIES: Unit-Train Option		Through-Train Option		
	Loading & Unloading Train Crew Costs	Loading & Unloading Locomotive and Car & Maintenance and Ownership Costs	Assembly & Disassembly Train Crew Costs	Assembly & Disassembly Locomotive and Car Maintenance and Ownership Costs	Auxiliary Car Pickup and Delivery Costs
Time Based Locomotive Maintenance ($/locomotive hr)		X		X	
Locomotive Ownership ($/locomotive hr)		X		X	
Time Based Car Maintenance ($/car hr)		X		X	
Car Ownership ($/car hr)		X		X	
Basic Daily Crew Cost ($/crew day)	X		X		
Car Pickup & Delivery Cost ($/coal ton)					X

Figure 6

TERMINAL COST CATEGORIES AND COST PARAMETER RELATIONSHIPS

FOR RAILROAD MODEL

Figure 7

LINE-HAUL COST CATEGORIES AND COST PARAMETER RELATIONSHIPS

FOR RAILROAD MODEL

COST PARAMETERS	COST CATEGORIES: Train Crew Costs	Fuel Lubricants & Train Supplies	Locomotive & Car Maintenance Costs	Locomotive & Car Ownership Costs	Incremental Roadway Maintenance Costs
Time-Based Locomotive Maintenance ($/locomotive hr)			X		
Distance-Based Locomotive Maintenance ($/locomotive mile)			X		
Distance-Based Enginehouse Supplies ($/locomotive mile)		X			
Locomotive Ownership ($/locomotive hr)				X	
Time-Based Car Maintenance ($/car hr)			X		
Distance-Based Car Maintenance ($/car mile)			X		
Car Ownership ($/car hr)				X	
Basic Daily Crew Cost ($/crew day)	X				
Excess Mileage Crew Cost ($/excess mile)	X				
Excess Time Crew Cost ($/overtime hr)	X				
Incremental Roadway Maintenance ($/gross ton mile)					X
Diesel Fuel ($/gallon)		X			
Lubricants ($/gallon)		X			

The Default Values

The representatives of twelve railroads who reviewed our cost parameters generally expressed concern that the variable costs calculated in our model could be mistaken for full costs. Four made suggestions regarding variations in work rules, treatments of crew fringe benefits, and equipment maintenance costs, which were incorporated in the default parameters.

FREIGHT NETWORK EQUILIBRIUM MODEL SUPPLY AND DEMAND DISAGGREGATION METHODOLOGY

Robert E. Brooks, President, TERA Consultants, Inc.

ABSTRACT

Methods developed for disaggregating coal and non-coal commodity supplies and demands to the county level from regional forecasts are presented. These methods were developed by TERA for use by Argonne National Laboratory in evaluating the environment impact associated with conversion of 42 powerplants in the Northeast region form oil to coal. They form the basis for the database used by the FNEM algorithms for projecting O/D and link flows on a detailed rail and water network representation of the U.S. coal transportation system.

OVERVIEW OF THE FNEM MODEL

PURPOSES OF THE MODEL

The Freight Network Equilibrium Model (FNEM) was developed by a team consisting of Transportation and Economic Research Associates, Inc., Tera Consultants, Inc., and the University of Pennsylvania under contract to the Argonne National Laboratory. The work was funded by the Economic Regulatory Administration of the U.S. Department of Energy for the primary purpose of evaluating the impact of the proposed conversion of 42 powerplants in the U.S. Northeast from oil to coal. The model was to be used to identify sources of supply for these FUA powerplants, to project link and path flow volumes for both coal and non-coal commodities, to identify potentially congested links in the rail network, and to project modal shares for coal transport.

MODEL REQUIREMENTS

The development of this model is based on a number of requirements established by ANL and the study team.

The first requirement is that detailed forecasts of coal movements on the transportation network are needed in order to identify potential difficulties in the implementation of the Fuel Use Act in the Northeast. Second, these forecasts must be consistent with regional forecasts of coal supply and demand previously developed by Data Resources Inc. for ANL. Thirdly, the model should represent the actual behavior of decision makers involved in coal movement on the rail network as faithfully as possible. Finally, the state-of-the-art in mathematical programming algorithms should be used in solving the resulting large scale model.

STRUCTURE OF THE MODEL

To meet the requirements of the previous section the TERA team developed a system which is shown schematically in Figure 1. This figure shows the primary database and programs used in the FNEM system.

The model is driven by regional forecasts of coal supply and demand from the DRI National Coal Model over the 1980-1991 time frame and by the DOT projections of rail freight originations and destinations by rail traffic regions for 1990.

The non-coal commodity forecast is processed by a program developed by TERA for disaggregation of traffic region supplies and demands down to the county level. The program also interpolates projections for 1985 based on the 1978 actual and 1990 DOT forecast and extrapolates to 1991 as well.

Coal supply and demand forecasts from DRI are based on a breakdown of the continental U.S. into a relatively small number of regions. These regions are shown in Tables 1 and 2. To be of use in the FNEM model, these are disaggregated to the county level and then reaggregated to the desired level. Two implementations of FNEM have been developed so far. In the first version (the Northeast model), DOT transportation zones were used as the basis for reaggregation. In the second version (the National model), FRA traffic regions were used. The latter are based on post-78 BEA's and have been dubbed by TERA as traffic BEA's or simply TBEA's.

The final dataset required to run FNEM is the network representation of the rail and water transportation system.

This database must include information on physical location of trackage, distances, junctions, free speed, signalling and density which are parameters needed in specifying cost functions for each link.

For the Northeast model this network begins with the FRA rail network database. This database is processed by programs which reduce its size by eliminating "dummy and logical" links and nodes which are not needed by the FNEM model. These dummies were apparantly used to assist certain previously developed algorithms to solve network flow problems based on this network and to provide certain conveniences in using the database for mapping of the rail network.

To this reduced form rail network TERA has added additional links needed for coastwise movements of coal by water. Together the rail and water networks make up a detailed and reasonably faithful representation of the coal transport network in the U.S.

One additional network has been developed and implemented for the FNEM National Model. This network is based on the DOT/TSC Transportation Network Model (TNM). From TNM TERA has extracted the basic rail and water linkages and some of the access and intermodal transfer links. To these TERA has added additional linkages to coordinate this network with the TBEA

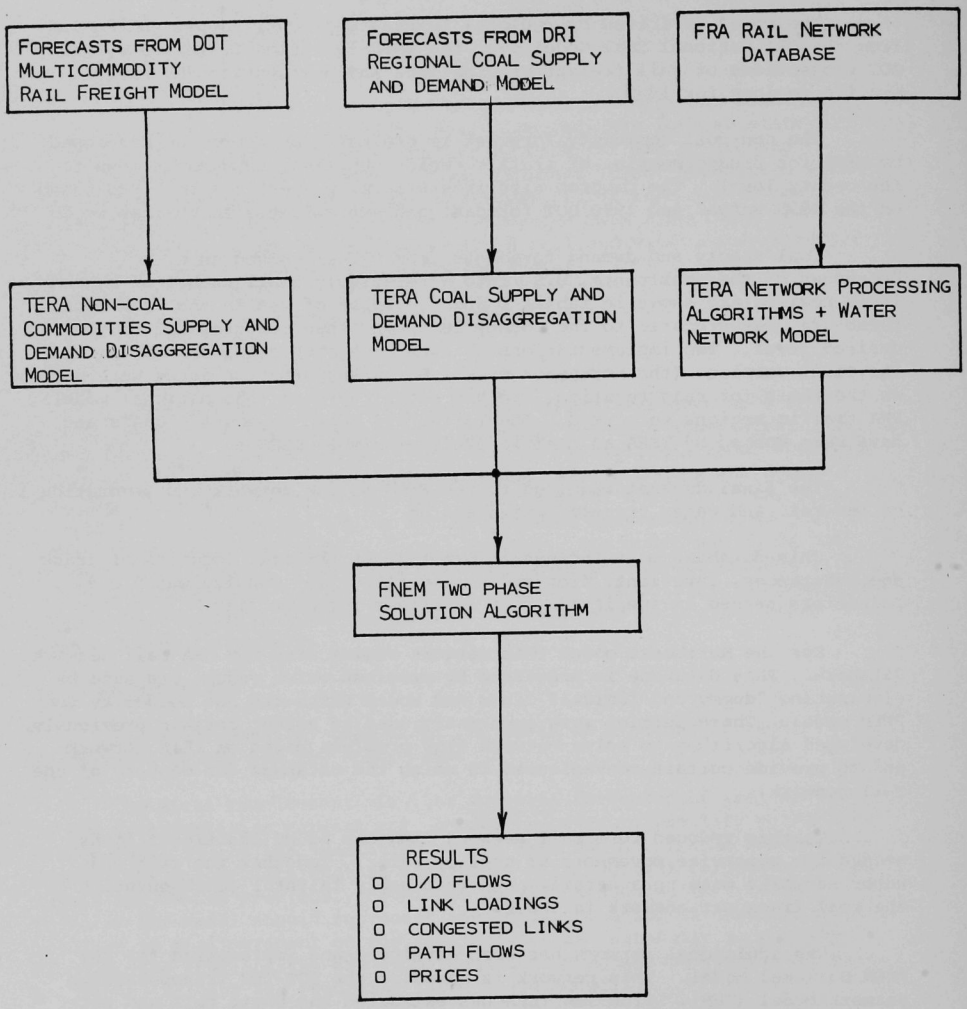


Figure 1 FNEM Model Structure

Table 1

DRI Coal Supply Regions

Name	DRI Code	Numeric Code	States
No. Appalachia	A	1	MD, OH, PA, WV(N)
So. Appalachia	B	2	AL, E.KY, TN, VA, WV(S)
Midwest	C	3	IL, IN, W.KY
Montana-Wyoming	D	4	MT, WY
Colorado-Utah	E	5	CO, VT
Arizona-New Mexico	F	6	AZ, NM
Lignite*	-	7	TX, ND

* Special region added by TERA.

Table 2

DRI Coal Demand Regions

Name	DRI Code	Numeric Code	States
New England	NENG	1	ME, NH, VT
Middle Atlantic	MATL	2	PA
South Atlantic	SATL	3	DC, VA, NV, GA, FL, SC, NC
East North Central	ENC	4	OH, WI, IN, MI, IL
East South Central 1	ESC1	5	AL, MS, KY, TN
East South Central 2	ESC2	6	MA
West North Central	WNC	7	CT
West South Central 1	WSC1	8	MD
West South Central 2	WSC2	9	DE
Mountain 1	MTN1	10	RI
Mountain 2	MTN2	11	NY
Mountain 3	MTN3	12	NJ
Pacific	PAC	13	All others

level supply and demand vector from the disaggregation routines.

These databases (detailed network, supply, and demand forecasts) are then fed into the two-phase FNEM solution algorithm developed by the University of Pennsylvania component of the team. This program first computes origin-destination flows, the decision variables associated with the shippers in the transportation sector. These are the decision makers who say how much they want shipped from here to there based primarily on tariff schedules. The model then takes the point of view of the carriers who decide the actual routing of each O/D shipment. These routings depend on actual costs of shipment and on congestion at various points in the network.

Output of this program consists of the O/D flows, link flows, and path flows. In addition the transportation costs and delivered costs are also computed. These outputs are processed by various report writer programs to reduce the output to tabular form for further analysis.

MODEL RESULTS

The FNEM models have been exercised over a variety of scenarios by ANL as a part of its environmental impact study of FUA conversions for DOE/ERA. Reports of its findings should be available from ANL in January of 1982.

FNEM DISAGGREGATION MODEL

The following sections describe the essential factors necessary for an understanding of TERA's disaggregation methodology developed for this study. This exposition is based on the FNEM National Model. The methodology developed for the FNEM Northeast Model is very similar except that its level of aggregation is the transportation zone rather than the traffic region (TBEA)

NON-COAL COMMODITIES

From the DOT Freight Forecast for 1990, O/D movements for 15 different commodities have been estimated at the TBEA level of detail. Call these movements x_{ijk} for commodity i between origin j and destination k. Then supply and demand for each TBEA (1-129) are computed using the following equations:

$$s_{ij} = \sum_{k=1}^{129} x_{ijk} \qquad (1)$$

$$d_{ik} = \sum_{j=1}^{129} x_{ijk} \qquad (2)$$

But since the x_{ijk} refer to 1990 flows, the s_{ij} and d_{ik} would also be for 1990. Since DOT has also provided 1978 values for each O/D movement from 1% Waybill statistics, one can interpolate for 1985 and extrapolate to 1991 using the average geometric growth rate between 1978 and the 1990 forecast

year. Let x_{ijk} be the flow value for 1978 of commidity i between origin j and destination k. Then the corresponding annual growth rate of r_{ijk} is given by:

$$r_{ijk} = (x_{ijk} = /x^{o}_{ijk})^{\frac{1}{12}} \tag{3}$$

and equations 1 and 2 (expressed for the years 85 and 91) become:

$$s^{85}_{ij} = \sum_{k=1}^{129} x_{ijk} \, r^{5}_{ijk} \tag{4}$$

$$s^{91}_{ij} = \sum_{k=1}^{129} x_{ijk} \, r^{13}_{ijk} \tag{5}$$

$$d^{85}_{ik} = \sum_{j=1}^{129} x_{ijk} \, r^{5}_{ijk} \tag{6}$$

$$s^{91}_{ik} = \sum_{j=1}^{129} x_{ijk} \, r^{13}_{ijk} \tag{7}$$

To compute county level non-coal originations and destinations, a disaggregation is performed based on county level value added in manufacturing (VAM). Using v_n for value added in manufacturing for county n and N_i for the set of all counties in TBEA i, the disaggregation model for non-coal commodities can be written as:

$$s^{85}_{in} = s^{85}_{ij} \, v_n / \sum_{m \epsilon N_j} v_m \tag{8}$$

$$s^{91}_{in} = s^{91}_{ij} \, v_n / \sum_{m \epsilon N_k} v_m \tag{9}$$

$$s^{91}_{in} = s^{91}_{ij} \, v_n / \sum_{m \epsilon N_j} v_m \tag{10}$$

$$d^{85}_{in} = d^{85}_{ik} \, v_n / \sum_{m \epsilon N_k} v_m \tag{11}$$

These county level values can now be reaggregated to any level which involves aggregations of counties (such as transportation zones for the Northeast model).

COAL SUPPLY/DEMAND DISAGGREGATION

The basic idea of the coal supply and demand disaggregation methodology is to convert regional level coal forecast data afrom the DRI coal model to the county level. This data can then be reaggregated up to the TBEA level (or any other level using counties as building blocks).

Supply Disaggregation

Disaggregation of DRI regional supply data to the county level is achieved in a manner similar to that in the Northeast model. Some differences are necessary, however, due to the fact that very high growth rates in some Western coal production areas are expected in comparison to the more developed North Appalachian region used in the Northeast model. Thus coal supply growth rates are allowed to be greater in the National model. In addition the average sulfur content of coals mined in each county is not restricted to be exactly the same as the average sulfur content of coal reserves in that county as in the Northeast model but is penalized if it is not.

The mathematical formulation of the supply disaggregation model is:

$$\text{Min} \sum_{i=1}^{n} f_i \, (YY_i + ZZ_I) + (SX_i + SY_i) + (P_i \cdot QT_i) \qquad (12)$$

s.t.

$$QT_i + YY_i - ZZ_i = Q78_i \cdot SUMP_k / SUMQ_k \qquad (13)$$

$$\sum_{j=1}^{6} X_{ji} - QT_i = 0 \qquad (14)$$

$$\sum_{j=1}^{6} A_j X_{ji} + SX_i - SY_i - SULF_i \cdot QT_i = 0 \qquad (15)$$

$$\sum_{i \in N_k} X_{ji} = PRI_{kj} \qquad (16)$$

$$QT_i \geq .5 \cdot Q78_i \qquad (17)$$

$$QT_i \leq RES_i / 20. \qquad (18)$$

$$QT_i \leq Q78_i \, (1 + .25)^{T-78} \qquad (19)$$

$$QT_i, X_{ji}, YY_i, ZZ_i, SX_i, SY_i \geq 0 \qquad (20)$$

Symbol definitions in this model are as follows:

f_i: weighting factor inversely proportional to $Q78_i$

YY_i: negative difference between forecast production and extrapolated production in county i (see discussion below)

ZZ_i: positive difference between forecast production and extrapolated production in county i

SX_i: negative difference between forecast and historical average sulfur content in county i.

SY_i: positive difference between forecast and historical average sulfur content in county i

P_i: 1978 average price of coal in county i

QT_i: forecast quantity of coal in county i

$Q78_i$: 1978 quantity produced in county i

$SUMP_k$: forecast production in DRI region k containing county i

$SUMQ_k$: 1978 production in DRI region k containing county i

x_{ji}: forecast production of sulfur class j in county i

A_j: average sulfur level in sulfur class j

PRI_{kj}: forecast production in DRI region k of sulfur class j

RES_i : reserves in county i

T : forecast year (78,85, or 91)

The significance of each expression in the model is described below.

Expression 12 is the objective function to be minimized. It contains the weighted sums of deviations from historical production trends in total quantity and sulfur contents and the mine mouth cost of coal produced. This objective function tends to promote production levels in accordance with historical patterns and to minimize total mine mouth cost of coal at the same time.

Equation (13) defines the positive and negative deviations between forecast and historical production levels.

Equation (14) defines total county production as the sum of county production in each sulfur class.

Equation (15) defines the positive and negative deviations between forecast and historical average sulfur contents.

Equation (16) is an identity which constrains total production of sulfur content j coals in counties i within region k to be equal to the DRI control total for that region.

Equation (17) limits forecast production to a minimum of 50% of historical level.

Expression (18) limits forecast production to a maximum of 5% of total reserves.

Expression (19) limits forecast production to a mazimum of 25% annual growth since 1978.

Finally, expression (20) simply states that all model variables are non-negative.

Note that the parameter values in (17) to (19) are arbitrary and can be set by the modeller to any particular values of interest to him.

This model is solved as a linear program using IBM's MPSX routine.

The results are written out to a file of county level production by year and by sulfur type.

A final step in this method involves a program which aggregates county level coal production up to the TBEA level for use in the National model.

Coal Non-FUA, Domestic Demand Disaggregation

For the national model the coal disaggregation methodology is designed to allow for great flexibility in the selection of DRI regional breakdowns. All that is required is that the DRI regions be aggregates of states and that there be no more than 13 such regions.

To set up the disaggregation method one first creates a data set containing the regional compositions for each DRI region. This simply consists of a list of state codes (FIPS) followed by a number from 1 to 13.

The demand disaggregation program is then invoked to estimate county level shares of each of the thirteen DRI regions in the national breakout. This is done by using historical levels of non-utility coal consumption from the EPA and projections of future coal generating capacity from FERC. These data are first aggregated to the county level. Then all county level projections in each of the 13 regions are summed to get regional totals. Dividing county values by regional totals gives an apportionment fraction for that county which is then used to factor DRI non-utility and utility (non-FUA) regional forecasts for 1985 and 1991 down to the county level.

These county level demands are then added together and aggregated up to the TBEA level to give total domestic non-FUA coal demand to be used in the national model.

FUA Demand Disaggregation

FUA demands by powerplant are estimated and forecast on the basis of projected utilization of coal by each plant within a given DRI region. Thus if two or more plants are in the same region, the FUA demand in that region is allocated to the plants according to their expected consumption in that year which is also based on their coal fired capacities. It is assumed that sulfur category percentages for each FUA plant in a particular DRI region are the same percentages as for total demand in that region. Thus both the national and the Northeast model include each of the 42 conversion candidate powerplants as distinct nodes with their own demands for each of the six coal types.

Export Demand Disaggregation

In an exactly analagous manner, export demand at 10 ports around the country is projected using estimated capacity in place of estimated consumption at FUA plants. Where two or more ports lie within a single DRI region, capacity is used to apportion that regional export demand to individual ports.

CONCLUSION

This report has summarized work performed by TERA in the development of disaggregated supply and demand vectors for the FNEM national and Northeast models. The subject of disaggregation is an important one since very frequently modelers find themselves in a position where level of regionality of various components of their model and database do not match. Techniques for aligning these data in a rational manner are therefore highly desirable.

In this paper such methods for disaggregating coal as well as non-coal projections to the county level have been described. These methods have been successfully employed by ANL in its exercise of the FNEM model for evaluating the environmental impact of the proposed FUA conversions in the Northeast.

COMPONENTS OF THE NATIONAL COAL MODEL AND USE OF AN AUXILIARY TRANSPORTATION MODEL

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In a way, I am here under false pretenses, I have only been working with the Data Analysis and Forecasting Branch of the Coal Division for about a month. My main assignment is to improve the National Coal Model, or NCM, but I don't yet know a great deal about coal and only a bit about the model. So I am here more to gain knowledge than to impart any wisdom or experience.

Of course, I am not a complete stranger to modeling in general or to Department of Energy (DOE) models in particular. I worked intensively on the Midterm Energy Market Model (MEMM) for over ten months before moving to my present assignment and had looked somewhat more superficially at other models (including the NCM) during the year preceding that. Before joining the Energy Information Administration (EIA), I was at the International Institute for Applied System Analysis, known as IIASA, near Vienna, for over four and a half years and came in contact with many models, most notably the supply and demand models used in their extended Energy Program. I cannot but be struck by the difference in emphases between IIASA and EIA. At IIASA, it was on long-term dynamic considerations; at EIA it is much more on detailed infrastruture in the short-term.

In the case of MEMM, a great deal of complexity is introduced by the handling of transportation. MEMM could be broken down into its various submodels quite easily except for transportation and, to a lesser extent, utilities, which permeate a large part of the model structure. When dealing with coal as the main subject, the problem of transportation becomes monstrous. Although it is represented in the NCM, it is done with what are essentially oversimplifications. It has been, and still is, intended that a transportation model be used in conjunction with the NCM. This leads to two critical questions: what transportation model, and how closely should it be coupled? I have no ready answer to the first and only a preliminary opinion on the second, namely that the coupling should be very loose. However, this may not accomplish the purpose.

I was originally instructed to report on a study that was done for the Coal and Electric Power Branches by Charles River Associates, Inc., (CRA). However, since CRA will report on that study themselves I will, instead, describe the NCM and then say something on our needs for a supporting transport model and what I believe it should do.

To facilitate the evaluation of issues concerning coal, the EIA maintains the NCM, a highly disaggregated representation of coal supply, transportation and demand. This computerized model is designed to project the future levels of U.S. coal production, transportation, consumption and prices, and to permit analysis of coal-related issues. Using standard LP formulation, it generates an equilibrium solution that balances coal supply and demand requirements by coal type for each region. The objective is to minimize the total cost of satisfying specified coal and electricity demands. Nearly 20,000 activities include building and dispatch of different types of power plants, transportation of coal by different modes, and interregional transmission of electricity. Approximately 3,000 constraints represent such conditions as limits on reserves, long-term contracts, transportation capacities, sulfur emission limits, transmission links and power plants construction.

The NCM projects and provides detailed output reports on all key attributes of the coal and electric utility industries by region and by target year. At present, the model provides projections for the years 1985, 1990 and 1995. For the coal industry, projections are provided for production by method of mining, consumption by sector, supply prices, and coal distribution and transportation quantities and costs. For the electric utility industry, projections are made of generation, capacity utilization and expansion, pollution control equipment requirements, pollutant emissions, fuel use by coal and non-coal type, and costs of capital, fuel, operations and maintenance, and pollution control.

Activities may be grouped into five major components of the NCM: electricity demand, non-utility demand for coal, electricity generation and transmission, coal transportation, and coal mining and preparation. The electricity demand component takes into account base, intermediate, seasonal peak, and daily peak load requirements in each of the 44 demand regions. Electricity demand is treated as inelastic with respect to its own price and estimates of the loads are derived exogenously.

Non-utility demand for coal consists of six sectors: metallurgical, export, industrial, new industrial, residential and commercial, and synthetic fuels. The levels for these demands are also specified exogenously and they are treated as

inelastic with respect to coal price. The demands are satisfied by reducing the quantity of coal available for electric utilities at a given price.

The electricity generation technologies represented are steam and combustion turbines, combined cycle power plants, hydroelectric plants, and nuclear reactors. Turbines may be fired by coal, gas, distillate oil, or residual fuel oil. Hydroelectric may utilize either pondage or pumped storage. Plants are assigned to each load category in order of increasing cost per kilowatt-hour subject to restrictions on plant-load combinations. Where coal-fired plants may be and are operated in other than base load, additional operating costs are explicitly modeled. This component also models the impact of differing SO_2 emission standards. For example, if an existing plant is retrofitted with a scrubber, additional capital and O and M costs are incurred and the loss of capacity and increased fuel requirement for the scrubber are also taken into account.

Coal stocks in each demand region are differentiated among 19 coal types. Eighteen are grouped into three ranks -- bituminous, subbituminous, and lignite -- each of which comprises six sulfur levels. The 19th type is metallurgical coal. Conversion of coal from physical units of supply to Btu's, in which regional stocks are maintained, is done by the transportation component. Also the 40 types of mined coal are reclassified into the 19 types here. Coal is assumed to be transported from a centroid in each supply region to a centroid in each demand region over a specified route. Transportation costs are measured as a per-ton charge and are not differentiated by transportation mode.

Finally, there is the mining and preparation component of the model. There are 31 supply regions. Price-sensitive supply curves are specified exogenously, as generated by the Reserve Allocation and Mine Costing submodel (RAMC). The supply of a specific type of coal in a supply region is given as a function of the minimum acceptable selling price (MASP). These are multi-step functions.

With this much detail, and there is more that I haven't mentioned, it is easy to see why the LP is so large. Of course, a considerable amount of detail is built into the coefficients by the generator which gets the information from tables of various kinds. Thus the LP is really selecting from multiple choices for many options. Perhaps I should point out that the model is not really dynamic. The different target years are based on precomputed inputs; in fact the 1990 and 1995 cases are simply revisions of the 1985 case which are solved starting with the optimal 1985 basis. These revisions do, however, take into account the 1985 solution.

The NCM is operated by means of a SUPERWYLBUR macro which has four options: G for generate (i.e., the 1985 model), L for solve the LP, P for reporting a solution and also forwarding information for revisions, and R for revising the model to either 1990 or 1995. These options can be combined as GL, RL, LP, GLP or RLP. Numerous files are required or generated. For the generate step, 8 input files are used, representing the various assumptions of the case. I won't go into further details now since this is an area which I expect to be examining further in the near future.

In spite of its size -- about 3,500 rows, 19,000 columns, 90,000 elements, plus ranges and bounds -- running time for the LP is not excessive. The standard LP software we have today, running on the biggest machines, can manhandle such monsters in a surprisingly short time. (When I think back nearly 30 years when we were first developing LP, it seems unbelievable.) Of course, solution time is not the only measure; such systems utilize vast amounts of machine resources. Although the NCM is now automated for use, I regard it as still rather clumsy operationally and quite so internally. This is an area which I intend to attack and am confident that a great deal can be done to streamline the overall complex. Indeed, I am anxious to get started since this is the kind of work I enjoy. But before I can fully plan all that needs to be done or gain a sense of confidence in the final effectiveness, the question of adequate handling of transportation must be resolved.

In their report, CRA laid out some of the fundamental problems in modeling the coal-transport sectors. That is, even ignoring size and profileration of detail, there still remain problems. For one thing, coal transport and market production are truly simultaneous and it is not possible to view one sector as cause and the other as effect. This can be appreciated by considering the decision process of a major utility selecting a site for a major new plant. If the choice they make affects capital investment in the transport network, this will affect decisions for follow-on plants by the same or a different utility.

CRA also points out that because of the changing nature of determinants of market interaction, certain kinds of economic analysis simply do not apply, for example, econometric studies using historical data or whenever long-run equilibrium must be assumed. It also cannot be assumed that unobserved factors remain constant in effect. For example, regulatory and environmental issues arise and cause substantial changes. It would be difficult to untangle the regulatory and price effects in an historical econometric study. They point out further that the most difficult conceptual issue that must be treated in an integrated model

is the indeterminacy in expected equilibrium price and production outcomes. To build a model, a specific rule for resolving this indeterminacy must be specified, or at least a mechanism for specifying it for each case must exist.

Let me point out that the NCM does produce an equilibrium. Its weakness is that transportation costs are not only exogenous -- which is probably unavoidable in light of the difficulties outlined above -- but they do not reflect either mode or the effects of demands generated by the model solution, nor do they properly account for capital investment. It seems that the use of scenarios combined with a grand iterative scheme is the only practical approach to achieving more realism and credibility in results. That is, even though we are not really planning, we must make assumptions very much as though we were, with some sort of faith that our great economic engine will in fact do the necessary things. Viewed differently, we should be able to point out where capital investments, say, would be beneficial and profitable. But to make such a modeling complex practically usable, we need something better than a transportation model which takes 90 minutes of CPU time and as many supporting files and programs as the main model itself.

I believe what we need is a much simpler transportation model, not aggregated in the ordinary sense, but ignoring details which have no bearing on the results sought. For example, questions of preferred routings or carrier options to use own-line routes are really of no importance in a situation of limited capacities. So-called shipments are really abstract aggregates and a single routing will probably not accommodate such a total anyway. If actual shipper A wants his goods to go by route X, that is a matter to be decided at a finer level of resolution than we are interested in.

It seems to me that we have, essentially, a four dimensional complex on which numerous constraints are defined. These constraints are mostly linear plus a few special side conditions. This, of course, is for a static situation. The complex consists of nodes -- both origin and destination --, modes of transport, and types of load. The modes of transport implicitly define arcs. Associated with each node-mode-load combination and each arc-mode-load combination are three or four parameters: capacity, cost, elapsed time and, perhaps, energy usage. Except for capacity, functions of these parameters should not be associated with a single node or arc but with a link. Let me explain in a little more detail.

Let:

i index a source node
j index a destination node
k index the mode, i.e., kind of transport
l index the type of load
Ni be a node
Bij be an arc between adjacent Ni and Nj

Now a link is a triple Ni-Bij-Nj. Each component has a capacity or set of capacities, Ai.kl, Aijkl and A.jkl over the existing k,l for i and/or j. Note that the capacity without regard to load type might be less than the sum for different types of loads, that is

$$Aijk < Aijkl + Aijk2 + \ldots$$

since different types of loads might be carried in the same mode.

Costs for transport are really associated with a link. Each individual cost component, say Cikl for a node and Cijkl for an arc, must be determined in some way but the cost for traversing a link is some function of them, G(i,j,k,l)=f(Cikl,Cijkl,Cjkl) which is not necessarily a simple sum. For example, it must be defined in such a way that costs associated with entering node Ni are not included in leaving Ni. Similar considerations hold for time and energy functions, say T(i,j,k,l) and E(i,j,k,l). The total disutility function for a link is then, for some f,

D(i,j,k,l)=f(G(i,j,k,l),T(i,j,k,l),E(i,j,k,l)).

One would not expect that these values would change significantly for capacities which are fairly heavily loaded. Hence, assuming a reasonably loaded network, the D-functions can be precomputed for all meaningful links, i.e., usable (i,j,k,l) combinations.

A route is a chain of interlocking links where Nj of one link is Ni of the next. Access nodes are special in principle but need no special treatment. An origin access would never be an Nj and a destination access would never be an Ni. However, any node might be an origin or destination.

A change of mode at a node (transfer node such as rail to barge) can be treated in either of two ways. The node considered as a transfer node may be treated as a separate node. This may lead to some complication in accounting for capacity. The other way is to have a dummy arc, and hence link, from the incoming mode to the outgoing mode. This is probably better since all parameters are readily accounted for. Either way, there is a discontinuity in the meaning of the k,l combination.

What one really has then is a multi-commodity, multi-mode transshipment problem with side conditions. Each node through which freight passes can be considered as a warehouse or transshipper. This still implies a formidable problem. Let us see if it can be simplified further.

Note that mode-load combinations are important in only two ways. One is to assemble the appropriate data and compute the D-functions. Suppose this is done. Presumably, this is a quick computer run although effort must be devoted to maintaining the data base and it must be possible to introduce scenario changes representing new capital investment.

The other way k-l combinations are used is to assign routes to shipments. A shipment cannot traverse a link which does not have its l-index. But if a link does have its l-index, it must have an appropriate k-index, else the link would not exist. The importance of the k-index is for capacity constraints. However, an arc capacity involves only one mode by definition. Thus every link is limited by its arc capacity. The difficulty arises with node capacities, and in at least two ways. First, a node capacity, even for one mode, will often be larger than the capacity of any one link entering or leaving it but not as great as their sum. Second, total capacity may be a function of all nodes which it can accommodate. There is a third possibility, that capacity might also depend on load types but this can probably be ignored. If there is sufficient mode capacity, there should be sufficient load type capacity. Possible exceptions, such as limited facilities for coal car to ship loading at a port, can probably be avoided by reducing the mode capacity, or by defining two ports, i.e., a transfer node and dummy arc.

Now what we want to minimize is the total disutility of shipments and these depend only on the l-index of each link used. The aggregate of shipments which are possible depend on capacities: first, on arc capacities which are simple or can be assumed so, and second on node capacities which may not be simple sums. I have not yet figured out how to solve a formulation such as I am implying but it does not seem beyond reach. Let us suppose a technique is available and computer time for obtaining a solution is modest. What could we do then? Let me sketch the steps which would seem reasonable.

First, we must assume that initial supply and demand quantities are available. Presumably these will be in terms of NCM centroids. If not, they must be re-aggregated in much the way that Argonne National Laboratory did in their Northeast Regional Environmental Impact Study. To just

what level the initial disaggregation should be carried is a matter to be decided but considerable study of this question has already been done and programs to do it even exist. Starting with the centroid quantities, one could do the following:

1. Compute the D-functions to reflect the desired scenario.

2. Solve the transport problem.

3. The shipments would be in terms of NCM centroid-centroid links, each with quantities and costs. The quantities would be recorded and the costs converted to per-ton costs between supply and demand centroids to be forwarded to the NCM.

4. The NCM would be run and then three sets of quantities compared: the original and final supplies, the original and final demands and the link quantities obtained from the two models. The outcome gives one of three results: (a) agreement is good enough; (b) new supply and demand quantities should be fed back to the transport model and the process repeated from step 2; or, (c) an anomolous situation exists which needs investigation.

Capital investment as such would be a side calculation. Capital costs and return would be used to inflate the original D-functions. The results of the transport model, e.g., marginal prices, might also be used to detect possible discrepancies in the centroid definitions.

This is a preliminary outline and I have not thought through all the details. But something of this nature seems to me to be what is needed. Playing two optimization models against each other should give more information than two disparate ones. In any case we need a model which is more easily solvable than any I have seen so far. Even a big LP is faster than these intricate transport models.

THE NATIONAL TRANSPORTATION PLANNING MODEL AND ITS USE FOR COAL TRANSPORTATION FORECASTING

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ABSTRACT

The National Transportation Planning Model is a methodology developed for the U.S. Department of Transportation and used in developing data and recommendations for the Trends and Choices Report, the Brunswick, Georgia-Kansas City, Missouri Multi-Mode Route Study, and the National Transportation Policies Through the Year 2000 Report prepared by the National Transportation Study Commission. (1,2,3) Of particular concern in both the Trends and Choices Report and the NTPSC study, was the effect of coal movement on the future transportation system, especially Western Coal.

The methodology includes a data base developed by the Transportation Systems Center in 1972 and updated to 1975 which documented 161,000 commodity flows by origin and destination BEA region, mode and commodity (based on 19 categories). This data base was used as a basis for several studies, which included forecasts, a parallel resistance modal split model, and assignments to networks, including detailed coded highway, rail and waterway networks and simplified "spiderweb" air and pipeline networks. The process was used to analyze network capacity problems and alternative solutions, to evalute a number of corridor alternatives and to explore three alternative economic scenarios.

INTRODUCTION

The National Transportation Planning model (NTP) is a methodology developed for the Office of the Secretary, U.S. Department of Transportation, to evaluate the impact of future change on the national intercity transportation system. It forecasts the movement of people and goods, by several modes, between BEA areas, areas tied economically to a city defined by the Bureau of Economic Analysis of the U.S. Department of Commerce.(4)

The model outputs flow on intercity networks, and aggregate statistics about that flow, including shipping costs, time costs, energy utilization, environmental impact, safety measures, capital requirements, tons shipped, ton miles and passenger miles, all by commodity and mode. Model output can be assigned, plotted, or tabulated, using standard urban transportation planning procedures (UTPS or PLANPAC). Thus, the NTP Model can be used to explore a myriad of alternatives, and see their impact, for passengers and freight, on financial, environmental and

energy issues, on a macro scale of the nation or the micro scale of an individual region or network link. It is best as a comparison device, comparing changed conditions to a baseline, relating the policy alternatives to the status quo.

The transportation of coal has always been a major element in the analysis using the NTP Model. Coal accounts for 11 percent of the commodity tonnage in the 1975 data base, and is the major commodity that is expected to change, dramatically, in the magnitude and orientation of flows, as Western coal develops and replaces petroleum for power generation. In the Trends and Choices study, forecasted Western coal was distributed assuming slurry coal pipelines and using the rail network. In the NTPSC study, three alternative energy production scenarios were used to examine the impact on the transportation network, including varying amounts of Western coal.

BASE DATA

COMMODITY FLOW

Historic data on commodity flows is a basic element of the NTP methodology, which determines modal split based on historic modal split and changes in the time and cost factors affecting modal split. Currently, the historic data consists of a data base on commodity flows among the 173 BEA regions of the United States which has been assembled by the U.S. Department of Transportation, Transportation Systems Center. This data base contains about 160,000 records of 1972 commodity movements. The freight data are classified according to 19 commodity classes (See Table 1.) at approximately a two-digit level of commodity classification.

The principal components of this freight data base are:

- Rail - the one percent Interstate Commerce Commission way-bill sample.
- Waterway - the U.S. Army Corps of Engineers 100 percent sample survey of all ships entering or leaving a port for both foreign and domestic traffic.
- Truck - the Census of Transportation conducted by the Bureau of the Census and the Survey of Fresh Fruit and Vegetable Unloads conducted by the U.S. Department of Agriculture. The data base distinguishes between private and regulated trucking.
- Pipeline - a model which synthesizes domestic pipeline movements within the United States to assemble pipeline flow data.

TABLE 1

COMMODITY GROUPS

CODE	DESCRIPTION
1	Farm Products, Field Crops
2	Forestry & Fisheries Products
3	Coal
4	Petroleum
5	Metallic Ores
6	Non-Metallic Minerals
7	Food & Kindred Products
8	Textile Mill Products & Apparel
9	Manufactures Not Identified in CCT Survey
10	Chemicals & Allied Products
11	Lumber & Furniture
12	Machinery (Non-Electrical)
13	Electrical Machinery
14	Transportation Equipment
15	Not Used
16	Paper & Allied Products
17	Petroleum & Coal Products
18	Primary Metal Products
19	Fabricated Metal Products
20	Miscellaneous Products Not Elsewhere Classified

- o Air - data from the Census of Transportation conducted by the Bureau of the Census and other data from the Civil Aeronautics Board to assemble the air flow data.

These data were assembled in 1972 and adjusted in 1975. They vary in quality significantly according to the mode and source of the data. At this time, it is felt that the weakest link in the base year data base relates to the movement of exempt commodities by truck.

NETWORKS

A series of base year networks are available, in computer coded format, for all modes of person and goods movement. The networks are all based on the 173 BEA zone system.

There are networks with link characteristics of speed and length for highway, rail and waterway modes. Air and pipeline networks are spider (centroid-to-centroid), with generated speeds and distances.

Highway. Highway networks include the entire Interstate and most major non-interstate through routes, except for those directly parallel to the Interstate. Major parallel routes greater than 50 miles from the Interstate are generally included, when such routes connect BEA centroids to the network.

Speeds are generally coded at 55 miles per hour on Interstates and Interstate level highways (four lane divided, limited access), at 50 miles per hour on other divided highway and at 40 miles per hour on two lane roads. There are exceptions, particularly around urban areas in the Northeast where a 5 mile per hour drop is coded.

Rail. The rail network includes most of the trunk line railroads. It includes many of the parallel, competing rail lines and provides a variety of paths between BEA's. Rail speeds vary from 20-60 miles per hour, based on available data from specific railroads, as assembled by the Federal Railroad Administration.

Waterway. The waterway network is much simpler than either the highway or rail network. It does not link all BEA's, although some of the more inland areas are connected through fairly long centroid connectors. Speeds are between 3 miles per hour (on canals and shallow rivers), 6 miles per hour on intracoastal waterways and 8 miles per hour on the Mississippi. Twenty mile per hour speeds are coded for Atlantic to Gulf and other trans-oceanic travel.

Pipelines and Airways. There are no coded networks for pipelines and airways. The distances are calculated from spider networks (centroid-to-centroid), a circuity factor is applied, and, for air, an average speed is applied. No speeds are used for pipelines, since they are continuous.

Like the commodity flow data, the network data varies significantly in quality, and is also current to 1975. Major improvements could be made in coding, including capacity constraints, greater detail on the waterway network including representation of the locks, and coded networks for natural gas, crude petroleum and petroleum product pipelines. For the freight movements, a spiderweb aviation network is adequate.

STEPS IN THE PROCESS

REGIONAL DISTRIBUTION

For Trends and Choices and the Brunswick, Georgia-Kansas City, Missouri study, the NTP Model was used with externally generated forecast distributions. For NTPSC, COMSIS developed a distribution methodology, based on tons shipped/dollar earned factors, using the OBERS projections. (5) This method was modified for energy commodities, including coal, to accommodate the energy commodity productions forecasts provided to NTPSC by Stanford Research, International. SRI forecasts were disaggregated to BEA levels and distributed to consumption regions based on OBERS population projections. These distributions were done for 1985, 1990, 1995, 2000 and 2005. (6)

For passenger distribution, COMSIS has developed a national trip generation and gravity model, using population and income as the independent variables, and producing a 173 zone trip distribution.

MODAL SPLIT

The National Commodity Modal Choice Model was developed by the U.S. Department of Transportation and is essentially a variant of the model developed by P.M.L. Pearson as part of his doctoral dissertation; Pearson later refined and applied the model under Department of Transportation sponsorship. (7) The cost function used in the model was developed by Herbert O. Whitten and Associates. The computer software and application package was developed by COMSIS Corporation.

The modal choice model assumes that each mode can be characterized for each commodity and each origin-destination pair, (I,J), by a resistance Z^c_{IJm},

Z^c_{IJm} : the resistance of mode m for commodity c on the O-D pair (I,J).

Then if Q^c_{IJm} is the flow of commodity c from origin I to destination J by mode m, the assumption is made that:

$$Q^c_{IJ1} \quad Z^c_{IJ1} = Q^c_{IJ2} \quad Z^c_{IJ2} = \ldots = Q^c_{IJM} \quad Z^c_{IJM}$$

where M is the number of modes (or modal combinations) serving the O-D pair (I,J). If we denote the total flow of commodity c from I to J by Q^c_{IJ}; then:

$$Q^c_{IJ} = \sum_{m=1}^{M} Q^c_{IJm}$$

and the modal shares are readily found to be:

$$\frac{Q^c_{IJm}}{Q^c_{IJ}} = \frac{\dfrac{1}{Z^c_{IJm}}}{\displaystyle\sum_{k=1}^{M} \dfrac{1}{Z^c_{IJk}}}$$

That is, the modal shares are functions of the M modal resistance describing the O-D pair. The Z's are assumed to be given by:

$$Z^c_{IJm} = K^c_{IJm} \left(C^c_{IJm} + \alpha^c T^c_{IJm}\right)$$

where:

C^c_{IJm} : transportation cost per ton for commodity c in mode m, measured in dollars/tons

T^c_{IJm} : time in transit for commodity c on mode measured in days

α^c : value/ton/day measured in dollars/ton/day

K^c_{IJm} : calibration constants that reflect the influence of variables other than time and cost on shipper choice of mode

From the definition it is clear that $\alpha^c T^c_{IJm}$ has the dimensions dollars/tons and thus the factor α^c converts times into unit costs commensurate with the other cost term in the resistance equation.

The Impedance Model is currently calibrated for 19 commodity classes, and programs are presently available for application of the model.

Application of the Model. The basic input to the model, as it has been applied, is the file of individual commodity flows between each of the 173 BEA areas. The model will re-allocate the modal share for a given BEA-BEA movement for a given commodity under conditions of changing transport cost and/or transport time. Only those modes that transport a given commodity between two BEA's will be considered as potential modes in the re-allocation process. Networks for each mode are also input.

The basic modal split procedure examines a specific origin-destination movement for a specific commodity. For each mode (i) involved in the specific movement, a shipping impedance (Z_i) is computed:

$$(1) \qquad Z_i = (\$_i + \alpha t_i)k_i$$

where:

$\$_i$: shipping cost in \$/ton and represents line haul, terminal, and other identifiable costs. These costs vary by mode, commodity, geography and spatial separation of origin and destination. Actual distances from a coded network can be used where available, or circuity (C) multiplied by airline distance (D).

t_i : time in transit and can be time from a coded network or time internally derived by applying an average modal speed to distance traveled. In either case, a terminal delay by mode is added to the line haul time to arrive at time in transit.

α : measure of each commodity's value expressed in dollars/ton. Applying an interest rate which is user-variable, this value is converted to dollars/ton, which is consistent with the $\$_i$ term.

k_i : calibration term which can be thought of as a factor which accounts for shipper's other perceived costs that are not included in the above terms. The calculation of k_i is described below and is performed once for each observation using the base flows and default cost tables. For purposes of this discussion, an observation is the movement of one commodity code between a BEA-BEA pair by all modes that service that movement.

The components of $\$_i$ and t_i are shown on Table 2.

TABLE 2

USER VARIABLE PARAMETERS -
NATIONAL COMMODITY MODE CHOICE MODEL

Variable	Description	Mode[1]
F	Variable Terminal Shipment Cost/Ton	R
T	Variable Terminal Cost/Ton	All
I	Density Multiplier	MC,PT,A
D	Actual Miles	All
M	Variable Line Haul Shipment Cost/Ton-Mile	R
L	Variable Line Haul Cost/Ton-Mile	All
B	Loss and Damage Payments/Ton	R
J	Constant Terminal Cost/Ton	R
K	Constant Line Haul Cost/Ton-Mile	R
H	Density Multiplier	R

The above variables combine to determine $\$_i$ as follows:

F + T*I + D*(M + L) + B + J + D*K*H

TD	Terminal Days	All
TT	Time in Transit (Days)	All
A	Commodity Value ($/Ton)	All
IR	Annual Interest Rate	All

The above variables combine to determine αt as follows:

(IR/360)*A*(TD + TT)

---

[1]Modes: R = Rail
MC = Motor Carrier
PT = Private Truck
W = Waterway
P = Pipeline
A = Air freight

For a typical case of three competing modes, the formulation would appear as follows:

(2)
$$Z_1 = (\$_1 + \alpha t_1)k_1$$
$$Z_2 = (\$_2 + \alpha t_2)k_2$$
$$Z_3 = (\$_3 + \alpha t_3)k_3$$

(3)
$$Q_1 Z_1 = Q_2 Z_2 = Q_3 Z_3$$

where:

Q_i : quantity of goods shipped by mode i

The values of k_2 and k_3 can be determined by setting k_i = 1 and combining relationships (2) and (3).

(4)
$$k_2 = \frac{Q_1(\$_1 + \alpha t_1)}{Q_2(\$_2 + \alpha t_2)}$$
$$k_3 = \frac{Q_1(\$_1 + \alpha t_1)}{Q_3(\$_3 + \alpha t_3)}$$

Having obtained values for k_i for each mode, the user can vary any or all of the cost components, calculate new Z values, and thus derive a new modal split.

(5)
$$Q'_i = \frac{1}{Z'_1} + \frac{1}{Z'_2} + \frac{1}{Z'_3}$$

For Trends and Choices, slurry pipelines were added for Western coal movement. This required creation of "dummy" movement records for coal from the BEA's in the West to logical destinations, with reasonable estimates of coal shipped, in the 1975 data base. These records made coal slurry a possible mode in future years, when increasing shipments and changing cost relationships made it more attractive. The resulting forecasts appeared reasonable.

The computer software allows the user extensive flexibility to vary the components of the cost function to examine various alternative conditions. Typical applications to date include evaluating policy changes related to: (a) increases in truck sizes and weights; (b) addition of a waterway user charge, and

(c) changes to network links to improve service by a specific mode. Output from the process includes summary tables by commodity and mode for:

- shipping/cost
- time cost
- energy consumed
- pollutants
- fatalities
- investment in system
- tons shipped

In addition, detailed records are produced to allow construction of a commodity flow matrix by mode which can be assigned to various computerized networks and graphically displayed.

ASSIGNMENTS

The results of the modal split model are a new set of 160,000 shipment records, one for each modal shipment by commodity between BEA's. These records can be merged into a 173-by-173 trip table, for each commodity, or for all commodities, for each mode. These trip tables can then be assigned using the urban transportation planning assignment programs, either LOADVN from PLANPAC or UROAD from the UTPS package (8,9).

These assignment programs provide a great deal of flexibility in assigning flows to networks. UROAD, for example, will permit all-or-nothing assignment, where the minimum impedance path is selected, and all commodities using that mode between that BEA pair are assigned to it. Incremental assignments can be done, where impedance (which is a user specified function of time, distance and cost) is adjusted after each incremental assignment. A variety of capacity restraint techniques can be used.

The assignment results can be plotted, producing annotated link plots or bandwidth plots in a variety of color combinations and scales, to graphically illustrate assignment results. The results of alternate assignments can be plotted together for ease of comparison. All of the techniques which have been developed for urban planning and systems analysis can be applied to the problems of national freight movement.

COAL APPLICATIONS

As described above, much analysis has already been done, for Trends and Choices and NTPSC, of the question of Western coal and its transportation impact. The 1975 data base, based as it is on 1972 data, does not include major movements of Western coal, although Midwestern and Appalachian coal are well represented. However, forecasts of future coal production all include major production in the West. With most of these future movements, there are, in the 1975 data base, small rail movements that serve as a basis for future modal split calculations. There are no movements of Western coal by other modes. The way the modal split model works, if no movements exist in the data base, for a given mode and commodity between two BEA's, there is no opportunity for flow to be shifted to that mode due to changing time and cost factors in the future.

To get around this limitation, for the analysis of Western coal, and especially for the analysis of coal slurry pipelines, the model was "fooled" with dummy records using that mode for a reasonable estimate of flow based on the capacity of the pipeline. This device permitted the mode to be considered for future flows, and, when time or costs were favorable, capture much of the flow.

The other major analysis effort required for both Trends and Choices and the NTPSC study was disaggregation of flows. Future forecasts were provided to COMSIS by region--coal producing region and coal consuming region. As the NTP Model operates on BEA-to-BEA flows, these forecasts had to be disaggregated and converted into BEA-to-BEA records of coal flow. Production was disaggregated based on actual coal production location. The BEA with the largest portion of the coal producing region got the largest portion of the production. Flows were disaggregated proportional to population in the consumption BEA's. Each consumption region's flow from each BEA production region that it received flow from was proportioned to all BEA's in the consumption region based on relative population. This created more flows than were realistically necessary, but provided a mathematical technique that could be applied in every situation.

LIMITATIONS OF THE MODEL

The model is heavily dependent on a data base of flows, and is therefore only as good as that data base. The 1975 data base, based on 1972 data, predates the dramatic change in energy costs initiated after the 1972 Arab Oil Embargo. It has limitations based on varying sample sizes, and problems of disclosure which resulted in Category 9, unidentified commodities. As a result of that problem, the major flows from Detroit are Unidentified Commodities.

The networks now being used are not consistent in detail, and do not have a tonnage capacity coded on them. They are not designed to handle multi-modal flows, except that terminal links for water and rail networks assume truck transfers in some cases.

As described above, the model is not readily responsive to major changes, new modes, new technologies, or major shifts in time and cost relationships. It is conservative, tending toward the status quo unless major changes occur in times or costs. Given the nature of goods movement decisions, this is probably realistic. Most goods movement mode and path decisions are long term and not volatile. However, when new technology, like coal slurry, or new markets are introduced, the model is cumbersome in its response.

FUTURE ENHANCEMENTS

Many simple modifications could be made to the NTP Model to permit more sophisticated analysis of the impact of changes in the movement of goods. Foremost among them is addition of capacity restraint techniques in the analysis of flows. Recent improvements to UTPS network coding and assignment programs will allow considerable flexibility in using capacity restraint. Diversion curves like those developed by CACI for the National Energy Transportation Study can be applied in an iterative modal split calculation (10,11).

The data base for the NTP model should be redeveloped for 1980, with better data and more confidence in sample adequacy. It could be (but would not have to be) updated to the new 184 BEA zone system. Additional zones could be created for major production regions, to avoid the necessity of splitting production forecasts by BEA.

Making the network element of the NTP methodology truly multi-modal would require considerable care and an extensive testing effort. The three or four networks could be coded as a single multi-modal network using intermodal transfer links, and use codes can be applied to prevent inappropriate transfers, but the increased number of possible paths on a multi-modal network would create the opportunity for illogical paths that thorough testing would be required to avoid.

The NTP Model is a multi-purpose, complex and flexible tool for the analysis of both person and goods movement on a national or multi-state scale, dealing with alternative modes and paths for assignment of flows. It has been very useful in its application to national and corridor alternatives and can continue to serve as a basic tool in the repertoire, with some effort expended on its upkeep and enhancement. Its applicability to coal movements has been shown and it has the ability to adjust to changing environments and provide useful, reasonable forecasts.

REFERENCES

[1]U.S. Department of Transportation, Office of the Secretary, National Transportation Trends and Choices (to the Year 2000), Washington, D.C., January 1977.

[2]Peat, Marwick, Mitchell & Co., et al., Brunswick, Georgia-Kansas City, Missouri Multi-Mode Route Study, Washington, D.C., 1977.

[3]National Transportation Policy Study Commission, National Transportation Policies Through the Year 2000, Washington, D.C., 1978.

[4]COMSIS Corporation, Documentation of National Travel Models for National Transportation Trends and Choices, Wheaton, MD, 1978.

[5]U.S. Department of Commerce, Bureau of Economic Analysis et al., OBERS Projections of Economic Activity in the United States, BEA Economic Areas, Volume 2, Washington, D.C., 1974.

[6]COMSIS Corporation, Compendium of NTPSC Data and Models, Wheaton, MD, August, 1980.

[7]P.M.L. Pearson, The Planning and Evaluation of Intercity Travel Systems, Ph.D. Dissertation, University of Waterloo, Department of Engineering, March, 1969.

[8]U.S. Department of Transportation, Federal Highway Administration, FHWA Computer Programs for Urban Transportation Planning, Washington, D.C., 1974.

[9]U.S. Department of Transportation, Urban Mass Transportation Administration, Urban Transportation Planning System - UROAD: Highway Traffic Assignment Program, Washington, D.C., February, 1981.

[10]Secretary of Transportation and Secretary of Energy, National Energy Transportation Study, Washington, D.C., July, 1980.

[11]CACI, Inc.-Federal, Transportation Flow Analysis: National Energy Transportation Study, Arlington, Virginia, January, 1980 (3 volumes).

81-TR-17

A Preliminary View of U.S. Coal Transportation Using the Princeton Railroad Network Information System

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ABSTRACT

The so-called Princeton Railroad Network Model has evolved into a very powerful information system for use by managers and decisionmakers in the U.S. railroad industry, including its operators, its users and its regulators. Coupled with improved data on coal producers and consumers, it seems to be a convenient information system for the analysis of both tactical and strategic coal transportation and coal marketing issues. The paper briefly describes the various elements of the Princeton Railroad Network Information System, the primary coal data bases currently used by the model, a brief description of current coal-via-rail traffic characteristics and some suggestions for how the information system could be used to address a broad range coal strategic planning issue including forecasts of transportation cost, capacity limitation, alternate routings and effects of mergers and deregulation.

INTRODUCTION - The Princeton Railroad Network Information System

With this paper the name of the Princeton Railroad Network Model is formally changed to the Princeton Railroad Network Information System. This is a change in semantics for the purpose of trying to more precisely identify the actual substance. Princeton - because the entity was improved and made usable at Princeton University, although a great deal of credit is deserved by The Federal Railroad Administration (FRA) for originally undertaking the network coding and data collection efforts (1,2). Railroad - because it best replicates and models railroad operations, service and cost, although a comparable U.S. highway network is nearing completion. Network, because the system is based heavily on the actual lines and stations of the U.S. rail system and it uses network-type mathematical models. Information Systems - (instead of model) because its most powerful attribute is its ability to take data and convert it into information. The data may exist in raw form in an exogenous data base or it may have been forecasted or otherwise modified by some mathematical relationships we call models. While the system is made up of many traditional models, its value is in its presentation of information instead of the idiosyncrasies of the models themselves.

The Princeton Railroad Network (PRN) Information System is currently used for research and education purposes at Princeton University and is maintained and used for development, production and proprietary purposes by ALK Associates, a consulting firm that is totally separate from Princeton University. The system is used primarily to perform computer-based analyses in support of railroad and shipper strategic planning, marketing, pricing, operations planning and cost analyses. The system consists of a collection of network and traffic/market data; efficient computer algorithms for graphical display, manipulation and editing; intracarrier, intercarrier, and hazardous material routing routines; blocking and cost models; freight car management routines; and traffic diversion packages for studies of mergers and other restructuring. The interactive environment in which the system operates and the efficient computer-graphic interface are the essential elements that convert a collection of data and models into an information system.

Network Data Bases - The entire computer environment of the PRN Information System is built around a simple link-node network data structure. Links have physical attributes, e.g., its a-node (from node) and b-node (to node), distance, track class, ownership, trackage rights and modelling attributes e.g., interline impedance, block sizes, see Table 1. There are 22,477 links that describe the U.S. and Canadian railroads. Nodes also have physical attributes, e.g., longitude, latitude, name, state, county, rail stations (FSAC, SPLC), TOFC ramp designations, rail yard designations, name of electric utility (if any) and name of coal mine (if any). The network is composed of 20,735 nodes. A geograhic display of the nodes and links of the U.S. and Canadian railroad system is shown in Figure 1.

Currently, the data structure for a 10,000 link-node representation of the U.S. highway system is nearing completion. The network will contain all Federal and most State roads with some county roads. Link attributes include distance, route type and number (e.g., US 1), number of lanes, lane configuration and toll structure. Node attribute includes longitude, latitude, city name, state, county.

TABLE 1

PRINCETON RAILROAD NETWORK INFORMATION SYSTEM

LINK ATTRIBUTES

EXOGENOUS DATA

Type	Note
a-node, b-node	basic identifier
distance	in tenths of miles
track class	A main, B main, A-branch, B-branch (1,2,3,4)
ownership/track rights	by subsidiary
interline impedance	for interline junctions, by direction
block size	for yard-to-yard links, by direction
grade, curvature	equivalent drag, for mainlines only
speed limit	for mainlines only
population density	average over length, 1970 census

DERIVED DATA

Type	Note
traffic density	by various measures of volume and specific traffic type
accident counts	from FRA Accident/Incident File 1974-1980

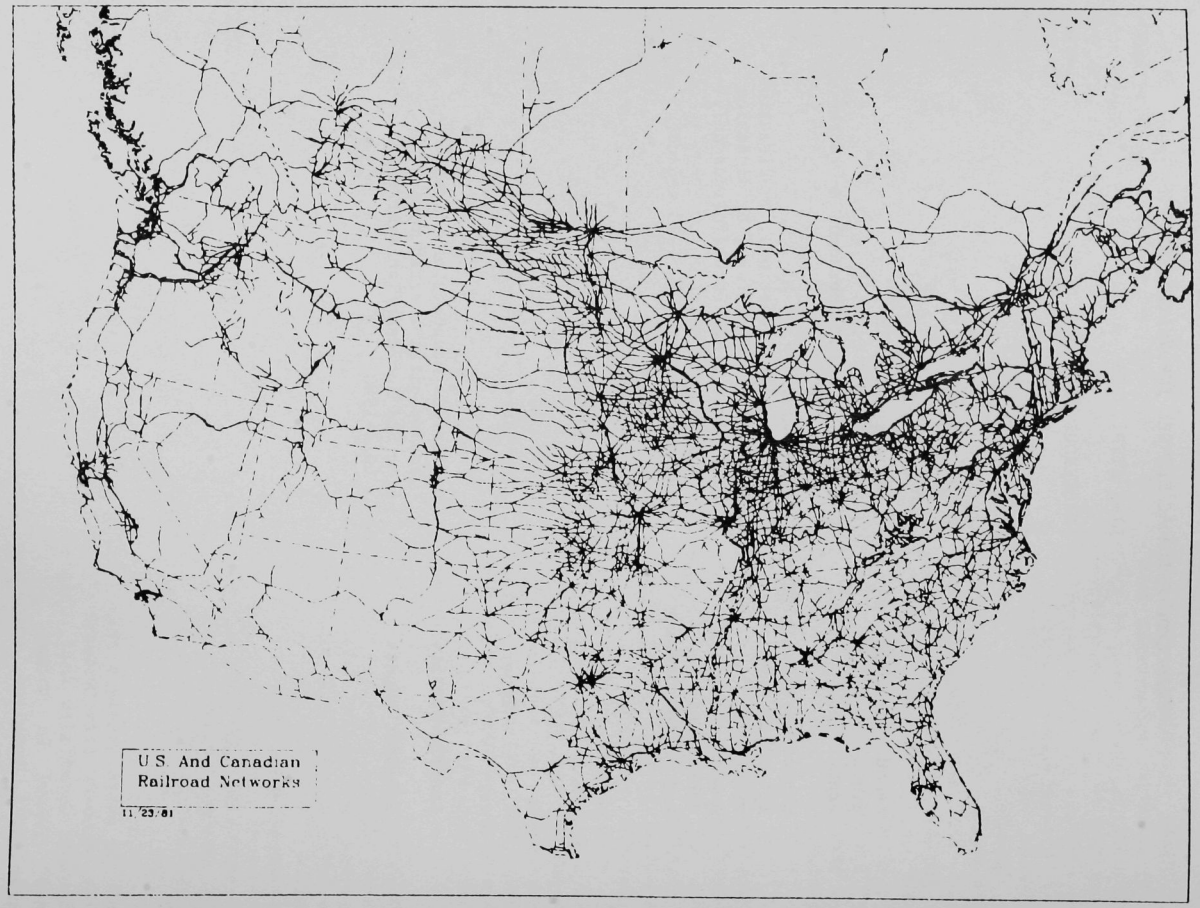

Figure 1

LINK	NODES	
454	436	449
455	436	503
526	498	502
527	498	14875
530	500	502
531	500	503
536	510	539
537	510	14875
541	516	529
542	516	532
552	522	532
553	522	534
554	523	531
555	523	534
556	524	531
557	524	532
563	528	529
564	528	539

NODE	X COORD	Y COORD
436	7607387	2740412
449	7698734	2500253
498	7648622	2706668
500	7622207	2728806
502	7623834	2727999
503	7620582	2729614
510	7658010	2692034
516	7671768	2676240
522	7685946	2651542
523	7685791	2649993
524	7682231	2654483
528	7663725	2683742
529	7665271	2681190
531	7682540	2649529
532	7685172	2658353
534	7688269	2649684
539	7662178	2686759
14875	7652984	2694816

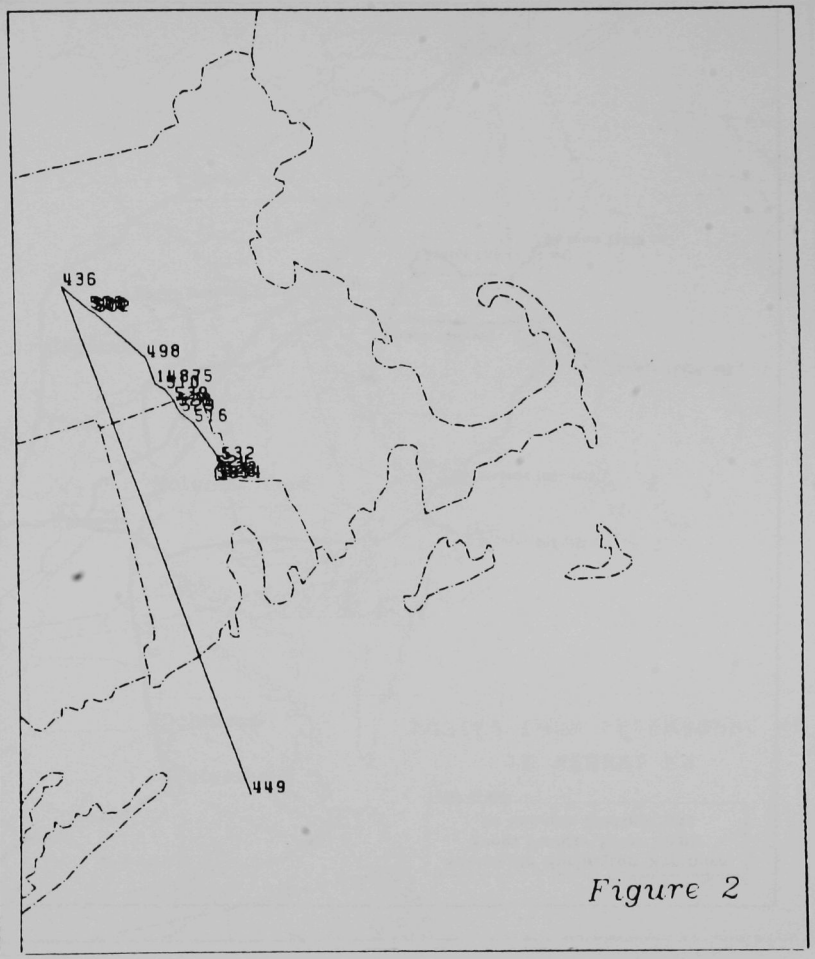

Figure 2

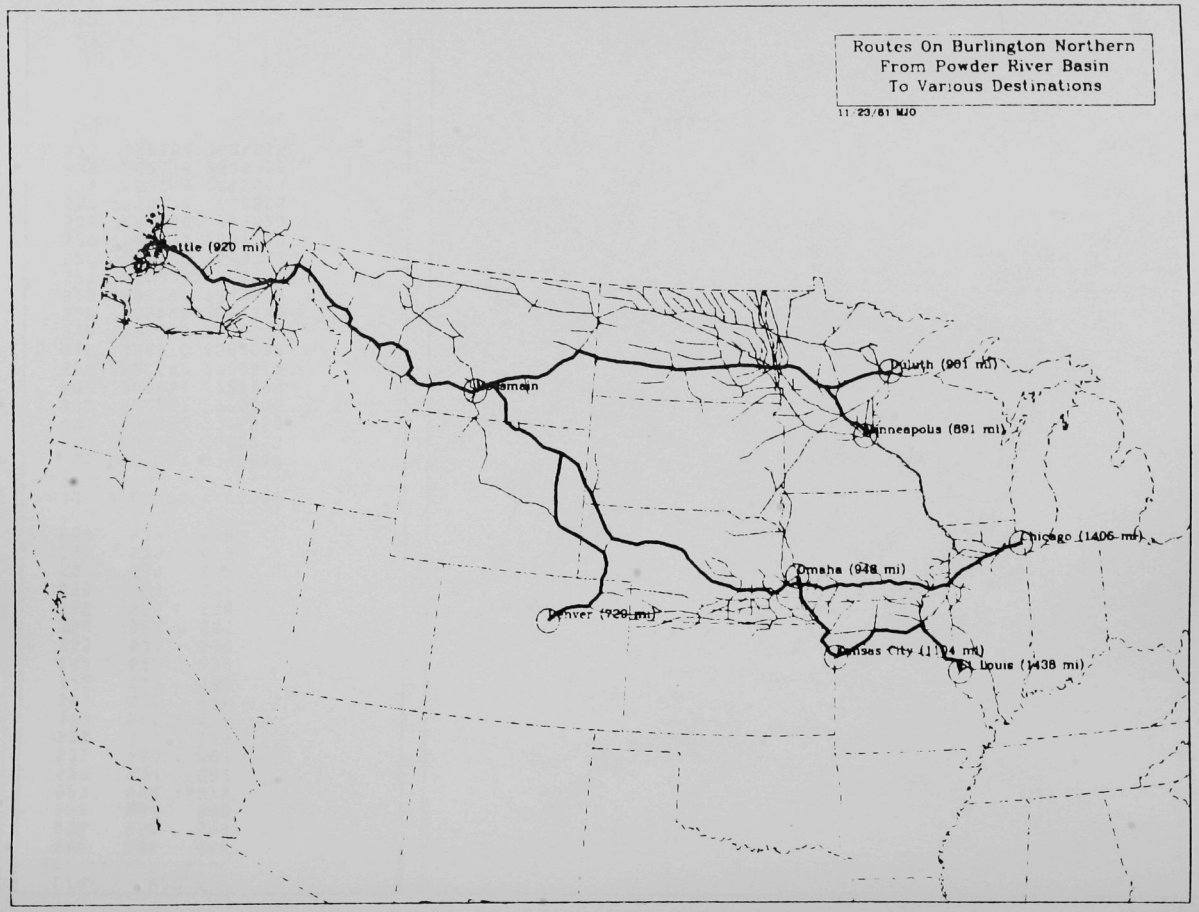
Routes On Burlington Northern
From Powder River Basin
To Various Destinations
11/23/81 MJO
Seattle (920 mi)
Des Moines
Duluth (901 mi)
Minneapolis (891 mi)
Chicago (1406 mi)
Omaha (948 mi)
Denver (929 mi)
Kansas City (1104 mi)
St Louis (1438 mi)

Figure 3

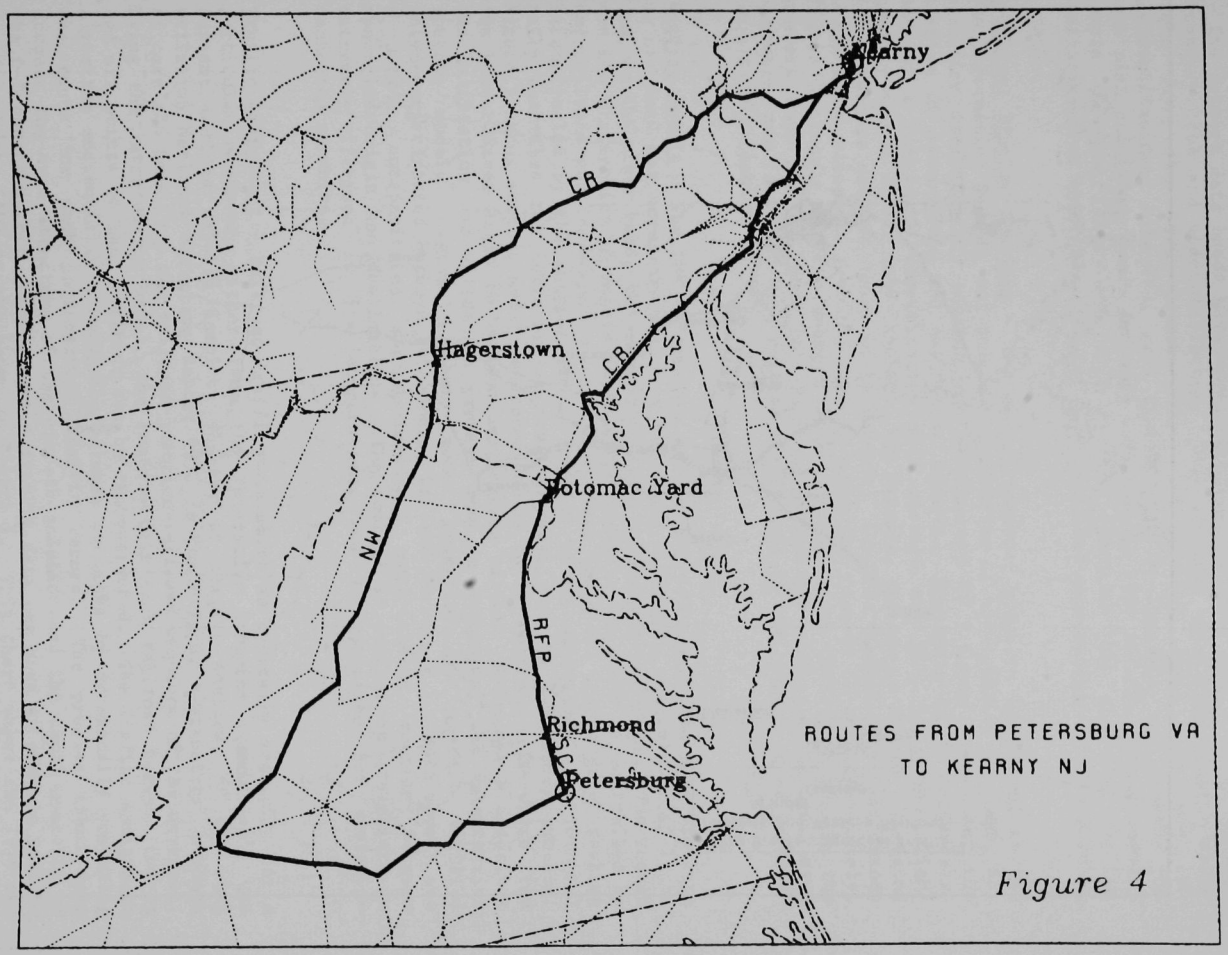
Kearny
CR
CR
Hagerstown
Potomac Yard
MN
RFP
Richmond
Petersburg
ROUTES FROM PETERSBURG VA
TO KEARNY NJ

Figure 4

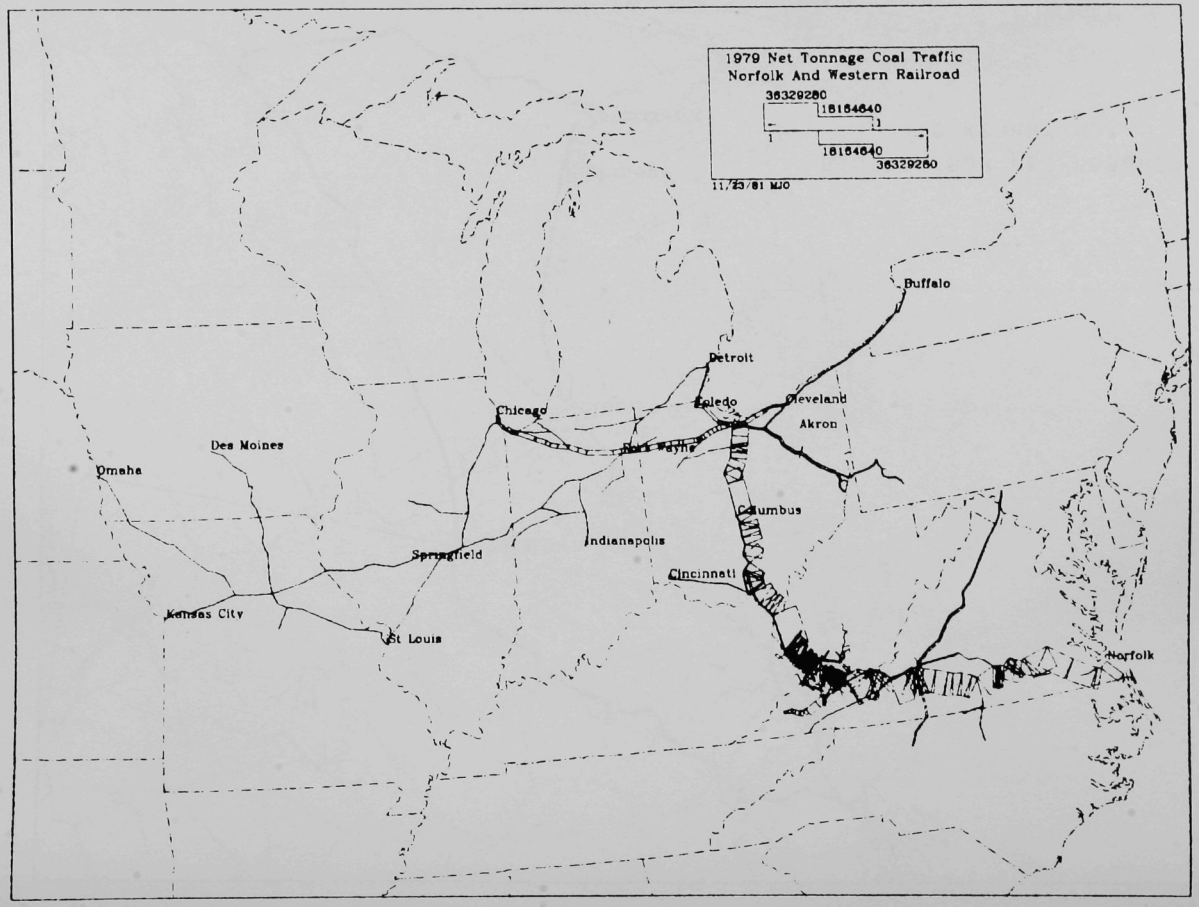
1979 Net Tonnage Coal Traffic
Norfolk And Western Railroad
36329280
18164640
1
1
18164640
36329280
11/23/81 MJO
Buffalo
Detroit
Toledo
Cleveland
Akron
Chicago
Fort Wayne
Des Moines
Omaha
Columbus
Indianapolis
Springfield
Cincinnati
Kansas City
St Louis
Norfolk

Figure 5

The network data bases have been correlated to other data bases to provide secondary link and node attributes. This includes population density along links from the 1970 Census (3), rail accident data from the FRA Accident/Incident File (4), rail traffic data by commodity and cartype for both past and future years from the 1973 through 1980 ICC one percent waybill sample (5) and FRA's 1990 rail traffic forecasts (6) and coal traffic statistics from the coal marketing file described subsequently in this paper.

Graphical Display Routines - The use of computer graphics is central to the PRN Information System, not only for production of high-quality displays, but also for manipulation, editing and maintenance of a large data base, the testing of assumptions and validating results. Operating in an interactive mode at a high data communication rate enables the user to receive high-quality output in a timely fashion. For example, the map in Figure 1 contains 46198 vectors and was drawn in 23 seconds. Graphics enable data base errors which would otherwise remain hidden in numerical form to be seen immediately; Figure 2 clearly shows a network error that would be hard to detect in the numbers shown in in Figure 2a. High resolution CRT terminals, user-oriented software, and fast hard copy enabled all figures in this report to be produced in a timely fashion.

Routing Models - The PRN Information System contains two models that simulate on one hand car movements within a corporate railroad's own network of lines and, on the other hand, the most likely routing between railroads. The reason for the distinction in models is that the intracarrier route is controlled by the railroad and is subject to its objectives while the intercarrier routing is controlled by the shipper and is subject to his objectives. Reference 7 fully describes the intracarrier routing model and its validation process. Figure 3 shows various model generated routes on the Burlington Northern from the Powder River Basin to various destination cities. Reference 8 describes the calibration and validation process used in developing the intercarrier routing model. Figure 4 shows model generated and waybill verified intercarrier routes between Petersburg, Va. and Kearny, N.J. Both models use a simple uncapacitated minimum-impedance path-finding routine between specified origin and destinations. The routine is written in assembler, is extremely efficient in its computation, and is optimized for sparsely-connected networks.

Traffic Assignment - Railroad traffic data which is typically available for a particular movement, either from the Interstate Commerce Commission's One Percent Carload Waybill Samples, shipper or carrier sources, or the coal utilities National Marketing Report (9), is the origin, destination, numbers of cars and tons, and the railroad-junction-railroad sequence of the movement. Using the intracarrier model, the route within each railroad between the on and off points on that railroad can be reconstructed. The Traffic Assignment Algorithm sequentially accumulates volumes on links by dynamically computing the route for each intracarrier traffic record. The process takes into account the tree structure of the minpath solution and the usual sparcity of the O-D demand matrix. The computed traffic data are used to produce traffic density charts (10) as are shown in Figure 5. This chart shows the 1979 net tonnage density for Coal on the Norfolk and Western based on the 1% Waybill

Sample.

A great variety of database subsets can be shown via such traffic density charts. For example, one could show where a railroad's carloads travel on an interchange partner. Figure 6 shows a map of interchange traffic with Conrail moving on the Illinois Central Gulf. Such a display could be used to estimate the current value of paticular segments of one railroad to another, termed Participatory Value (8).

Traffic Impacts of Restructuring - The PRN Information System contains two models which determine the redistribution of rail traffic following mergers, consolidations, abandonments, line extensions, controlled transfer of properties, or other corporate restructuring of the U.S. railroad system. The first, termed the Elementary Theory (11) is most suitable for analysis of simple mergers. In such a case, the Elementary theory assumes that shippers will, for the most part, follow historical routing patterns, adjusting only incrementally to the changes brought about by the merger. The procedure involves classifying markets (origin-destination pairs) into seven market types, and the routes in each market into six route classes. A 7 x 6 diversion coefficient matrix is then constructed which, for each market type, diverts traffic between route classes. The result of the model, using a logically derived diversion matrix, is to divert a great deal of traffic from existing multicarrier routes, and some traffic from existing single carrier routes, to new single-carrier service offered by the merged carriers. A second result is to allow for new originating long-haul opportunities for the merged system by the inclusion of routes generated by the Intercarrier Routing Model. The Elementary theory also allows for retaliation by other railroads against the merging carriers where they serve as an overhead or, to a lesser degree, terminating carriers on a move.

The second traffic diversion model, termed the Advanced theory (12), is more appropriate for analyzing convoluted reconfigurations, such as multiple mergers or controlled transfers. In such an environment, it is assumed that shippers will rethink their routing patterns based on level of service considerations. The Advanced theory accomplishes this by looking at origin-destination traffic data, generating routes on the restructured rail system using the Intercarrier Routing Model for each possible origin railroad/termination railroad combination, and distributing traffic among the routes based on surrogate level-of-service measures.

Three basic outputs are produced by both models. The first is the overall change in car and ton handlings, carmiles, tonmiles, and revenue for each U.S. railroad as a result of the reconfiguration. The second is a series of traffic density maps depicting the gains and losses in traffic on each railroad. The final output is a printout by market of the routes (in terms of railroad-junction-railroad sequences) and market shares before and after.

Empty Car Management, Blocking and Costing - Three new models have recently been added to the Princeton Railroad Network Information System. These are the Freight Car Management model which generates empty car movements to satisfy car loading demands; the Blocking Model which groups cars into blocks thus enabling the construction of an operating plan and the estimation of yard

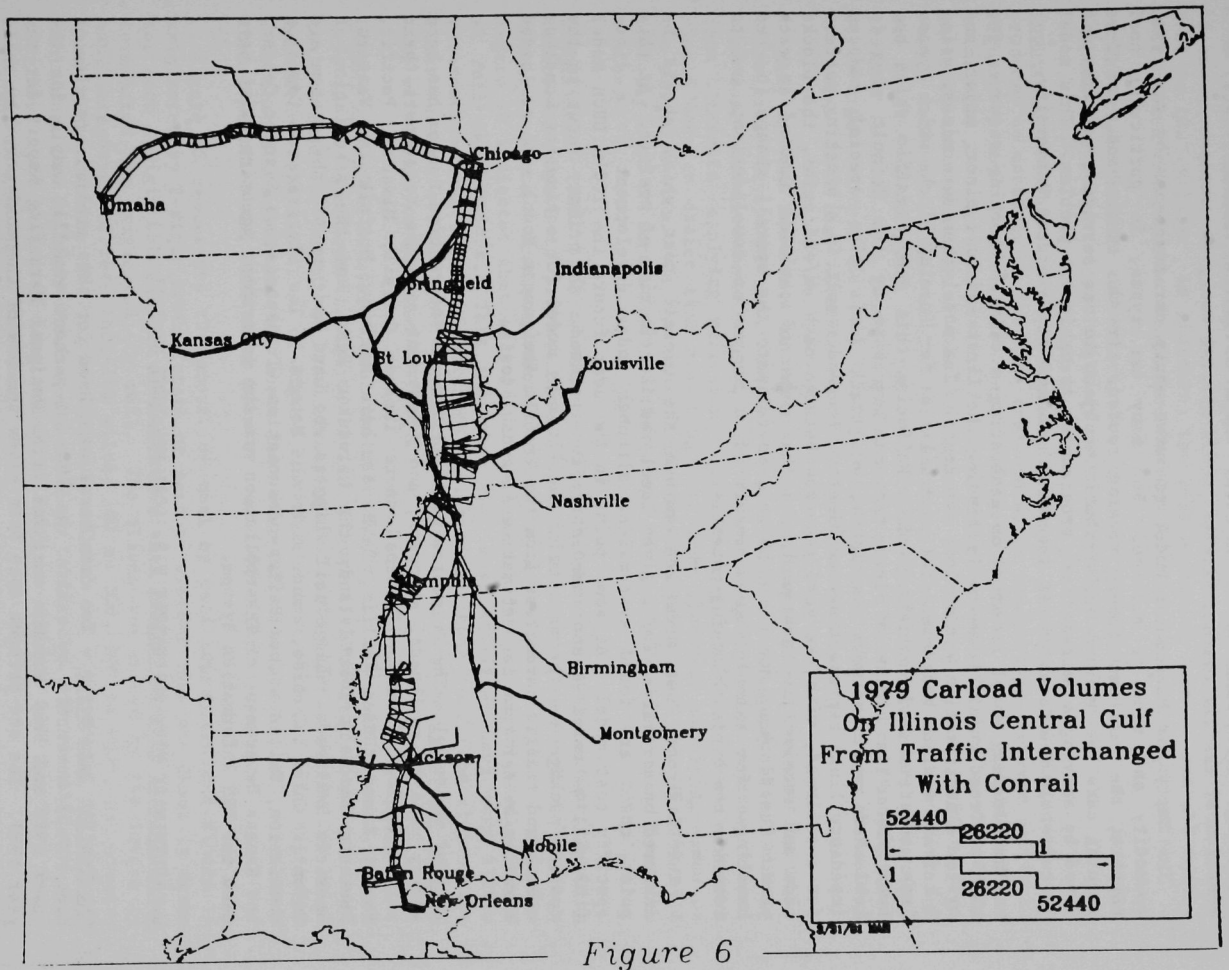
Chicago
Omaha
Indianapolis
Springfield
Kansas City
St Louis
Louisville
Nashville
Memphis
Birmingham
Montgomery
Jackson
Mobile
Baton Rouge
New Orleans
1979 Carload Volumes
On Illinois Central Gulf
From Traffic Interchanged
With Conrail
52440
26220
1
1
26220
52440

Figure 6

switching costs; and the Cost Model which estimates railway costs as a function of traffic characteristics.

The Empty Car Management Model computes empty car movements by car type, commodity and type of service. For many car types, in particular coal hoppers, the cars are simply reverse routed. On the other hand, for free running cars the optimum redistribution subject to car service constraints is found by solving a mathematical programming transhipment problem. This model is currently the focus of AAR sponsored research at Princeton University.

The Blocking Model is based on generating a default blocking sequence for each railroad on/off movement by finding the first and last minor, major, and system classification yards along the route. The model then determines, using a certain minimum blocksize, the possibilities for forming blocks which bypass intermediate default-pattern yards. Following this step, traffic which has been placed in blocks of less than minimum size by the default step is reblocked on a network consisting of track links plus special reduced impedance links representing the blocks. The end result is a blocking pattern for a railroad, with the yard sequence between each on/off point, the blocks made and received at each yard, and the number of carloads handled at each yard. The Blocking Model can be used to estimate the overall change in yard handlings, for example, as a result of a merger or conslidation, and to identify new bypass blocking potential.

The Railroad Cost Model determines the overall cost which should be incurred by a railroad for a given level and distribution of traffic. At this point, costs are found systemwide, although under development is a line-specific cost model. At some point in the near future the ICC's URCS Model (13) will be released and immediately incorporated. Of primary input to the costing package are the results of the blocking model for estimating handling costs, and traffic parameters from the Traffic Assignment Model such as loaded carmiles by car type for estimating line-haul costs.

Uses of the Model - The Princeton Railroad Network Information System has been widely used by railroads, shippers, and government agencies to support their rail planning efforts. Railroad users include Conrail, Missouri Pacific, Family Lines, Union Pacific, P&LE, Southern Railway, Norfolk and Western, Southern Pacific, Rock Island, the Milwaukee Road, and the Association of American Railroads. Large rail shippers who have made use of the system are DuPont, Union Carbide, and General Motors. The Interstate Commerce Commission, United States Railway Association, Transportation Systems Center, and Kansas Department of Transportation are the government agencies which have used the PRN Information System.

A PRELIMINARY VIEW OF CURRENT U.S. COAL MOVEMENT BY RAIL

The Traffic Data Bases - Two data bases were used for this preliminary view of U.S. coal movements by rail: the ICC one-percent waybill sample for the years 1979 and 1980 and the coal utilities National Marketing Report for the year 1980. The one-percent data base gives the HOW of the coal moved by rail. It specifies the entire railroad junction-railroad routing from origin to destination for each sampled movement. It also gives the rail transportation

cost (rail revenue) and net tonnage. The coal Marketing Data gives the WHAT of the movements. It gives details about the coal content and the cost of the coal to the utility. In addition, the coal Marketing Data is for all modes, thus market share can be determined between Rail and Water transportation.

The coal traffic characteristics that will be viewed are as follows: cooperation, competition, length of haul and traffic density.

Cooperation - This is a measure of the extent to which coal is moved from producer to consumer on the same railroad or is interchanged between carriers. Figures 7 and 8 show the amount of coal traffic which originates and terminates on the same railroad (this includes transhipment to waterborne vessels) and the amount of traffic requiring interchange between 2, 3, 4, 5 or even 6 railroads. The national average for all commodities is that about 50% are local (one carrier), 25% are two carrier, 12.5% are 3 carrier, etc. Coal traffic is much more concentrated towards single carrier traffic patterns. Sixty-eight percent of coal traffic is local and 93% requires at most 2 carriers. Less than 2% moves over more than three railroads.

Many reasons are cited for this propensity towards local movement by rail, principally equipment ownership and supply issues. This may also indicate that coal consumers have not not fully explored opportunities to acquire coal from alternate supplying railroads. With the coming mergers, coal consumers should have an easier time acquiring coal from alternate supplying areas of the merged system. On the other hand, the Stagger's Rail Act of 1980 will probably tend to further reduce the volume of coal travelling on multicarrier routes.

Competition - This is a measure by which one determines the extent to which railroads compete to serve a mine and a utility and the extent to which a utility buys coal transportation from competing railroads (Figures 9 and 10). Figure 10 indicates that only 38.5 % of coal traffic is competitively served at rail destinations. This indicates that most utilities have very little alternative rail service. Although utilities purchase coal from alternative mines because of different coaal characteristics, they nevertheless tend to stay with mines on the same railroad.

Length of Haul - Length of haul characteristics for all coal movement in the U.S. in 1979 is shown in Figures 11-14. Figure 11 shows the distribution of coal volume in length of haul groupings of 100 miles. Figure 12 is a cumulative representation of Figure 11. Notice that 15.3% of all coal moves less than 100 miles and 69% moves less than 500 miles. Only 12% moves more than 1000 miles and 1.5% moves greater than 1500 miles.

Figure 13 represents the amount of coal by rail terminated and Figure 14 originated by 2-digit SPLCs (state or part of state). One pie chart is drawn for each 2-digit SPLC. The area of the pie is proportional to total tonnage terminated (or originated) by rail. The slices are shaded by the length of haul categories of less than 100 miles, 100 to 500, 500 to 1000, and greater than 1000. Notice the extremely small volumes of coal moving by rail to Louisiana, New England, Florida and Northern California. Notice also the very long hauls and mixing of long and short haul in Illinois and that some long-haul coal is getting to Alabama.

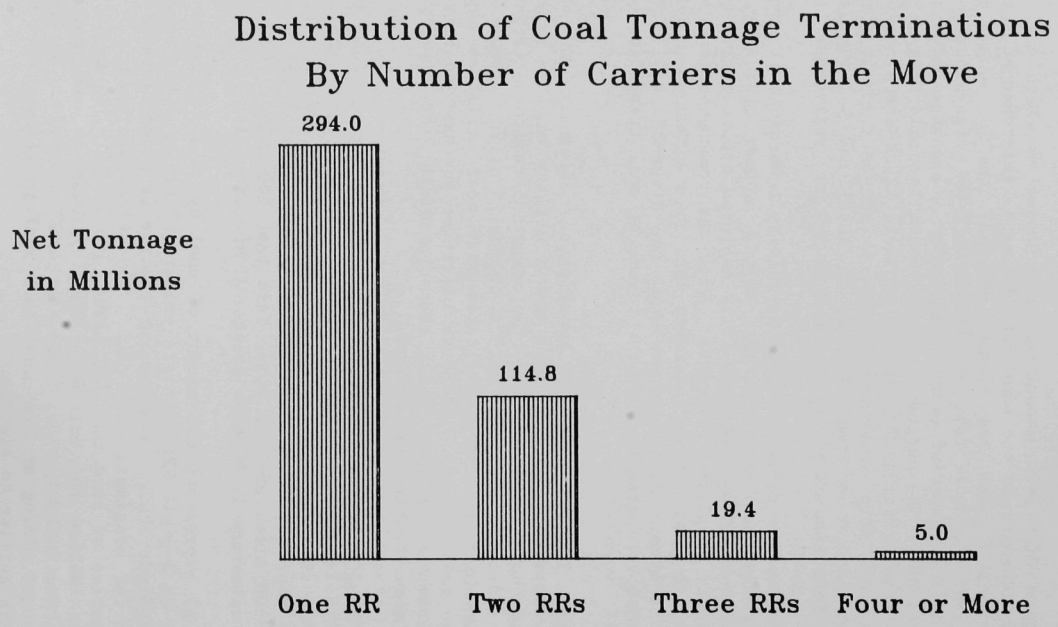
Distribution of Coal Tonnage Terminations
By Number of Carriers in the Move
Net Tonnage
in Millions
294.0
114.8
19.4
5.0
One RR
Two RRs
Three RRs
Four or More

Figure 7

Coal Tonnage Terminations
by Number of Carriers in the Move

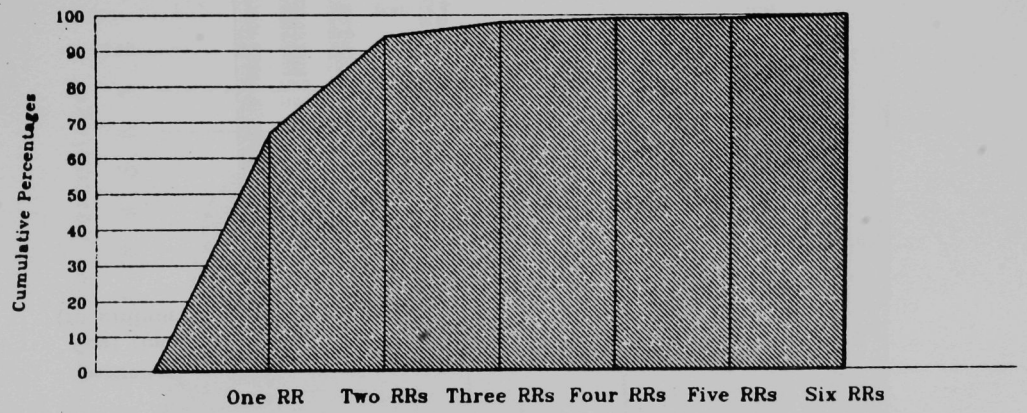

Figure 8

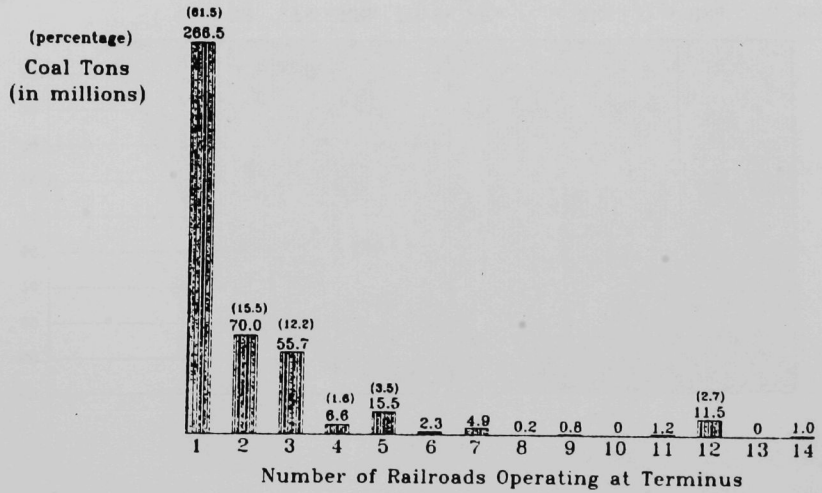
Distribution of Coal Tonnage Terminations
by Number of Railroads Operating at Terminus
(percentage)
Coal Tons
(in millions)
(61.5)
266.5
(15.5)
70.0
(12.2)
55.7
(1.6)
6.6
(3.5)
15.5
2.3
4.9
0.2
0.8
0
1.2
(2.7)
11.5
0
1.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Number of Railroads Operating at Terminus

Figure 9

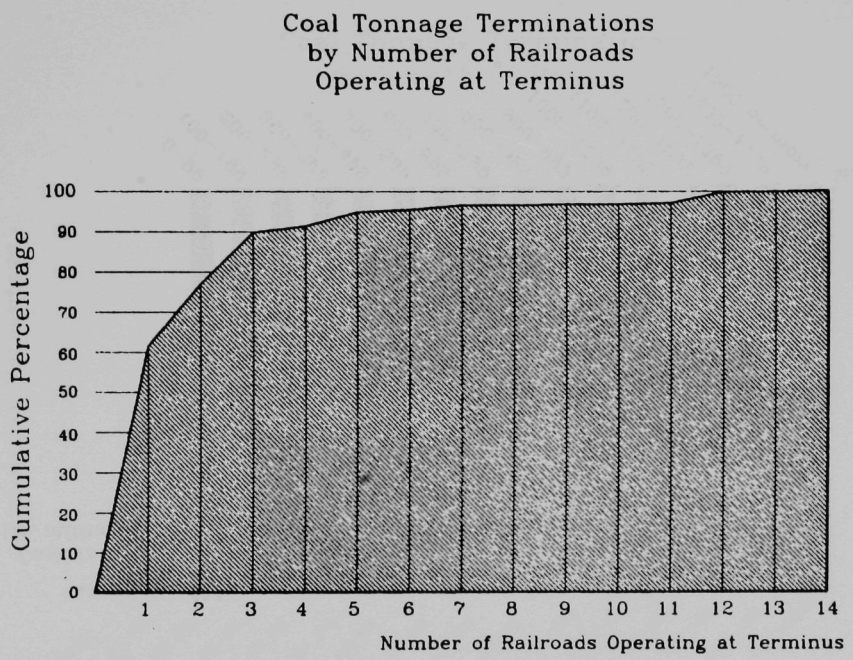
Coal Tonnage Terminations
by Number of Railroads
Operating at Terminus
Cumulative Percentage
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Number of Railroads Operating at Terminus

Figure 10

Distribution of Coal Tonnage Terminations by Distance Moved

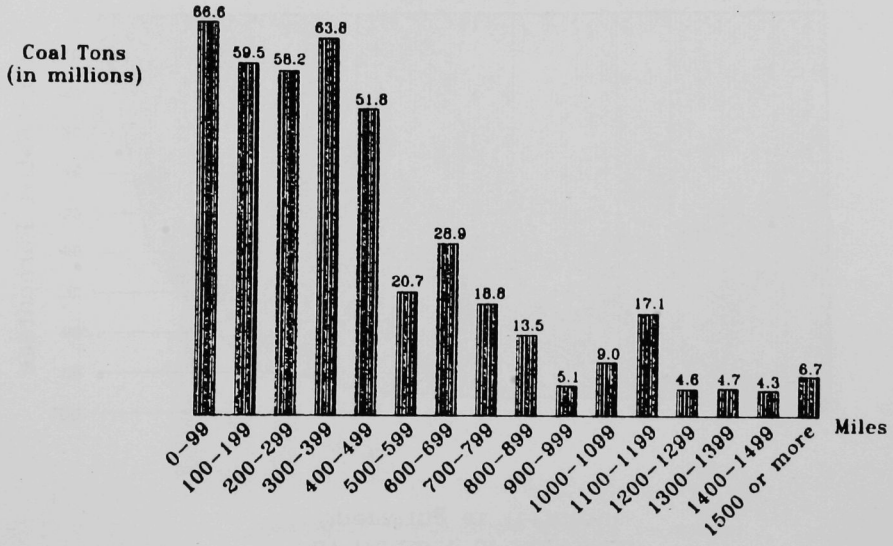

Figure 11

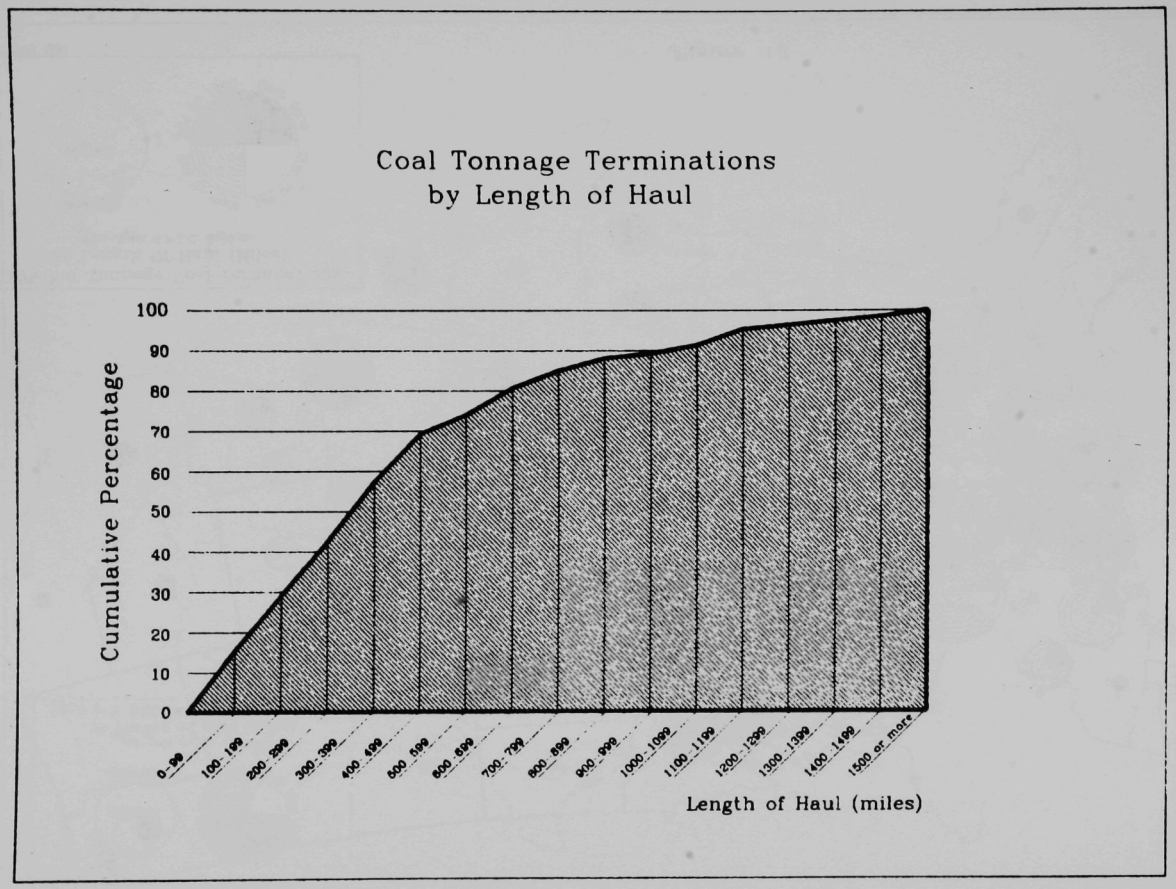
Coal Tonnage Terminations
by Length of Haul
Cumulative Percentage
100
90
80
70
60
50
40
30
20
10
0
0-99
100-199
200-299
300-399
400-499
500-599
600-699
700-799
800-899
900-999
1000-1099
1100-1199
1200-1299
1300-1399
1400-1499
1500 or more
Length of Haul (miles)

Figure 12

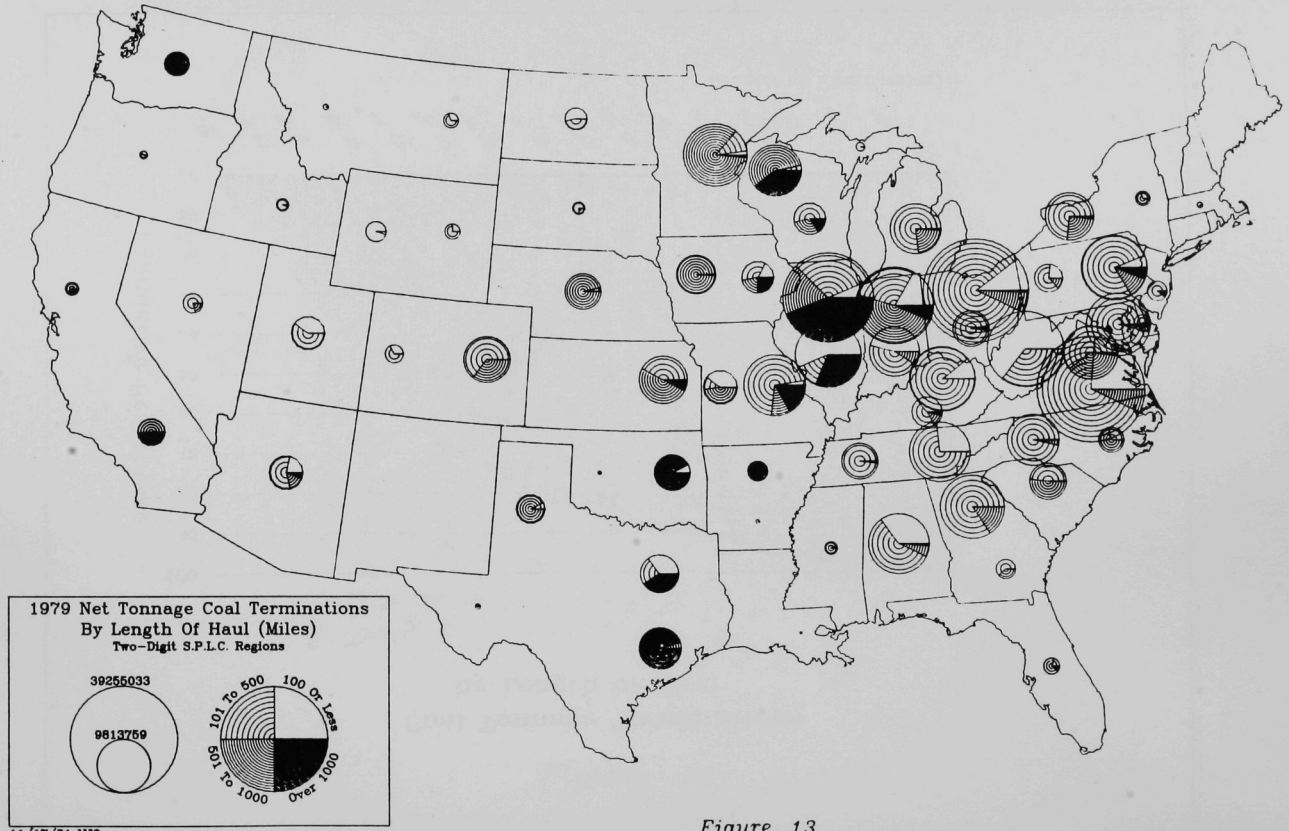
1979 Net Tonnage Coal Terminations
By Length Of Haul (Miles)
Two-Digit S.P.L.C. Regions
39255033
9813759
100 Or Less
101 To 500
501 To 1000
Over 1000
11/17/81 MJO

Figure 13

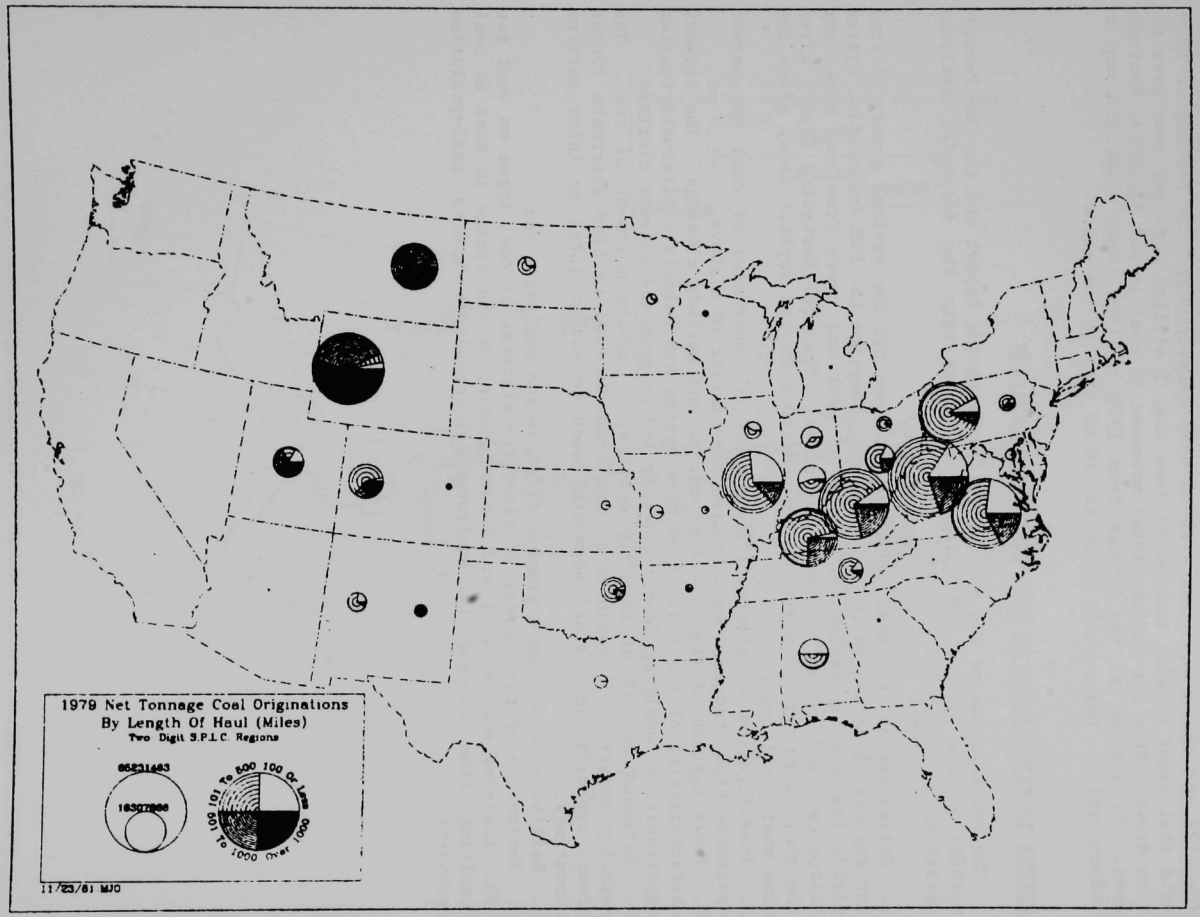
1979 Net Tonnage Coal Originations
By Length Of Haul (Miles)
Two Digit S.P.L.C. Regions
65531463
16307966
100 Or Less
101 To 500
501 To 1000
Over 1000
11/23/81 MJO

Figure 14

Traffic Density - Figures 15 and 16 show U.S. wide coal traffic density charts for 1979 and the change from 1979 to 1980 respectively. In looking at 1979, note that light density volumes of less than 5 million tons per year have not been drawn. Note the bidirectional movement of coal in the Illinois, Kentucky area. In looking at the change from 1979 to 1980, note that the map of reduced volumes has a scale which is 1/4 of that of the gains.

FUTURE INVESTIGATIONS OF U.S. COAL TRANSPORTATION

The combined use of the coal Utilities Marketing Report and the One Percent Waybill Sample by the PRN Information System make the following analyses possible.

1. Estimation of the total price for coal per BTU for various grades of coal for any rail location in the U.S. For any location the PRN Information System yields the serving railroads, length of haul and route from any mine, and historical rail rates for comparable moves. The coal Marketing Report gives the coal characteristics and in conjunction with the waybill data, gives the mine month coal cost.
2. Investigation of alternative supplies and consumers of coal for market dominance-type studies. Such studies are similar to 1 above.
3. Investigation of the impact of merges and gateway closings. The network characteristics of the PRN Information System can calculate alternate routing opportunities resulting from any merger and/or proposed gateway closings.
4. Estimate impacts of capacity constraints on the movement of coal. The capacity constrained transhipment model can be used to find alternate routes around capacity constrained segments based on either intra or inter carrier reroutings.
5. Rail/water modal share graphic displays and analyses, and
6. Evaluation of the impacts of alternate mixtures of coal types on cost per BTU. Analyses similar to 1 and 2 but focusing on the change in cost of coal resulting from changes in environmental standards and/or anti-pollution equipment.

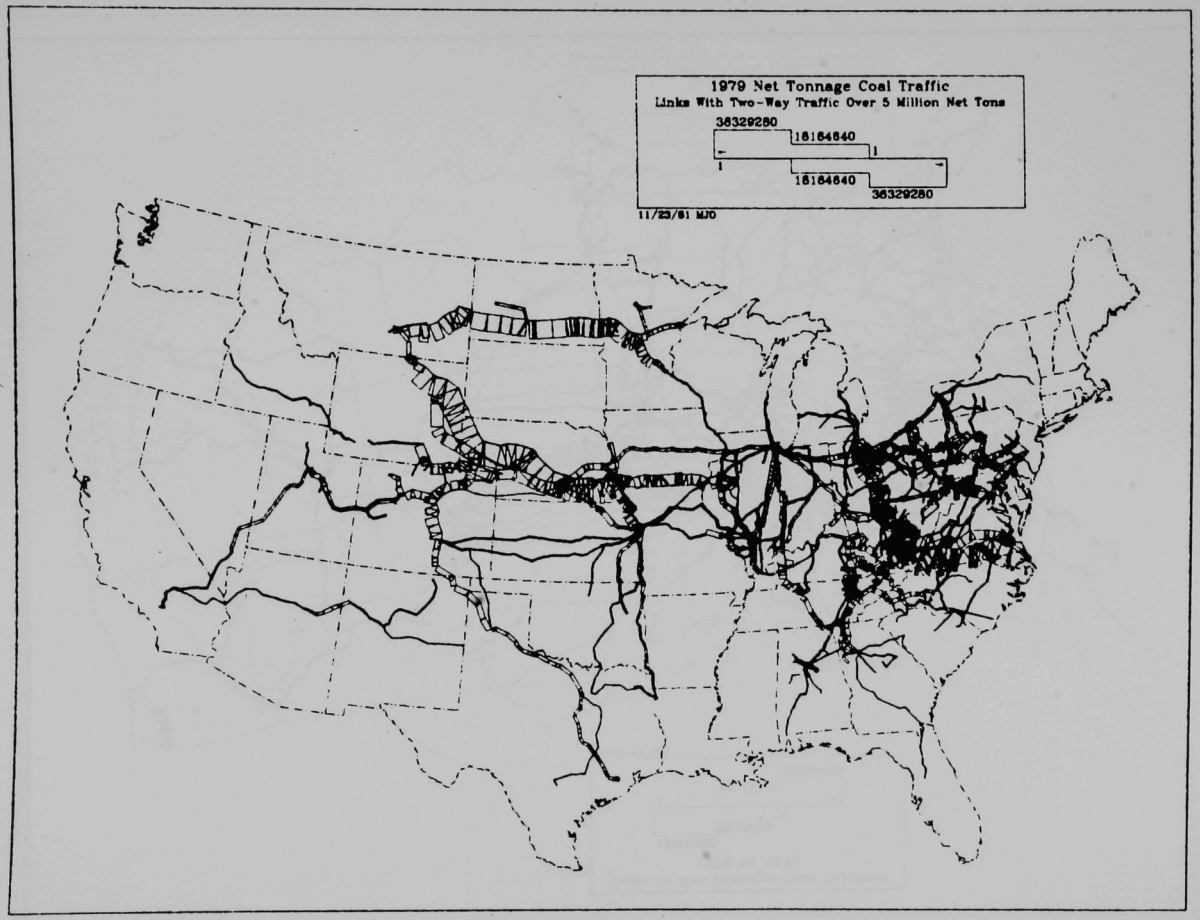
1979 Net Tonnage Coal Traffic
Links With Two-Way Traffic Over 5 Million Net Tons
36329280
16164640
16164640
36329280
11/23/81 MJO

Figure 15

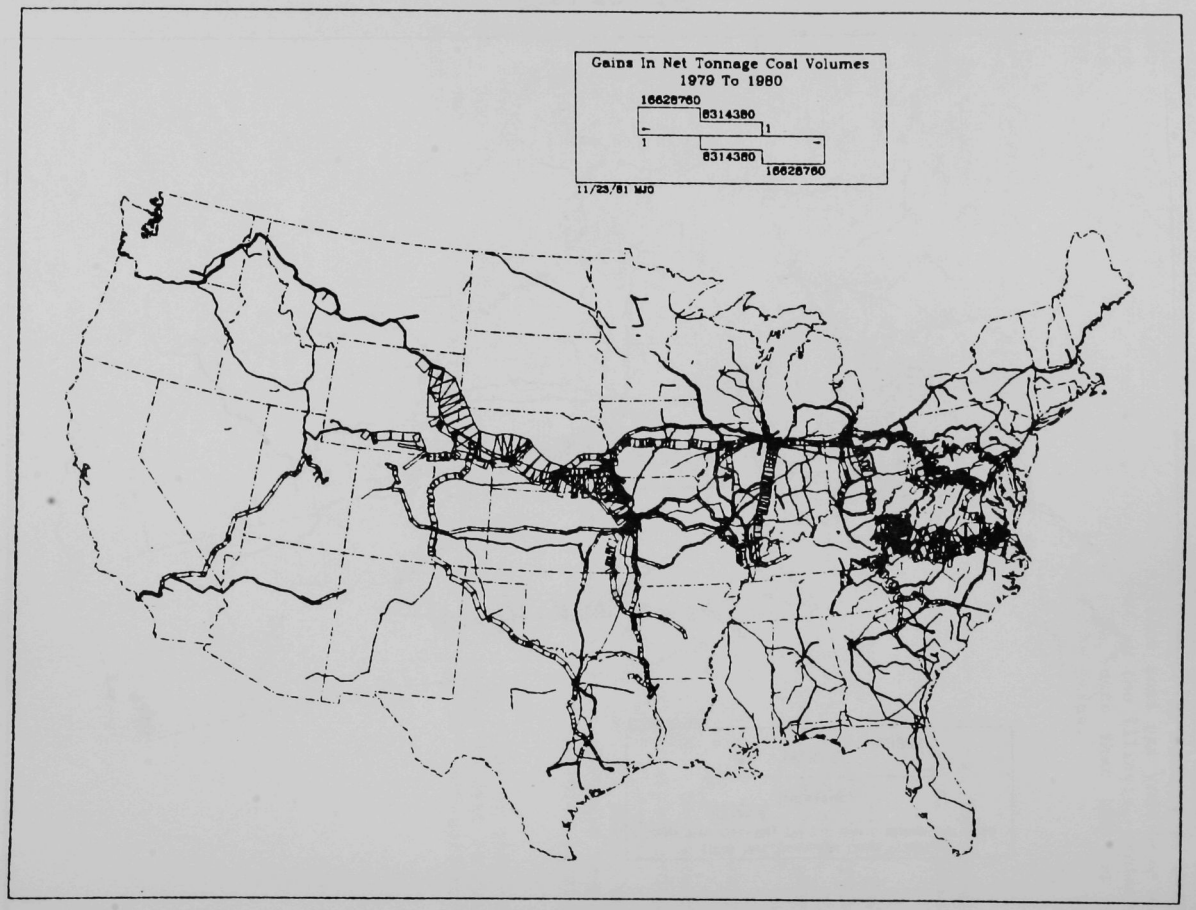
Gains In Net Tonnage Coal Volumes
1979 To 1980
16628760
8314380
1
1
8314380
16628760
11/23/81 MJO

Figure 16a

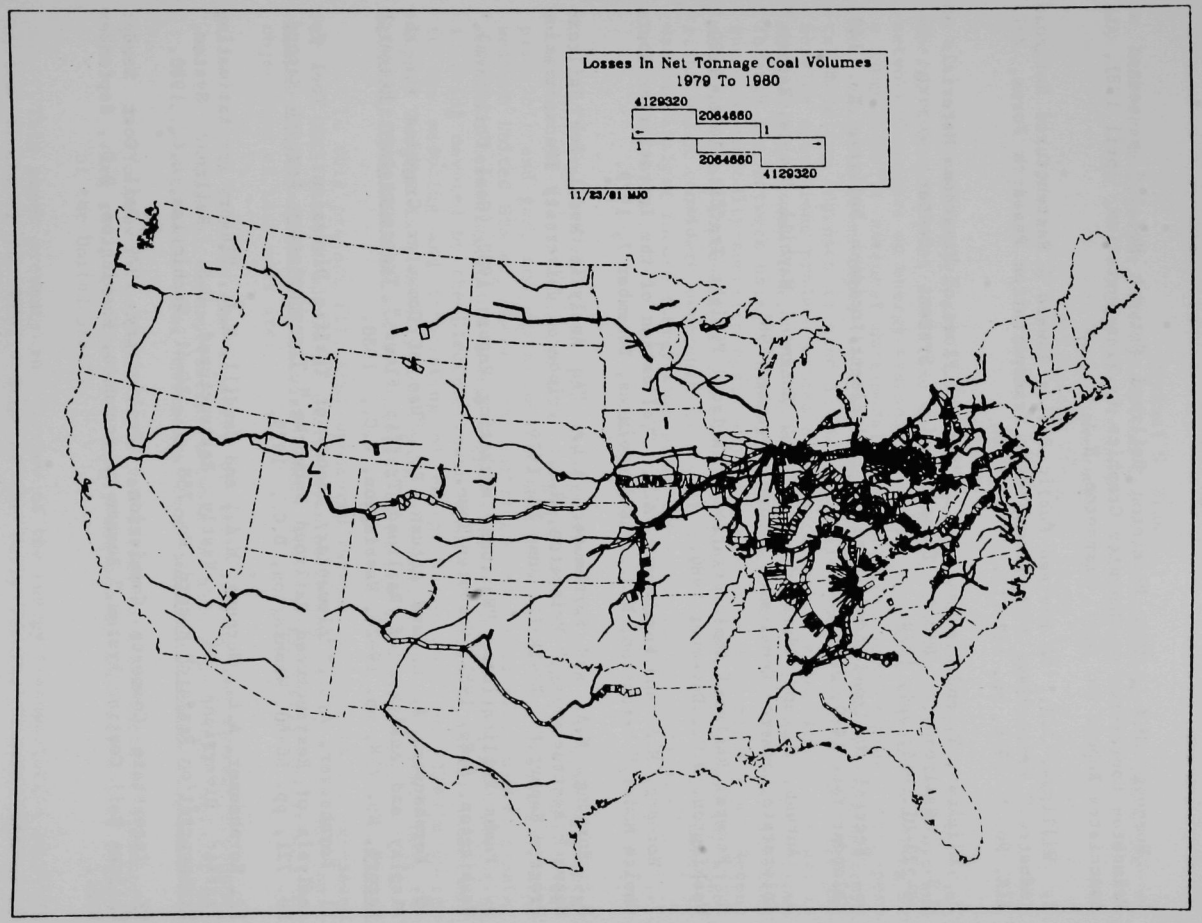
Losses In Net Tonnage Coal Volumes
1979 To 1980
4129320
2064660
1
1
2064660
4129320
11/23/81 MJO

Figure 16b

REFERENCES

1. Hornung, M.A., "The Princeton Railroad Network Model," presented at Princeton Conference on Computer Graphics in Transportation, April 1981, ALK Associates Report No. 81-1, Princeton, N.J.

2. Williams, J.H., "A Revised Public Policy Toward A Restructured Railroad Industry," Proceedings 19th Annual Mtg. Transportation Research Forum, Vol. XIX, No. 1, 1978, pp. 112-118.

3. Glickman, T. and Brachman, M.E., "Bridged Flows of Hazardous Materials on U.S. Railroads," USDOT Transportation Systems Center Report No. SS-223-U1.1-44, July 1979.

4. Federal Railroad Administration, "Accident/Incident Bulletin No. 149, Calendar Year 1980, June 1981.

5. Antush, R. and Oderwald, W., "1980 Enhanced Waybill Sample Report," Interstate Commerce Commission Report, November 1981.

6. Federal Railroad Administration, "Railroad Freight Traffic Flows, 1990," Washington, D.C., December 1980.

7. Hornung, M.A. and Kornhauser, A.L., "Validation of the Intracarrier Route Choice Model," Princeton, N.J., ALK Associates, December 7, 1979.

8. Hornung, M.A. and Kornhauser, A.L., "An Analytic Model for Railroad Network Restructuring," Princeton, N.J.: Princeton University Transportation Program Report No. 79-TR-11, June 18, 1979.

9. Pasha Publications, "National Marketing Report 1980 (Coal Utilities)," Washington, D.C., 1981, Computer Tape.

10. Kornhauser, A. L. and Antush, R., "Use of Computer Graphics for the Display and Analysis of Railroad Traffic Flows," Transportation Research Record, No. 758, pp. 19-24, Washington, D.C., 1980.

11. Kornhauser, A.L., "Elementary Theory of Traffic Diversion: A Tool for Analysis of Restructured Railroad Networks," Transportation Reseach Record, No. 721, pp. 56-60, Washington, D.C., 1979.

12. Kornhauser, A.L., Hornung, M.A., and Caudill, R.J., "Theory for Estimating Traffic Diversions on a Vastly Restructured U.S. Railroad System," Transportation Research Record, No. 758, pp. 34-41, Washington, D.C., 1980.

13. Interstate Commerce Commission, "Preliminary 1979 Rail Cost Study: Uniform Rail Costing System," Bureau of Accounts, Washington, D.C., September 1981.

MULTIMODAL NETWORK MODEL FOR COAL TRANSPORTATION ANALYSIS

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ABSTRACT

Improved analytical tools are developed for accurately forecasting energy transportation costs and for determining the impact of technology and network structure on energy transport supply. The basis for this modeling is a comprehensive national multimodal transportation network model which permits analysis of multiple commodity shipments over the network. A hierarchical modeling approach is used in which detailed models of individual freight service operations produce estimates of node and link impedances for use in the larger network model. The network model routes orgin-destination flows through the network using a minimum path algorithm with additional features such as commodity-specific costs and an equilibrium flow algorithm. Recent methodological improvements include development of a railroad routing algorithm which considers ownership as a path choice determinant. The model is used to analyze future energy transportation costs and capacities.

INTRODUCTION

Transportation costs play an important role in determining energy costs to the user. With the increasing emphasis on the use of coal to replace oil and gas, and given the availability of large coal resources in the western United States, energy transportation costs will play an even greater role in determining future energy supply costs. Consequently, much attention is being devoted by the Electric Power Research Institute (EPRI) and others to the modeling and forecasting of energy transportation. EPRI's Energy Supply Program is presently developing information and analytical tools for investigating the cost and availability of energy transportation.

In this project (1), EPRI sponsored further refinements and extension of the CACI network models of energy transportation (2, 3, 4) to develop a system of transportation network models for energy supply analysis. The objectives of this work are:

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 reliable tools for forecasting the costs of transporting coal from the coal supply regions to the coal demand regions of the United States.

This paper presents an overview of the energy transportation analysis system developed for EPRI. Some of the early results obtained with this model are also summarized.

ANALYTICAL STRUCTURE

The centerpiece of the EPRI energy transportation analysis system is a large multimodal freight transportation network model. This model stimulates the process of routing anticipated movements of both fuels and other (non-energy) commodities over a computerized representation of the nation's multimodal interregional freight transportation network. A relatively detailed multimodal network is used because the various modes of transportation, and the various routes within transport modes, compete for the freight traffic offered by shippers. All commodities are included in the analysis because shippers compete 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. Given this flow pattern, the models also compute the estimated dock-to-dock transit time, energy consumption, and transportation cost for each commodity movement.

The analytical focus of the model is on allocating intercity freight traffic to specific transport modes and routes, in a manner which is consistent with the network structure of the transportation system and with the operation of transportation markets. That is, the model is sensitive to the primary variables and trade-offs which dominate shipper decision-making and accounts for interactions among shippers in their joint use of transportation facilities. The model also approximates transportation market equilibrium and reports on the performance of the elements of the transportation system and on the service rendered to shippers. Both system performance and shipper service are measured in terms of transportation cost, transit time, and energy use.

Given the above stated model purposes and specifications, a descriptive or predictive, rather than normative, model design has been adopted. The model's design objective may be stated in somewhat simplified form as follows: to route given intercity commodity movements through a given multimodal transportation network composed of elements with known operating and performance characteristics. Hence, the scope and purpose of the model are confined to measuring the system performance and shipper service which might be expected with a specified transportation network configuration. It is the role of the analyst using the transportation network model to design and execute model run sequences which incorporate the network description and commodity flows suitable for the desired analysis.

The distinction between the normative and predictive approaches to impact assessment is crucial to proper understanding of the structure and use of the transportation network model. Normative models typically internalize the task of choosing optimal actions from among a set of possible alternatives. In doing so, however, they make use of numerous simplifying assumptions which often cause the model to bear questionable resemblance to the actual modeled system. Predictive models, on the other hand, answer "what if" types of questions and leave it to the analyst to ensure that an acceptable alternative is included in the list of queries. The transportation network model is purposely designed to be of the latter variety. Stated simply, the purpose of the model is to replicate, as faithfully as possible, the operation of the transportation system. Development and testing of

desirable system configurations remains the analyst's responsibility. The model can certainly aid the analyst in this endeavor, but it can provide no guarantee that the optimal strategy will be discovered.

Figure 1 shows the hierarchical modeling structure developed to implement these design objectives. Interregional commodity flows, a model input, define the demand for transportation. The supply of transportation is defined by the structure and behavior of each transport mode, as represented in the network and operations data base. The national freight network developed for EPRI includes approximately 2,200 nodes and 3,900 links and is an aggregated version of detailed networks prepared by several federal agencies. Cost, transit time, and energy use are estimated for network nodes and links with a set of detailed modal simulators. These modal simulators are exercised "off-line" from the main model, and the resulting node and link operations data are included in the network description. Given all of these input data sets, the transportation network model allocates the intercity freight traffic to specific transport modes and routes, and predicts transportation costs, service levels, and energy use.

TRANSPORTATION NETWORK DATA

While the network model is completely general and can be used in conjunction with any transportation network including any number of modes, subject only to computer storage and processing limitation, this analysis made use of an aggregated computerized network. This national level network represents the nation's multimodal transportation system and was prepared from several detailed networks developed for various governmental agencies over the past twenty years. The size of the base network is shown in Table 1. In the network, nodes represent individual transportation facilities such as coal mining origins, marshalling yards, ports, locks, or pipeline pumping stations. The links represent mainline intercity and interregional linehaul segments that operate between nodes. These links may represent a single facility or the combined capacity of several individual modal facilities serving a single corridor. Roughly 75 percent of the link miles represent single facilities, and 25 percent feature corridor level aggregations of two or more linehaul facilities.

Computer plots of the 1980 transportation networks are displayed in Figures 2 through 5. These modal systems serve as the base networks. Changes for future years are made to reflect network expansions either already underway or planned and highly likely to occur.

Space does not permit detailed discussion of the several modal simulators used to generate node and link time, cost, and energy use data. The simulators used are listed in Table 2. These include some of the most well known operations and cost models for the various modes developed in recent years. For details, see references 1 or 3.

TRANSPORTATION NETWORK MODEL

REPRESENTATIONS

The large size of the networks to be simulated and the complexity of potential intermodal interactions dictate that the transportation network

model be relatively abstract in comparison with the detailed modal simulators with which many analysts are familiar. In keeping with this view, the transportation network model includes the features summarized below.

Transportation Networks. The multimodal transportation network is represented as a set of connected links and nodes. Links represent linehaul transportation facilities and are described by the nodes at each end of the link, length, transport mode, and transit time, cost, and energy-use parameters. Nodes have attributes such as name, number, location (coordinates), mode, and time, cost, and energy-use parameters. A special class of links, called "access links," represent local transportation and connect commodity origin-destination regions to the network. Another special link class represents intermodal transfer facilities and operations and is used to stitch together the modal subnetworks into an integrated multimodal network.

Performance Functions. The operating characteristics of links and nodes are represented in abstract form, as functions relating the cost of traversing a link or node to the amount of traffic which uses it. These costs are intended to be fully allocated costs and hence may not be equivalent to the transportation rates paid by shippers. (The model formulation is completely general; hence rates could be used if desired.) Similar functions, called "time functions," relate transit time to shipment volume, and "energy functions" relate energy use to volume. Cost, time, and energy functions for intermodal transfers and for regional access are also used. Performance attributes of linehaul links may vary by direction of travel.

Commodity Movements. Each requirement for transportation is described by origin region, destination region, commodity type, and tonnage. Optional specification of allowable modes or routings is also permitted. Commodity types are defined by a two-digit classification and by weighting factors specifying the trade-off between cost, transit time, and energy use to be observed in developing network routings for shipments of this type. These general weightings for the commodity may be overridden for specific shipments. Commodity types may also have associated factors which are used to adjust node and link performance functions to account for commodity-specific characteristics. This extremely important and useful feature is a departure from previous large-scale network models.

Transportation Equipment. Individual power units, cargo vehicles, traffic control systems, and other transportation technology representations are implicitly included in the link and node performance functions and commodity-specific adjustment factors. Hence no separate vehicle representation is used.

ALGORITHMS

The main operation of the model consists of several algorithmic processes that select paths and assign traffic. These main logical operations of the model are further described below.

Path Selection. A principal function of the model is determining the least-disutility path for each commodity movement. Included in the input data are definitions of the multimodal network in terms of nodes and links.

Each commodity movement is defined in terms of origin and destination regions, tonnage, commodity type, and route restrictions, if any. The problem is to find, for each movement, that path between the origin and destination regions which minimizes disutility or "impedance," where a path is defined as a sequence of connecting nodes and links.

Determining routes between two points in a network is a familiar problem in transportation analysis, and the transportation network model uses standard solution techniques which have been developed for finding the least-time or, in this case, least-impedance route. The impedance of traversing a network element is defined as the weighted sum of:

- Cost, as determined from the element's cost function;
- Transit time, as determined from the element's time function; and
- Energy use, as determined from the element's energy function.

Weightings on these variables vary with the commodity.

The minimum path algorithm finds that path from origin to destination which minimizes the sum of the disutilities incurred for traversing the nodes and links making up the path. Consistent with prevailing market theory, decentralized shipper decision-making is assumed; that is, locally optimal paths (those which minimize disutility from the individual shipper's viewpoint) are generated rather than globally optimal paths (those paths which minimize total systemwide disutility).

The minimum path algorithm used may be represented mathematically as follows. The disutility of a path is a function of time cost and energy use:

$$Z_{ij} = f\,(T_{ij}, C_{ij}, E_{ij})$$

where

Z_{ij} = disutility between origin region i and destination region j

T_{ij} = time between i and j

C_{ij} = cost between i and j

E_{ij} = energy use between i and j

Path disutility is computed as a function of facility transit time, t_k, facility shipping cost, c_k, and facility energy use, e_k, as determined by the facility's time, cost, and energy functions. A commodity-specific linear combination of these variables is used:

$$Z_{ij} = \sum_{k \varepsilon P_{ij}} a_m t_k + b_m c_k + w_m e_k$$

where

a_m = time weighting factor for commodity m (depends on value per ton and "inventory charge")

b_m = cost weighting factor for commodity m

w_m = energy weighting factor for commodity m (zero in most applications, since energy costs are included in c_k)

P_{ij} = collection of network elements in the path from i to j

Path Constraints. Commodities may be restricted as to which modes of transportation they may utilize. In this case, nodes and links of the disallowed modes are not considered in the path selection process. (For instance, nonpetroleum products will not be shipped via a petroleum pipeline.) Also, individual shipments may be restricted to following a specified route from origin to destination. Links and nodes are limited to carrying flows below their capacities.

Assignment Algorithm. Link and node disutilities are initially set by evaluating the performance functions at some user-specified volume estimate or, optionally, at the point of least disutility. Shipments are assigned to paths using normal minimum path logic. Once all the shipments have been routed, the performance functions are reevaluated at actual flow volume levels for output reports.

OUTPUTS

Many types of output reports, with various levels of detail, are produced by the model. Standard outputs are listed below.

- Path Traceback--optional for each shipment; displays nodes along the selected path through the multimodal network, and gives the total distance, cost, time, energy use, and disutility of that path.

- Network Flow Report--for each link and node in the network:

  -- Tonnage assigned
  -- Transportation cost
  -- Transit time
  -- Energy use
  -- Total disutility

- Modal Summary Report--for each mode, by node and link class:

  -- Average tons and ton-miles (linehaul links only)
  -- Average and total transportation cost
  -- Total energy use
  -- Total disutility

- Commodity Summary Report--for each commodity class, by mode:

  -- Modal share of tons and ton-miles
  -- Modal share of transportation cost, ton-days, energy use, and disutility

The model also produces four types of (optional) output data files, as listed below.

- Network File--this is a copy of the input network file, with the exception that all initial node and link volume estimates are replaced by final assigned volumes.

- Network Flow File--a machine processable version of the network flow report.

- Path File--contains the following information for each shipment:

  -- Commodity code
  -- Origin region
  -- Destination region
  -- Modes used
  -- Tonnage or quantity
  -- Transportation cost
  -- Transit time
  -- Energy use
  -- Distance
  -- Disutility weighting factors
  -- Sequence of nodes in least-disutility path

- Modal Traffic Files--one such file may be produced for each mode. Each file consists of shipment records with the following contents:

  -- Commodity code
  -- Tonnage
  -- Beginning node of a single-mode route or route segment
  -- Ending node of a single-mode route or route segment

These files, particularly the network file and the path file, may be used to generate specialized reports not included as standard model outputs. Prime examples of outputs which may be readily prepared from these files are computer graphics such as minimum path plots and network flow maps.

EQUILIBRIUM ASSIGNMENT

The present version of the transportation network model is normally used in conjunction with equilibrium-seeking traffic assignment routines. An assignment of commodity shipments to specific routes in a transportation network is in equilibrium if it is impossible to decrease the impedance of any shipment by switching it to a different route. It is reasonable to assume that such an equilibrium assignment will result if routing decisions are made by a large number of shippers each independently attempting to

minimize their own transportation costs. Hence, equilibrium route assignments should normally be used to predict flows in networks. The transportation network model assigns each shipment to the least impedance route using a shortest path algorithm. If all network node and link impedances were constant, an equilibrium assignment would result immediately. However, impedances are actually functions of the flows through each network element. The model initially evaluates the impedances using estimated flow volumes and assigns routes based on these estimates. In general, the resulting flows will not equal the estimated flows, and the system will not be in equilibrium. In previous applications, the model was used in an iterative fashion with the flows resulting from one route assignment used as the basis for calculating impedances for an improved assignment. Unfortunately, it is well known that a sequence of such iterations may not converge to equilibrium, particularly with all-or-nothing assignment logic since a true equilibrium may require shipments to be split between two or more routes.

Fortunately, algorithms which guarantee convergence to an equilibrium route assignment are available (5, 6). The algorithm employed with the transportation network model works by iteratively combining a sequence of route assignments of the type already generated by a run of the model. Hence adopting equilibrium assignment required only the development of two utility programs and a rather simple modification of the model itself; for full details see references 1 or 4. Technically, this procedure should be termed "quasi-equilibrium assignment," since the multi-commodity version used is a heuristic modification of the algorithm described in references 5 and 6, and no proof of convergence has been attempted.

RAILROAD ROUTING MODEL

As indicated in Table 1, two different railroad networks were developed for EPRI. The more aggregated network is used by the transportation network model and is useful for corridor analysis and in the determination of modal splits. Once this network has been used in conjunction with the multimodal network, rail traffic can be analyzed in more detail by using the railroad routing model. This is a single mode model that uses the larger rail network displayed in Figure 6.

The railroad routing model differs from the transportation network model in several key areas:

- Shipments are routed from node to node rather than from region to region.
- Linehaul links are further described by the owner of the track.
- Routings are determined by considering the trade-off between staying on a particular railroad and switching railroads to avoid circuitous routings.

The concept of disutility is preserved in the routing model. However, the algorithm used to find paths differs from that used by the transportation network model. The railroad routing model finds a sequence of transfer points where a shipment may switch from one rail line to another. The best transfer point is defined by the following disutility equation:

$$Z_{ij} = f(T_{ij},C_{ij},E_{ij})/a + D_{jd}$$

where

$f(T_{ij},C_{ij},E_{ij})$ = disutility between node i and node j as defined for the transportation network model

a = user specified trade-off factor between staying on a rail line and avoiding circuitous routings

D_{jd} = distance between node j and ultimate destination d.

Given that the shipment is at node i, the program finds a node j that can be reached from node i on a single rail line with minimum Z_{ij}. Node j becomes the transfer point and the process is repeated with i = j until the destination d is reached.

The railroad routing model implements the routing algorithm defined above as follows:

1. Determine the distance from every node in the network to the destination node via the minimum distance path. Railroad ownership is ignored in this step.

2. Starting from the origin node, find the minimum impedance path to all nodes which can be reached via links owned by a single railroad; links not assigned to any railroads can also be used.

3. For each node of the tree found in step 2, compute

$$Z = \frac{\text{impedance from origin to node}}{\text{circuity limit factor}} + \text{distance from node to destination}$$

4. Select the node with the minimum value of Z as an intermediate node; a single railroad path to it was found in step 2. If this is the destination node, stop; if not, repeat step 2 starting at the intermediate node rather than at the origin node.

The circuity limit factor controls the trade-off between staying on a single railroad for as long as possible even if the route is circuitous vs. switching railroads to take a shorter route. The value of this factor is essentially the number of extra impedance units the model is willing to spend in order to get a shipment one mile closer to the destination via the current railroad. The algorithm, which is still being tested, has shown some ability to reproduce actual railroad routings. Table 3 gives an example.

The railroad routing model is comparable to and compatible with the transportation network model in many ways. The two models share a common language (SIMSCRIPT II.5), basic structure, and input/output scheme. Essentially the railroad routing model is a customized version of the transportation network model which makes allowances for the additional rail data and uses a different routing algorithm.

Figure 7 shows the way in which the transportation network model and railroad routing model can be used in an integrated fashion. Total interregional commodity flows are presented to the transportation network model which loads them onto the corridor level multimodal network. The node-to-node rail traffic generated in this run, which is available in the output of the transportation network model, is then input to the railroad routing model which loads this traffic on the detailed rail network. Since the two networks are compatible, as indicated by the dashed line connecting them, this analysis sequence produces comparable transportation network model and railroad routing model results for the rail mode.

INITIAL APPLICATIONS

The EPRI energy transportation analysis system was used to conduct preliminary studies of several possible future network systems. Some indicative results of these analyses appear below. Detailed findings are given in the project final report (1).

BASELINE: 1980, 1990, 2000

These model runs hypothesized a steady shift from petroleum to coal as a fuel source, and increased use of western coal, following future coal movement forecasts developed by EPRI. Only limited transportation network improvements were assumed to test the ability of the current and committed system to accommodate future coal movements and to obtain baseline cost estimates against which to measure the effects of network changes.

Table 3 shows some typical origin-destination coal transportation cost estimates produced by the model; literally thousands of such data points appear in the model's output data files.

The 1990 run features 1.4 billion tons of coal shipped between regions, up from 622 million tons forecast for 1980. The average cost of transporting coal will increase by about 10 percent (in constant dollars) over this period, due primarily to shifting origin-destination patterns which necessitate longer coal hauls, and due also to increasing congestion of transportation facilities. Over this same time interval, the cost of moving nonenergy commodities will rise by 28 percent. Smaller cost increases are projected for the succeeding decade, during which coal shipments will rise to 2.2 billion tons annually. Without increases in capacity the transportation network will be unable to move all of this coal; approximately 100 million tons of coal (mostly produced in the west) were unable to find an uncapacitated network routing in the year 2000 baseline run. Adding this traffic to an already congested network would cause average transportation costs to be much higher than those shown in Table 3. Hence, if this coal traffic develops as anticipated, there will be a need to invest in additional rail capacity in those corridors serving the western coal fields.

EFFECT OF USING RATES INSTEAD OF COSTS

A special 1980 scenario was constructed in which marginal costs were used to simulate transportation prices for all commodities other than unit train coal. Estimated prices for unit train compatible coal were determined

from formulas developed through rate-cost regression analysis (1). 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 differentials on model behavior.

Table 5 displays the percentage of market tonnage by transportation modes. All traffic is included and the results are given for both the "cost" run and the "price" run. Comparison reveals that there is little difference in modal splits; multimodal transport and rail capture a bit more of the market using prices, while highway and waterway decrease somewhat. The cost efficiencies associated with high speed long distance rail transportation continue to attract the largest share of the traffic.

This analysis demonstrates that rates as well as costs can be used with the transportation network model developed for EPRI. But comparing the outputs of the network model for both rates and costs, it is apparent that similar results were achieved. Therefore, costs can be used with confidence in lieu of prices when predicting modal shares, service levels, and energy use. This is a fortunate result, since estimating transportation prices is a difficult and expensive process, to be avoided if possible.

COAL SLURRY PIPELINES

A special transportation system run was made for the year 1990 to determine the potential impacts of two proposed coal slurry pipelines on energy supply. First, the proposed ETSI line from Gillette, Wyoming, to White Bluff, Arkansas, was added. This line will be 1,036 miles long and 38 inches in diameter. It will have the potential to deliver approximately 25 million tons of coal per year. An additional egress feeder line was added to move coal to Baton Rouge, Louisiana. The second potential line that was introduced to the model was the Texas Eastern Line from southern Montana and northern Wyoming to the Texas Gulf Coast. This line is expected to be a 42 inch line with an annual capacity of up to 38 million tons.

For the purpose of comparative analysis, projected coal shipments from Wyoming to Arkansas, Louisiana, and Texas were constrained to flow over each of these lines in order to obtain sufficient tonnage for this sensitivity analysis. The overall effect of Wyoming coal being diverted to the coal slurry pipelines was felt nationwide. Slight shifts in modal assignment occurred due to reductions of coal traffic on several rail lines in the west. Using national averages, the cost of transportation for noncoal commodities was reduced by two-tenths of a percent per ton-mile, and the average time for moving noncoal commodities was improved by 13.6 percent.

Total costs of moving unit train compatible coal by rail, on the other hand, declined by .14 mills per ton-mile as less economical rail shipments of coal were diverted to slurry pipelines. Nationwide, total unit train coal movements by rail declined by 6.0 percent, and combined water and joint movements declined by 3.7 percent. The cost of moving unit train compatible coal by all modes was projected to be reduced from 5.7 to 5.6 billion dollars. While this cost decrease is slight, it can be concluded that the savings in time achieved by congestion relief represent the greatest benefit, i.e., faster rail service caused by lower capacity utilization as a result of coal being diverted from rail.

For individual shippers, the use of slurry pipelines would result in cost saving of from $1.06 to $3.67 per ton in the corridor from the western areas of the Northern Great Plains Region to the South Central Region. The savings, while substantial, are accompanied by other problems. The question of water rights and water used in the slurry process is both controversial and complex. In the west, water is a limited resource, even considering recent studies which indicate that with proper management sufficient supplies are available. In addition, construction of coal slurry pipelines is being impeded by right-of-way issues.

The cost savings for slurry pipelines predicted by the model are predicated on the assumption that current cost estimates for constructing and operating slurry systems prove to be correct. The systems tested here did not include a line to return water to the head of the pipeline. Any increase in capital costs, whether for this feature or any other, will reduce or eliminate the slurry pipeline cost advantage.

SUMMARY OF FINDINGS

The computer models developed for EPRI can be used as an analysis tool to clearly depict the impact of transportation networks changes on energy supply. The predictive power of the models is also useful in projecting the long run cost components of energy supply attributed to transportation.

Considering the transportation network system and the massive increases in coal utilization projected for 1990 and the year 2000, movement costs can be expected to rise substantially. Shortfalls in capacity, even considering transportation alternatives, contribute to this rise in costs. This increase is somewhat surprising given the ubiquity of the transportation system. Coal traffic is projected to increase so quickly that existing and planned network changes simply cannot accommodate all of the traffic. As a result, increased costs can be anticipated due to increased congestion. Longer haul distances associated with the use of western coal also exert an upward pressure on costs.

A second conclusion is that transportation can constrain the nation's ability to achieve targeted levels of coal consumption. The presently anticipated (though not formally committed) network will support shipment of no more than 2.1 billion tons per year, assuming that the predicted shift to western coal occurs. Similarly, the system will support utilitization of no more than 1 billion tons of western coal. Although not explicitly tested, it appears that a somewhat higher coal consumption level could be supported with greater reliance being placed on Midwestern and Appalachian sources. In comparison, total interregional coal transportation was about 623 million tons in 1980, and by the year 2000 the scenario projections call for future interregional coal flows to increase to 2.2 billion tons per year.

These two key findings together indicate that the United States is near the threshold of requiring immediate investment in increased long-distance coal transportation capacity. The flow plots developed in this analysis (1) show the corridors where these increases are needed. Required capacity can be provided in a number of ways, including upgrading of existing rail lines, building new lines, increasing lock and channel capacities in river corridors, and building coal slurry pipelines.

The reader must bear in mind that the modeling results are based on the use and interpretation of a computerized mathematical model of the U.S. interregional freight transportation system. Although care has been taken to make the model as realistic as possible, no model can ever replicate reality perfectly. This is especially true considering that input data and new forecasts of commodity flow information change over time, often dramatically. Hence, model results must be tempered with an understanding of the assumptions and limitations of the transportation network model, the data base, and the coal flow data. Given this understanding, it is seen that the modeling results are useful for highlighting the overall system effects of energy production-consumption-transportation scenarios, for identifying modal transport corridors which will constrain energy supply if there is no investment in additional capacity, and for estimating fuel transportation routings and costs.

REFERENCES

1. CACI, Inc., Transportation Network Models for Energy Supply Analysis, Final Report, Research Project 1219-3, Electric Power Research Institute, Palo Alto, CA, January 1981 (Draft).

2. Bronzini, M.S., "Evolution of a Multimodal Freight Transportation Network Model," Proceedings--Transportation Research Forum, Vol. 21, No. 1, 1980, pp. 475-485.

3. Bronzini, M.S., Freight Transportation Energy Use, Report No. DOT-TSC-OST-79 -1 (I-IV), Transportation Systems Center, Cambridge, Massachusetts, October 1978.

4. 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.

5. LeBlanc, L.J., Morlok, E.K. and Pierskalla, W.P., "An Efficient Approach to Solving the Road Network Equilibrium Traffic Assignment Problem," Transportation Research, Vol. 9, 1975, pp. 309-318.

6. Eash, R.W., Janson, B.N. and Boyce, D.E., "Equilibrium Trip Assignment: Advantages and Implications for Practice," Transportation Research Record, No. 728, 1979, pp. 1-8.

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TABLE 1. TRANSPORTATION NETWORK (1980)

Mode	Miles	Links	Nodes
Rail*	87,366	1,401	863
Highway	103,504	1,290	581
Waterway**	20,707	482	459
Domestic Deep Draft***	33,012	105	78
Crude Pipelines	23,343	102	64
Products Pipelines	33,578	208	124
Coal Slurry Pipelines	278	5	6
Intermodal Transfers	--	346	--
Total	301,788	3,939	2,175

*This network is also available in a less aggregated version, consisting of 1,481 nodes and 3,091 links representing 145,585 miles of track. The less aggregated version is used for railroad routing analysis.

**Includes Great Lakes and intracoastal shallow draft routes, as well as inland rivers.

***Includes Panama Canal and St. Lawrence Seaway routes.

TABLE 2. MODAL SIMULATORS

Mode	Simulator	Ref.**	Functions Provided* Cost	Time	Energy
Rail	TSC rail cost model	1	X		
	CACI rail capacity model	2,3		X	
	CACI train delay simualtor	4		X	
	TSC train performance calculator	4		X	X
Highway	AAR truck cost model	4	X		
	ORNL truck speed model	5		X	
Waterway	CACI lock capacity function generator	3		X	
	TSC waterway cost model	6	X		X
	INSA inland navigation simulation model	7		X	
Pipeline	PMM & Company pipeline functions	8	X	X	X

*These modal simulators are supplemented by published data and procedures, particularly for the highway and pipeline modes. See reference 4 below.

**References:

1. J.F. Murphy, "Rail Cost Modeling, Vol. I, Rail Freight Operations Cost Methodology," DOT Transportation Systems Center, Cambridge, MA, September 1976.

2. CACI, Inc., "A Train Dispatching Model for Line Capacity Analysis," Interstate Commerce Commission, Rail Services Planning Office, Washington, D.C., January 1976.

3. CACI, Inc., "Waterway and Rail Capacity Analysis," DOT Transportation Systems Center, Cambridge, MA, September 1976.

4. CACI, Inc., "Freight Transportation Energy Use," 4 vols., Report Nos. DOT-TSC-OST-79-2, I to IV, DOT Transportation Systems Center, Cambridge, MA, July 1979.

5. R.J. Olsen and G.W. Westley, "Synthetic Measures of Truck Operating Times Between the Metropolitan Centers of BEA Economic Areas: 1950, 1960, and 1970, with Projections for 1980," Report No. ORNL-NSF-EP-78, Oak Ridge National Laboratory, Oak Ridge, TN, January 1975.

6. CACI, Inc., "Inland Waterway Transportation Cost Model," DOT Transportation Systems Center, Cambridge, MA, June 1977.

7. CACI, Inc., Inland Navigation Systems Analysis, Vol. 5, Waterway Analysis," Office of the Chief of Engineers, Corps of Engineers, Washington, D.C., July 1976.

8. Peat, Marwick, Mitchell & Co., "Energy and Economic Impacts of Projected Freight Transportation Improvements," DOT Transportation Systems Center, Cambridge, MA, November 1976.

TABLE 3. TYPICAL RAILROAD ROUTING ALGORITHM RESULTS

Coal From Fleming, KY to Norfolk, VA		
	Path 1--Circuity Limit Factor = 10 (Shortest Route)	
1.	Fleming-Blackey-Hazard-Winchester, KY-	via Family Lines
2.	Ashland, KY-Kenova-Huntington-Barboursville-Charleston-Raleigh-Ronceverte, WV-Clifton Forge-Glasgow, VA-	via Chessie
3.	Roanoke-Lynchburg-Pamplin-Petersburg-Norfolk, VA	via Norfolk & Western
	Path 2--Circuity Limit Factor = 14 (Correct Route)	
1.	Fleming-Blackey-Hazard-Winchester-Sinks-Corbin-Pineville-Harebell, KY-Cumberland Gap, TN-Hagans-Big Stone Gap, VA-	via Family Lines
2.	St. Paul-Cedar Bluff-Bluefield-Roanoke-Lynchburg-Pamplin-Petersburg-Norfolk, VA	via Norfolk & Western
Coal From Donkey Creek, WY to Houston, TX		
	Path 1--Circuity Limit Factor = 14 (Correct Route)	
1.	Donkey Creek-Orin-Wendover, WY-Northport-Sidney, NE-Sterling-Brush-Denver, CO-	via Burlington Northern
2.	Colorado Springs-Pueblo-Trinidad, CO-	via Santa Fe
3.	Dalhart-Amarillo-Estelline-Acme-Chillicothe-Wichita Falls-Bowie-Fort Worth-Waxahachie-Corsicana-Teague-Dobbin-Houston, TX	via Fort Worth & Denver

TABLE 4. ESTIMATED COAL TRANSPORTATION COSTS

Supply Region	Demand Region	Transportation Costs ($/ton)*		
		1980	1990	2000
Northern Appalachia	New England	12.15	17.70	18.00
Southern Appalachia	Southeast	7.40	8.80	8.90
Midwest	West Central	8.40	10.40	12.25
West Northern Great Plains	East Central	18.60	20.80	23.30
Rockies	Pacific	16.90	20.20	21.35
Network Average		11.90	13.10	13.60

*Expressed in 1980 dollars.

TABLE 5. MODAL TRAFFIC SHARES: COST VS. RATE

Mode	% Tonnage		Difference
	Cost Run	Price Run	
Rail	35.4	36.3	+0.9
Highway	22.3	20.0	-2.3
Water	11.5	10.9	-0.6
Domestic 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	0.1	0.1	0.0
Multimodal	7.1	9.0	+1.9

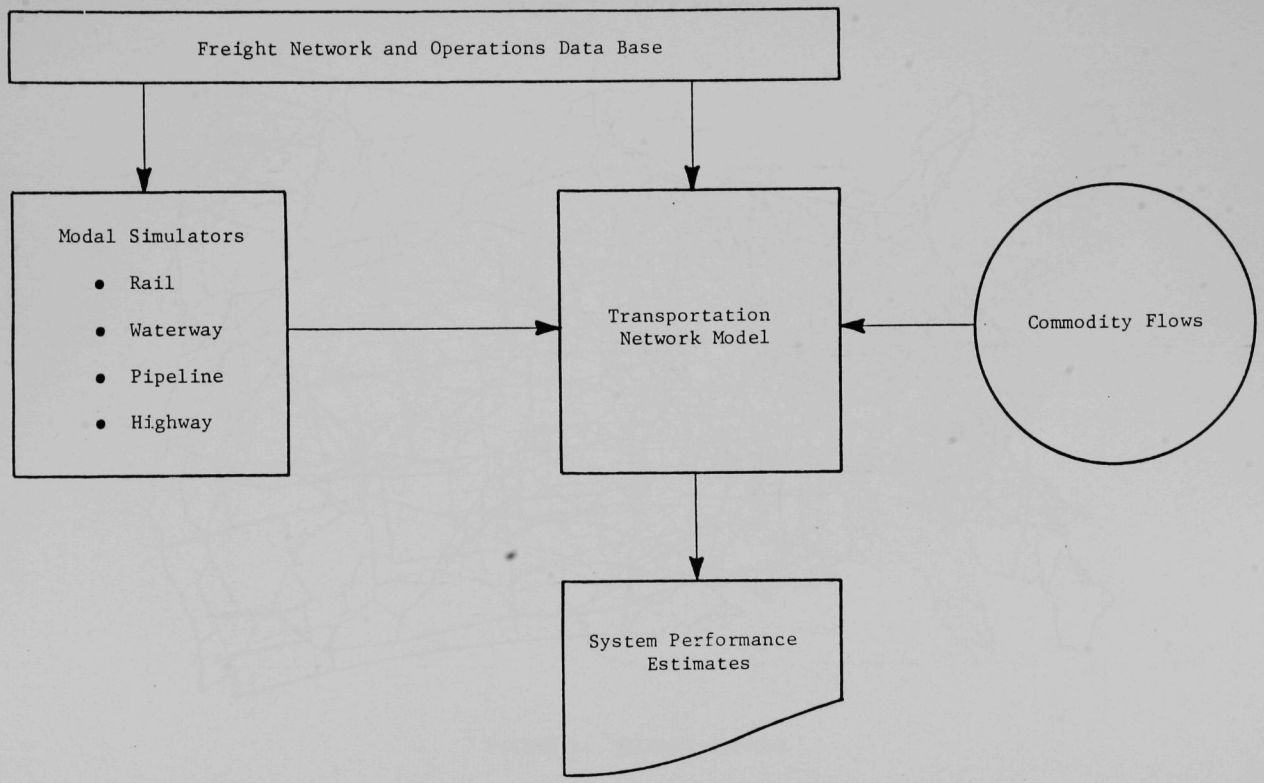

FIGURE 1. HIERARCHICAL MODEL STRUCTURE

FIGURE 2. RAIL NETWORK

FIGURE 3. HIGHWAY NETWORK

FIGURE 4. WATERWAY NETWORK

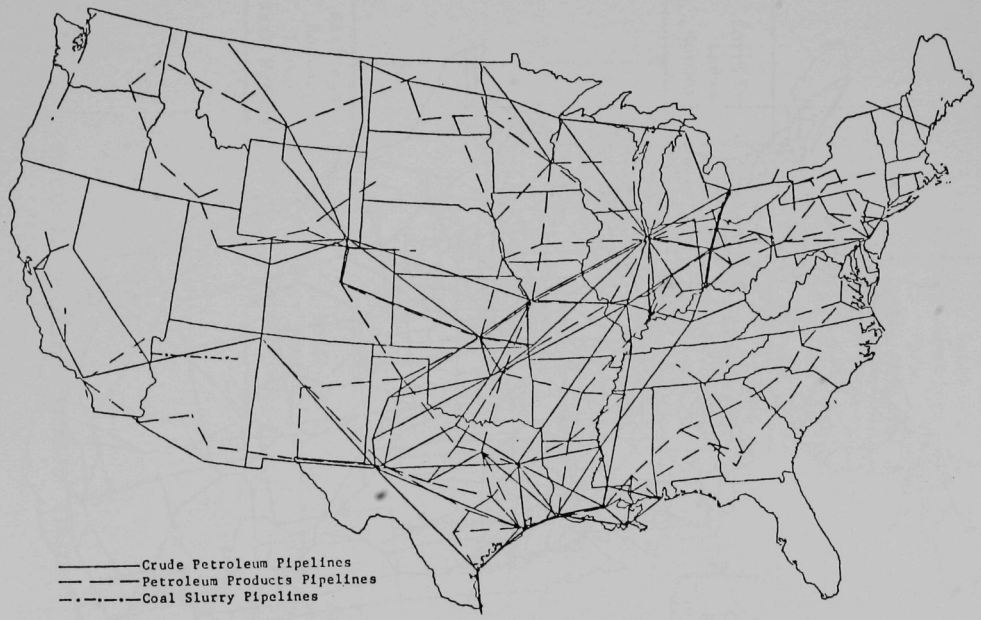

FIGURE 5. PIPELINE SYSTEMS

FIGURE 6. DETAILED RAIL NETWORK

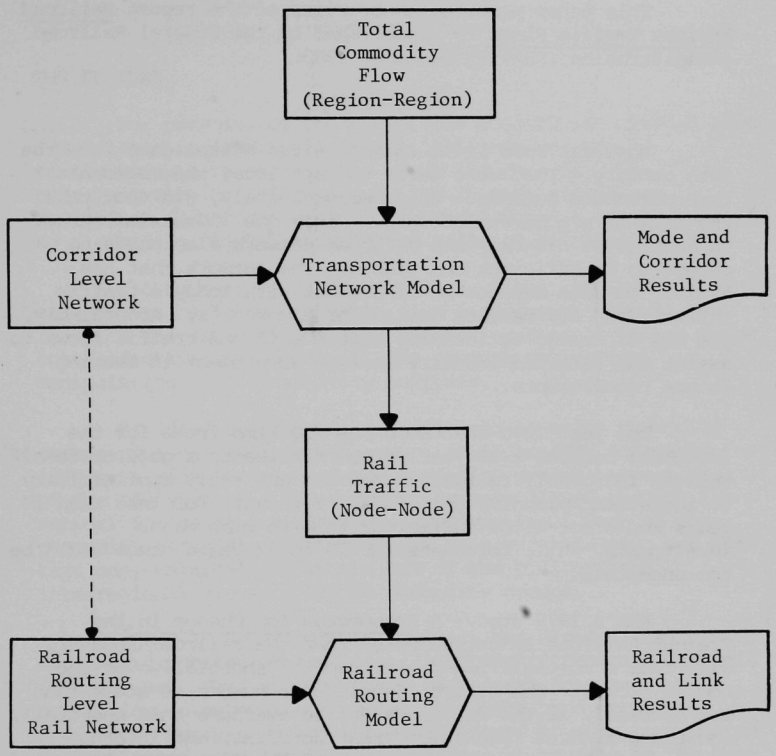

FIGURE 7. MULTISTAGE MODELING STRATEGY

RAIL FREIGHT FORECASTS - 1990

Raphael Kedar, Federal Railroad Administration

ABSTRACT

This paper provides an overview of the report Railroad Freight Traffic Flows 1990 published by the Federal Railroad Administration (FRA) in December 1980.

INTRODUCTION

Most railroad lines in the United States date from the 19th century. They were built to meet local and regional transportation demands. Only, progressively, did they take the form of a coherent network. Since the industrial market in America is dynamic, the railroad network also needs to change to be efficient and viable. The network that has evolved to date may not be consistent with today's traffic patterns and may be less suited for tomorrow's. Accordingly, the FRA attempted to identify future railroad traffic flows to assist the railroad industry and the Government in meeting future requirements.

The year 1990 was chosen as the time frame for the forecasts because a 10 year period represents a good trade-off between reasonably reliable forecasts and their applicability to investment-planning decisions. Forecasts for less than 10 years would not allow sufficient time to plan major investments, while forecasts for 15 to 20 years hence would be too uncertain.

FRA's 1978 study, A Prospectus for Change in the Freight Railroad Industry, noted that the railroad industry will face a multibillion-dollar capital shortfall over the coming decade. The report identified a number of steps that are necessary if the railroads are to overcome this shortfall, including reduced regulation, restructuring, and internal management changes. Congress enacted the Staggers Rail Act of 1980 to substantially reduce regulation of railroads, but the remaining steps must still be implemented.

The report examined a projected mainline network of the U.S. railroad system. The analysis was based upon minimum distance routing of traffic and did not include the circuity of rail movements due to corporate ownership or physical condition of lines. The effort focused on prospective traffic flows without regard to capacity constraints on the mainlines or in the yards.

The maps in the report are the first to show railroad commodity flows vividly and comprehensively. They provide insight not only into the railroad network but also into the geographic structure of American industry. Innovations in network analysis, economic forecasting, and computer graphics make such presentations possible.

METHODOLOGY

THE REGIONS

For purposes of the study, the country was divided into 129 traffic regions. All freight originations and terminations were assigned to these 129 regions. The principal city or railroad junction in each region was designated a centroid or a node. The 129 nodes were connected by a series of links representing railroad mainlines.

The numbers of traffic regions, links, and nodes were selected to be large enough to give a representation of the flows on the railroad mainline network, yet small enough to be cost-effective and to permit ease of data collection, manipulation, and sensitivity analysis.

Railroad freight was divided into 14 major commodity groups plus one "all other" group. Rail traffic forecasts for 1990 were made for each of the commodity groups between each of the 129 regions. The commodities were flowed through the network following a minimum-distance routing. Each of the commodity group flows is displayed on a separate map, but the last map--enlarged--shows the sum of the bidirectional, interregional flows of all 15 commodity groups.

The U.S. Department of Commerce has divided the continental United States into 171 Bureau of Economic Analysis (BEA) areas. They are the basis of Federal forecasts of production, consumption, population change, and economic activity. Forty-three of these BEA areas, however, originated or terminated very little railroad freight traffic in the past and are not expected to change in the near future. In this study, these 43 BEA areas are joined to appropriate adjacent areas that have significant railroad activity. In one case, the BEA area representing the greater New York area was divided in two because railroad routings to New York City differ from routings to the New Jersey side of the Hudson River.

One hundred twenty-nine (129) FRA traffic regions resulted from combining these 43 BEA areas with adjacent areas and dividing one area. Each region was designated a

centroid--either a principal traffic-generating or terminating point within the region, or a major railroad junction. These centroids became the nodes of the railroad network. For analytical purposes the centroid is the point at which all traffic within the region originates or terminates.

THE NETWORK

The so-called Outlook Network, a general representation of the physical railroad mainline network, is a series of links (representing mainlines) that connect nodes (representing the major traffic originating or terminating points or major railroad junctions).

The railroad mainline network map represents the results of the following step-by-step analysis. A preliminary map was drawn to show existing physical mainlines chosen on the basis of their traffic density. Subjective judgment was used to select the links for the network map. In areas where traffic volume was very low, links were removed from the network; conversely, in certain high-density traffic areas, additional links were added to provide a clearer representation of the network.

Each link represents one or more mainlines. For example, the link from Las Vegas to Salt Lake City represents one mainline owned by the Union Pacific Railroad. The link from Cleveland to Buffalo denotes two mainlines, one owned by the Consolidated Rail Corporation (Conrail), the other owned by the Norfolk and Western Railway. The link between Chicago and Davenport represents five mainlines owned by the Santa Fe, the Burlington Northern, the Milwaukee Road, the Chicago and North Western, and the Illinois Central Gulf. The mileage applied to each link shows the actual mileage if a single mainline were represented, or the average mileage if multiple mainlines were represented.

Traffic was routed on the basis of minimum distance, as determined by a mathematical algorithm. Minimum distance routing does take into account corporate ownership or the physical condition of lines. Some traffic routings are determined by the carrier or the shipper who use a variety of considerations when selecting their specific routings. While computer technology allows corporate ownership and other considerations to be taken into account when determining routes, this analysis shows the basic commodity flows only; it does not attempt to show all the possible routings.

Since there are over 40,000 freight stations in the United States, the development of a computer model to represent the railroad network connecting those 40,000 freight stations would be too costly to be practical. As the network representation becomes less detailed, the costs of finding minimum paths and assigning commodity flows decrease substantially. It was necessary to exchange the detail of network representation for the cost of computing time. The result is an easily displayed, comparatively small network that connects the principal traffic originating and terminating points.

The network also contains all the railroad mainlines included by the U.S. Department of Defense in its Strategic Rail Corridor Network, a network based on estimates of defense traffic requirements in peacetime. Not included are the branchlines and secondary lines that serve specific military installations.

THE FLOWS

Traffic flow lines on commodity maps show the relative amounts of net tonnage for the commodity movements on the various links. Net tonnage does not include the weight of locomotives and freight cars for both loaded and empty movements. Gross tonnage, which includes locomotive and freight car weight, is approximately 2.5 times net tonnage, although there are variations according to commodity. For coal and other heavy-density commodities, gross tons are about 1.7 times net tons; gross tons of lighter density commodities are much as 3.2 times net tons.

The traffic flow data forecasts were provided in the form of matrixes. One matrix containing 16,641 cells (129 by 129) was prepared for each commodity. Since most of the traffic in each commodity group moves to and from a limited number of regions, flow data are found in only a small number of cells in each matrix. Traffic flows do not allow for any capacity constraints on either links or nodes. If constraints were applied, the algorithm would flow the traffic over the shortest path up to the maximum capacity of any link or node. The remaining traffic would then seek the next shortest path with unused capacity. Such constraints are not applied because of the assumption that railroad companies would make the necessary investments to overcome the constraints and accommodate the forecast traffic efficiently. Railroads would not attempt to accomplish this through artificial and unrealistically circuitous routings.

This method of graphical display does not show the traffic flows that occur entirely within single regions. Some of these flows are substantial (for example, iron ore movements within the Duluth region) and could compete for mainline track capacity with the interregional flows.

Each commodity map has its own scale to permit the reader to observe more acutely the relative flows of each commodity over the national network. Had a uniform scale been selected, the difference in flows of some of the smaller commodity groups could not be so easily observed.

THE FORECASTS

The future transportation requirements of American industry are a function of both the supply of and the demand for various commodities. Commodity production and consumption forecasting requires assumptions about demographic trends, employment, financial markets, the housing market, the role of the public sector in the economy, energy costs and requirements, and other determinants of the size and composition of the national economy.

In this report, the 1990 commodity flow forecasts made by Data Resources, Inc., were based on the following assumptions:

- Real gross national product would grow at an average annual rate of 2.8 percent to $3.50 trillion in 1990 from 2.54 trillion in 1978.

- The total U.S. population would increase from 218.4 million in 1978 to 243.5 million in 1990.

- The labor force would grow at a rate of 1.7 percent per year between 1980 and 1985 and 1.3 percent per year between 1985 and 1990, compared to growth rate of 2.4 percent per year between 1970 and 1980.

- The inflation rate is expected to decrease from 12.9 percent in 1980 to 9.9 percent in 1981 and 7.9 in 1984, before it returns to 8.3 percent at the end of the decade.

- Government spending would continue to be stable at 21.8 percent of the gross national product.

- The rate of increase in productivity would rise from 1.1 percent per year in 1978 to 1.8 percent per year in 1990, as both the capital/labor ratio and average work force expand.

- The rate of unemployment should decrease from 6.0 percent in 1978 to 5.6 percent in 1990.
- The cost of fuel oil imports should decrease from $101.5 billion in 1978 to $92.9 billion in 1990.
- Energy demand would grow to 89.1 quadrillion Btu in 1990 from 78.1 quadrillion Btu in 1978. (One quadrillion Btu equals 500,000 barrels of petroleum, per day per annum.)
- Energy sources for electric utilities should change, as follows:

Fuel	1978 %	1990 %
Coal	43.2	52.8
Natural Gas	14.1	7.0
Petroleum	16.4	6.8
Other/(including nuclear, hydro, solar, etc.)	26.3	33.4

The following assumptions were made for each commodity.

- The location of production and consumption in 1990.
- The total commodity flows that link production and consumption at specific locations.
- The railroad share of the total flow for each commodity.

These assumptions depend on a myriad of occurrences in the railroad industry, as well as in the rest of the world. This study uses "most probable" rather then either optimistic or pessimistic assumptions. (If required, the network model system could be used to analyze "most probable," "extreme case," or any other set of assumptions.)

The forecasts do not assume any major changes in the capacities of other modes that might result from reduced regulation of these modes. Reforms of trucking and railroad regulations have occurred only recently. When there is sufficient evidence as to how the Interstate Commerce Commission will interpret the new laws and how trucking companies, railroads, and shippers will respond to those interpretations, new forecasts can be made to include the effects of reduced regulation.

Assumptions were made regarding changes in the capacity of other modes. For example, the construction of high-capacity locks on the Mississippi River at Alton, Illinois, scheduled for completion in 1988, is not expected to affect railroad traffic significantly through 1990. Even though three coal slurry pipelines have been proposed for construction before 1990, none has cleared all the legal barriers that must be overcome before construction is possible. Therefore, the forecasts for coal movements are based on the assumption that no new slurry pipelines will be operating before 1990.

The railroad freight traffic forecasts involve the following six steps.

(1) Econometric models were developed to forecast railroad originations and terminations in each of the three railroad districts--Eastern, Southern, and Western--for 14 major commodity groups plus one "all other" group. The models are based on the 1949-to-1978 data from the Freight Commodity Statistics (FCS), supplemented by railroad data from other sources, and relate historical and forecast industrial production and consumption measures and mode-share statistics to railroad originations and terminations.

(2) The One-Percent Carload Waybill Sample provided origin-to-destination flows for 1978 between the districts. The FCS totals were used to develop the factors for each of the interregional and intraregional flows that will expand these flows to 100 percent of the originations and terminations reported by FCS.

(3) Flows between districts in 1990 were projected with the econometric models from Step 1 and the data from Step 2. Trends in district interactions were analyzed to ensure their proper reflection in the 1990 interdistrict estimates.

(4) Matrixes of interdistrict growth factors were created for each commodity group by dividing the 1990 interdistrict flows (from Step 3) by the 1978 interdistrict flows (from Step 2).

(5) The 1978 Carload Waybill Sample was used to prepare a region-to-region flow matrix, by commodity, for the 129 regions.

(6) The growth factors from Step 4 were applied to the 1978 interregional flow matrix (from Step 5) to develop a 1990 interregional flow matrix.

In all the commodity forecasts, specific information regarding each commodity was taken into account. For example, 1990 coal flows reflect the opening of new mines, the expansion of some existing mines, the conversion of some powerplants to coal, and the construction of coal-fired powerplants, as well as historical flows.

Total railroad traffic is expected to grow from 1.5 billion net tons in 1978 to 2.1 billion net tons in 1990, an average annual growth rate of 2.58 percent.

Copies of Railroad Freight Traffic Flows 1990 may be obtained from the FRA by writing to:

Raphael Kedar
Chief, Research and Analysis Division, RRP-22
Federal Railroad Administration
Washington, D.C. 20590

THE MODELING OF COAL AND TRANSPORT INDUSTRY INTERACTION

Thomas P. Egan, Charles River Associates

ABSTRACT

This paper addresses the issue of the interaction of the coal and transport market and the modeling strategy implications of this interaction. In addition, it describes a specific model simulation study of this interaction recently performed for the U.S. Department of Energy by Charles River Associates (CRA) with subcontracting assistance from CEXEC, Inc. and Manalytics, Inc.

The paper begins with a summary of the key features of coal and transport market interaction. These features imply that forecasting models of either market should include algorithms which properly account for the feedback effects of decisions in one market upon decisions in the other.

To demonstrate this interaction, CRA simulated the impact of a range of post-Staggers Rail Act transport rate scenarios on 1990 coal production, transportation, and prices by iteratively running the National Coal Model (NCM) and the Transportation Freight Model (TFM). The TFM forecasted transport rates for use in the NCM while the NCM forecasted coal flows for use in the TFM.

Using the TFM and NCM iteratively, CRA simulated the impacts on coal markets if 1) all transport rates were set equal to fully allocated costs and 2) if rates were all set at 180 percent of variable costs. The results of the simulations are that a coal region's market share is very sensitive to transport rates from it; that coal markets are more interregionally competitive than some analysts believe; and that, at least in the long run, delivered coal prices differ by relatively little between the two cases while coal region market shares differ substantially.

INTRODUCTION

Transportation rates and the transport network's structure are key factors that affect where coal is used and where it is produced. Conversely, the transportation industry's network investment and rate decisions are based on expectations about where coal will be consumed by utilities and produced by

mining firms. Consequently, coal markets do not determine the regional market structure and the prices faced by the other two. Instead, there is a dynamic interaction of the utility, coal and transportation industries that simultaneously determines some of the important regional production, capacity, and price characteristics of both of them. The interactive nature of the coal and transportation industries suggests that the modeling of this interaction is an important new research direction.

This paper describes a modeling simulation study of coal and transport industry interactions that was recently performed at CRA under the sponsorship of the Coal and Electric Power Branches of DOE's Energy Information Administration (1). Important contributions to this research were made by our subcontractors CEXEC, Inc. and Manalytics, Inc. Our research strategy was not to develop new models but rather to modify and work with two presently available and substantially evolved models of the coal and transportation industry.

Specifically, we used the National Coal Model and a version of the transportation network simulation model originally developed under U.S. Department of Transportation funding. Using these two models interactively, we simulated the regional coal production and price consequences of possible new rail rate-setting practices that might result as a consequence of the Staggers Rail Act of 1980. The goal of the particular simulation runs that we performed was not to predict what regional coal production, transportation flows, and prices will actually be, but rather to examine the differences that specific transport rate developments might make.

Four interrelated results of our study are particularly important:

- The coal and transport markets are dynamically interactive and modeling either one in isolation by assuming a constancy in the other will lead to misleading forecasts.

- The competition among coal producing regions will be more vigorous than many analysts currently anticipate, at least in the long run.

- Mine region competition will act as an important constraint on rail rates, particularly on rates for Northern Great Plains coal shipments.

- Over the range of rate developments simulated, 1990 delivered coal prices varied far less than regional coal production as competition among regions offset transport cost changes.

The balance of this paper has five sections. In the first, we briefly summarize the main patterns of the coal and transport markets' interaction. The second section sets out our view of the modeling strategy implications of these patterns. In the third section, we summarize the specific modeling strategy that we employed in our recently completed study for DOE. The paper's fourth section describes the results of the simulation runs, while the fifth section summarizes our conclusions and recommendations.

COAL AND TRANSPORT MARKET INTERACTIONS

Before describing the specific modeling strategy adopted in our DOE study, a brief summary of the key characteristics of the coal and transportation market interaction is appropriate. These characteristics are important determinants of the appropriate modeling strategies.

In Figure 1, coal is shipped from hypothetical Wyoming and Kentucky mines to midwest destinations at some distance from both mines. The sum of the mine and transport costs from both regions is shown as the vertical height of the sloped lines, and the slope of these lines reflects respective transport costs as a function of shipment distances. The intersection of the two sloped lines establishes a market boundary. To the left of the intersection point Kentucky coal cannot compete with Wyoming coal and vice versa.

Suppose a utility adds a generating plant, somewhere on the line between the Wyoming and Kentucky producers of Figure 1. Such a plant is shown at Site A in Figure 2. Clearly, the Wyoming producer has a lower delivered cost. How much could the railroad from Wyoming charge the utility to deliver the coal (assuming no regulatory constraint)? If the utility's next best alternative is the Kentucky coal shown in the figure, the railroad could charge up to just below the delivered cost of Kentucky coal. The difference between the Kentucky and Wyoming delivered costs is the economic surplus or "rent" on Wyoming coal at Site A.

The determination of actual market boundaries, transport rates and rents are considerably more complicated than is shown in Figures 1 and 2. Four principal factors hamper this determination:

- The difficulty of accurately determining transport costs;
- Rate bargaining indeterminancy;

- Rapidly changing market characteristics and institutions; and
- The simultaneity of coal production and transportation infrastructure capital investment decisions.

Each of these four needs a brief explanation.

Railroad costs are not easily established. The average extra cost of making a shipment, known as its "variable cost," provides a minimum amount which the railroads must recover to avoid losses on a particular shipment. While variable operating costs can be conceptually attributed to specific coal movements, fixed or common costs such as track installation are shared among all commodities, and consequently the share attributed to coal may vary by carrier and route.

Thus, common costs create a problem in defining rent: how much of the potential rent at a given site (based on the competing region's variable cost over the relevant period) is necessary recovery of common costs and how much (if any) is pure locational rent?

Although measuring the exact amount of locational rent at a given site is difficult, there is at least as much difficulty in determining who will actually obtain the rents. Much of the preceding discussion was phrased as though such rents would automatically go to the carrier, but this need not be true.

There are several groups in the coal market that at least conceivably possess market power (i.e., some control over the market price and hence the allocation of rents). There are at least five such groups in the coal market: the mines (with the subactors management and labor), the railroads (or other transportation companies, such as barges or coal pipelines), the utilities (or other firms that use coal as an input), the state governments, (e.g., through taxation), and the federal government (e.g., through leasing policies). On the surface at least, every one of these groups, with perhaps the exception of utilities and mine management,* theoretically could possess sufficient market power to capture some of the available rents.

Microeconomic theory indicates that the outcome in terms of price and quantity consumed of a five-way bargaining process is indeterminate. Even the simple two-way problem between a monopsonist and a monopolist has an indeterminate solution. In such cases, if markets are stable, a study of the existing situation sometimes reveals the likely future outcome. Unfortunately, the coal and transportation markets are now in flux.

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*Coal mining is quite competitive, although this is not a question CRA's study addressed. Utility commission regulation leads utility management to bargain on behalf of their customers.

One important change in the institutional framework within which coal production and transportation decisions are made is the push toward transportation market deregulation which culminated in the recent passage of the Staggers Rail Act of 1980. The Act permits long-term transportation contracts and "no market dominance presumption" for rates of less than 180 percent of variable costs after 1984, and this will have transportation rate and coal market boundary consequences. Other changes include the rise in real oil prices, new concerns about the acceptability of nuclear power, and evolving environmental standards for coal.

Overlapping and compounding the issue just summarized is the point that coal production, transport, and consumption decisions are truly simultaneous. It is not possible to view one sector or another as "cause" and the other sector(s) as "effect." A major utility might choose one coal source for an important new plant simply because an otherwise cheaper coal supply cannot be delivered in time over the existing transportation network. But without the demand represented by the new plant, it does not pay to improve the transportation network sufficiently to meet the demand. Thus, follow-on plants will suffer the same difficulty.

More generally, the forces leading to future increases in coal usage are well known and will lead to substantial and simultaneously determined changes in coal and transportation market characteristics. If the use of coal expands rapidly, as expected, over the next two decades, some analysts are concerned about the ability of the various rail carriers to finance the necessary capital investments to move the coal. This concern is particularly acute for coal movements originating in the Northern Great Plains coal region and for Appalachian coal movements terminating in eastern U.S. ports. The need to finance the necessary investments is expected to force rail costs and rates up for the carriers most affected. These rate increases may in turn have major effects on delivered coal prices, coal market boundaries, and therefore on the magnitude and timing of the transport investments needed.

IMPLICATIONS FOR MODELING STRATEGIES -- AN "IDEAL" STRUCTURE

The market factors reviewed above imply that forecasts of coal transportation rates based solely on historical data or theoretical models are highly questionable. This point implies further that coal market model forecasts of delivered coal prices and market boundaries that result from rate forecasts developed in this manner are also highly questionable, at least for some coal market regions.

On the other hand, transport market modeling approaches such as the rail network simulation models used to forecast rail infrastructure, investment needs, coal shipment routings and transport costs will also yield highly questionable results when coal market responses to transport investment and rate decisions are not integrated into the analyses performed.

Under ideal conditions, an integrated model of coal markets and transportation markets of the form shown in Figure 3 could be developed as an alternative approach to the current models used.

In the modeling structure depicted in the figure, the simultaneity and the other important characteristics of coal and transport market interactions described above are accounted for. The coal market model provides coal transportation demand information to the transport market model. It also provides mine price information which the transport model will need to determine transport rates. Information on the end-use cost of alternative fuels is also needed by the transport model's rate determination algorithms. For example, if the transport rates to a specific power plant make coal use more expensive than residual oil generation, it is unlikely that such a rate would be established except in cases where the rate is necessary to cover the variable costs of the coal shipment involved. Information on the end-use costs informs the transport model about the ceiling for the amount of common or joint cost recovery possible on a particular origin to destination coal shipment route. Factor price information provides the supply side of the transport market model with the information it needs to determine the variable cost of shipments and the optimal magnitude, timing, and location of transport network infrastructure investments. The key output of the transport model would be forecasts of transport rates which are needed by the coal market model to forecast mine prices and delivered coal prices.

The simultaneity of the coal and transport markets is seen in the passing of mine price, coal consumption, and coal production information to the transport model. The transport model, in turn, provides transport rate forecast information to the coal market model.

Perhaps the most difficult conceptual issue that would need to be treated in developing an integrated model such as shown in Figure 3 is the indeterminacy in expected equilibrium price and production outcomes. In order to build a mathematical model, a specific rule for resolving this indeterminacy must be chosen. For example, if the rent accruing to the transport sector depends on the relative market power of the various bargainers, a specific allocation of the rent between the transport sector and other sectors must be chosen for forecasting purposes. While there are many ways this can be done, the key point for modeling is that conditions to resolve the indeterminacy must be specified. In a flexible system, they can be specified as scenarios.

MODELING APPROACH UTILIZED

In our work for DOE, project objectives and resource limitations precluded our tackling the development of a new, fully integrated model such as depicted in Figure 3. However, we did utilize and link the capabilities built into two large existing models. This linking allowed us to simulate important aspects of coal and transport market interaction in a way that can be expanded upon in the future.

This section of the paper summarizes, in turn, the main features of the two models utilized, the model linking procedure, and the definitions of the scenarios and assumptions simulated.* Methodology improvement suggestions are presented in the paper's final section.

The objective of CRA's study for DOE was to determine the impacts on coal markets and coal prices of several transport market and transport rate scenarios. To accomplish this objective, we linked a transport network simulation model, the Transportation Freight Model, with the National Coal Model, and passed coal flow forecast and transport rate information iteratively between them until coal flows converged. This linkage is shown in Figure 4. In effect the Transportation Freight Model (TFM) served as the study's Transport market model and the National Coal Model (NCM) served as the study's Coal Market model. The role of the TFM was to provide transport rate forecasts for use by the NCM. The NCM in turn generated the coal shipment forecasts needed as inputs by the TFM to forecast rail rates. After an iterative passing of rate and coal flow forecasts between the two models, the coal flow forecasts produced in successive NCM runs began to converge at the DOE region level of aggregation. The last NCM run of the iterative sequence provided the forecasts of coal consumption, production flows, and prices under the transport market scenarios being simulated.

THE NATIONAL COAL MODEL (NCM)

The National Coal Model was developed by ICF, Inc. It has been used extensively in studies performed for federal agencies. A version of the NCM is currently installed on DOE computers. The primary documentation for the NCM was produced by ICF, Inc. (2).

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*Paper length and presentation time constraints preclude anything but an abbreviated description of the models and scenarios. For complete model and scenario descriptions, we refer the reader to our report to DOE and the references cited therein (1).

The demand side of the NCM has a utility and nonutility sector. The nonutility demands are specified as regional point estimates for coal of a specific heat and sulfur level. The utility demand component begins with an exogenous point estimate of kWh sales in the forecast year. This regional demand is met in the NCM by a cost minimizing mix of interregional energy (kWh) purchases and/or new and existing baseload, intermediate load, and peakload generation. Power plant types include coal, oil, gas, nuclear, and hydro.

Mining region supply curves are built up as a stairstep function of existing mine variable costs and the price that new mines will require to earn a non-negative discounted cash flow at a utility discount rate. The discount rate and mine productivity assumptions are user inputs to the supply curve generation algorithms.

The NCM uses standard linear programming to minimize the total cost of electric energy and nonutility coal demands.

The NCM Coal Transport Sector is described in the NCM documentation on pages III-111 through III-130. The starting point used to establish the NCM transportation links was a U.S. Bureau of Mines report, Bituminous Coal and Lignite Distribution, Calendar Year 1973. This report was used to identify coal shipment links. In addition to these links, Western Montana (WM) and Wyoming (WY) were linked to all 44 utility demand regions. Washington (WA) and Alaska (AK) were linked to west coast demand regions.

The cost of transportation on the links was estimated in three steps:

- Calculate rail mileages between supply and demand regions;
- Establish rail cost equations for each link; and
- Estimate barge routing costs and substitute barge for unit train costs when lower.

Each supply and demand region was given a centroid from which link distances were measured using published rail miles data cited in the NCM documentation. In describing its rail costing methodology, the NCM documentation begins by noting wide variances in coal rail tariffs which are caused by a variety of factors.

The NCM documentation then reviews several rail cost studies and sets out its conclusions that for purposes of establishing NCM Coal Transport Costs, a linear function of rail mileage would be adequate. Three separate functions were estimated for the Appalachian, Midwestern, and Western regions using "straight-line approximations" to plotted data on rail tariffs versus

mileage taken from the ICC study Investigation of Railroad Freight Structured Coal (December 1974). A fourth equation was estimated based on the results of a study by Martin Zimmerman, which shows western rail rates as a function of mileage that differs depending on whether the western shipment crosses the Mississippi or not. The four equations showing unit train costs (TC) as a function of mileage (M) are given in Table 1.

The interactive patterns of the coal and transport markets were discussed above. Based on those conclusions, the historically based transport rate algorithms set out in Table 1 are inadequate for forecasting coal market flows, production, and delivered coal prices under a variety of possible transport market and rate formation scenarios. Since such forecasting was the objective of our DOE contract, DOE, CRA, and CRA's two subcontractors (CEXEC, Inc. and Manalytics, Inc.) jointly decided to use the Transportation Freight Model (TFM) as the basic tool with which to select the transport costs and rates for the NCM corridors.

THE TRANSPORTATION FREIGHT MODEL (TFM)

The TFM is a transport network model that allocates commodity flows to different rail and barge routes. The model is designed to be useful for studying a variety of user-specified transport market scenarios. There are several versions of the Transport Network Model now in use. The version used in CRA's project was developed under U.S. Department of Transportation (DOT) sponsorship. The documentation for a later version of the model is found in a four-volume report prepared for DOT by Michael S. Bronzini and CACI Inc. (3). The version of the model that we used does not include the energy use algorithms and the truck and pipeline network structure as described in the Bronzini/CACI documentation. However, aside from these differences, the two versions of the model are similar enough for us to cite the Bronzini/CACI documentation as the principal source for the following description of the TFM. The various versions of the network models were reviewed in a recent paper by Michael Bronzini (4).

In the TFM, interregional commodity flows (a model input) define the demand for transportation in the model. The transportation system is considered to be a network of nodes and links.

The entire TFM network consists of:

- Regions -- commodity origin-destination areas (user-specified);
- Nodes -- terminal points of linehaul transportation facilities, representing direction change, facility class change, intramodal switching, and point-located facilities such as navigation locks and rail yards;

- Access links -- facilities that connect regions to nodes, and represent local transportation;

- Linehaul links -- linehaul transportation facilities; and

- Transfer links -- intermodal transfer facilities.

Each link and node in the network is identified by a mode and facility class. Each class has associated with it a cost function and a time function:

- Cost functions relate cost, in dollars-per-ton or ton-mile, to total tonnage using the facility; and

- Time functions relate transit time, in hours or hours-per-mile, to total tonnage using the facility.

Shipments are assigned to paths through the network which minimize the shipper's "disutility" or "impedance," thereby determining modal selection(s), intermodal transfer(s), and route selection. The disutility of a path is a function of time and cost. Since coal is a relatively low-valued commodity, its time delay cost is approximately 1 percent of fully allocated costs in the TFM.

In the TFM, shipper optimal, rather than globally optimal, paths are generated. This corresponds quite well to usual transport market behavior, which is devoid of significant centralized control over mode and route selection by individual shippers. Particular shipments may be constrained to specified paths or modes. Links and nodes are limited to carrying flows below capacity.

A circuity constraint is applied to minimum path computations, by considering only those routes which lie within an ellipse with foci at the origin and destination regions. This constraint accelerates the process of searching out numerous paths through large networks.

In using the TFM model, we have specified the origin and destination regions to be the same as the NCM regions and added the National Energy Transportation Study non-coal commodity flow forecast to the NCM flows to define transport demand (5).

The various versions of the network model are not only differentiated by levels of network disaggregation, mode coverage, and user options. They are also differentiated by the disutility or impedance functions used to allocate shipments on the network.

The rail transport cost impedance equations used by CRA in the TFM are based on a rail freight costing algorithm developed by John F. Murphy for DOT called the Train Cost Model (TCM). Murphy's rail cost algorithm forecasts fully allocated cost of a bulk commodity train shipment under varying trackage conditions, terrain conditions, number of cars, average load per car, and other variables (6). The TCM forecasts fully allocated costs as the sum of the following components:

- Roadway Maintenance;
- Roadway Capital;
- Locomotive Maintenance;
- Locomotive Capital;
- Fuel Oil Costs;
- Crew Costs;
- Railcar Capital;
- Terminal Costs; and
- Linehaul Congestion Costs.

The original set of TCM equations, specified in 1974 dollars, was already incorporated into the TFM structure at the time our contract began. As part our work for DOE, the TCM algorithm parameters were upgraded to 1990 costs in 1979 dollars and modified to bring the algorithms as close to a representation of unit train conditions as the TCM algorithms and available rail cost engineering data permitted. This work was done by our subcontractor, Manalytics, Inc., whose report to CRA is presented as Appendix A to our report to DOE (1). Modifying the TFM cost equations to reflect the Manalytics analysis and the running of the TFM were carried out by our subcontractor, CEXEC, Inc. Two important assumptions used in these modifications were that the necessary transport system investments would be in place by 1990 to handle increased coal traffic, and that these investments would not materially affect the cost of an individual coal movement. Future research should closely examine the consequences of changing these assumptions.

At this point it is necessary to state one very important feature of the TFM and all the network models presently in existence. These models can only forecast transportation costs and not transport rates. To use the TFM model to generate rate forecasts, the system user must explicitly introduce a rate formation modification to the TFM's impedance cost algorithms. The general point made above concerning the indeterminancy in transport rent sharing implies that this requirement will be present in any transport market/transport rate forecasting system. This point has important implications for implementing transport market scenarios, as will be explained below.

INTERFACING THE NCM AND TFM

An effective interfacing of the NCM and TFM, in which TFM-based transport rates are used as overriding inputs in the NCM's transport rate algorithms, requires three conditions:

- Same origin and destination region definitions in each model;
- Consistency in the specification of the calendar year to which each model's outputs and inputs pertain; and
- Same origin-to-destination tonnage flows in each model.

CRA wrote two simple interfacing programs to ensure such model input and output compability. Using these interface programs, the sequence of steps used to run a scenario is as follows:

- Run the NCM to obtain a 1990 forecast of coal flow patterns using NCM transport rates;
- Input the coal flows from the NCM output to the TFM.
- Run the TFM;
- Input the TFM rate forecast into the NCM; and
- Using the NCM outputs, compare DOE region to DOE region coal flows from the first two NCM runs. If all flows are within 10 percent, stop; if not, repeat the above steps until the flow quantities converge.

This section closes with a description of the methodology used to design the specific transport rate scenarios simulated in our DOE study.

SCENARIO SPECIFICATION

Project objectives stipulated that we characterize the impacts on coal markets and prices of several transport market and transport rate scenarios. However, project resource constraints permitted the simulation of only two such scenarios.

The scenarios chosen were two rate formation rules that we believe effectively bracket much of the post-Staggers Rail Act coal transport rate bargaining environment. Specifically we assumed that future rate bargaining would generally result in rates that exceeded fully allocated costs (variable cost plus the share of fixed costs allocated to a specific movement) but were less than the Staggers Act's "no market dominance presumption" 180 percent of variable cost ceiling.* While rate bargaining will not universally result in rates between these limits, most rates will fall within this range because the transporting railroad will seek to bargain to at least recover all costs associated with the specific coal movement in question and will probably also seek to avoid the ICC intervention possible if the rate exceeds 180 percent of variable cost.

We therefore defined Scenario 1 as a hypothetical world in which all 1990 coal transport rates will equal fully allocated costs (as forecasted by the TFM). In Scenario 2, all 1990 rail rates were assumed to equal 180 percent of variable costs. Barge rates were assumed to remain at fully allocated costs.

To modify the TFM's impedance functions so that they would estimate 180 percent of variable cost forecasts, we multiplied each of the impedance functions by a factor of 1.277. The factor 1.277 was derived as follows. First the ratio of variable to fully allocated cost for 100-ton car coal traffic for three ICC regions (Official, South, and West) was established from 1977 ICC Rail Form A data. These ratios were 0.7119, 0.7136 and 0.7023 for the Official, South, and West, respectively. These ratios averaged to 0.7093, which when multiplied by 1.80 yielded the 1.277 multiplier.

Before discussing the simulation run results, one very important additional assumption needs to be stipulated. In the simulation runs that we performed we assumed that all necessary rail infrastructure investments will be in place by 1990 to handle the increased flow volumes forecasted. It is widely appreciated that this assumption is not necessarily valid for some important coal transportation routes. This important issue is discussed further in the final section of the paper.

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*The actual post-1984 ceiling stipulated in Section 202 is the "cost recovery percentage" which may not exceed 180 percent of variable costs.

SIMULATION RUN RESULTS

The results set out in this section stem from the two main types of analysis we have performed on the forecast data produced by the models: an NCM run oscillation analysis, and a comparison of forecasted coal market conditions under Scenario 1 and Scenario 2 transport rates.

NCM OSCILLATION ANALYSIS

As explained in the previous section, the procedure for running each scenario was to iterate between the NCM and the TFM until coal flow convergence occurred in successive NCM runs at the DOE region level. However, in Scenario 1, at the end of five NCM runs, a clear coal flow oscillation pattern had emerged. Therefore, CRA recommended that a sixth NCM run be made and an analysis of the flow oscillations be undertaken. Over the six runs, minor oscillations were observed from run to run for coal flows to most DOE regions. However, major oscillations were observed in the flow of Northern Great Plains coal to the South Atlantic, Midwestern, and Southwestern markets. Table 2 illustrates the patterns.

To analyze these oscillations, we examined the major coal flows into each DOE region at the NCM region level as well as the TFM fully allocated costs associated with these flows. Our analysis concluded that in the South Atlantic, Midwest, and Southwest demand regions, the market share of Northern Great Plains coal is very sensitive to transport rates. Furthermore, it was determined that forecasts of coal flows from all mining regions at the more disaggregated NCM region level are generally very sensitive to transport rates. Therefore, analysts should interpret any NCM forecasts at this level of disaggregation with caution.

The South Atlantic, Midwestern, and Southwestern coal market all exhibited the same pattern: slight increases in the transport rate for Northern Great Plains coal drives that mine region's coal from the market in some states in the three DOE demand regions. Since the patterns are similar in all three markets we summarize our analysis for the South Atlantic in this paper. The complete analyses for all three regions is found in our report to DOE.

In the NCM, the South Atlantic utility coal demand is composed of the coal demands of the separate states within that region. The South Atlantic demand region includes North and South Carolina, Georgia, North Florida, South Florida, Western Kentucky and Alabama/Mississippi. In the Georgia and Western Kentucky demand regions, substantial instability was observed across runs. In the 4 NCM runs with TFM fully allocated costs (NCM runs 3 through

6), 6 NCM coal supply regions were the principal competing supply sources for Georgia. The transport costs and flow patterns across runs for these supply regions are shown in Table 3. Inspection of the table indicates that the inter-supply region competition for the Georgia market exhibits a complex pattern. With the exception of Western Montana, transport cost fluctuations are minor and cost changes from one NCM run to the next do not have a clear inverse relationship to flows.

The general stability of the transport costs from eastern origin points indicates that shifts in these rates may not be the cause of the fluctuations in coal flows from eastern regions to the Georgia market. In contrast, it appears that a 28 percent increase in transport costs from Western Montana to Georgia drives Northern Great Plains coal completely out of the Georgia market. Southern Wyoming's Georgia market share is also very volatile. It appears to compete with South West Virginia, Eastern Kentucky, and Western Montana for market position. However, transport costs do not appear to be the major determinant of Southern Wyoming's Georgia market shares, at least over the range of transport costs indicated in Table 3, unless there is a dramatic "knife edge" sensitivity between transport costs of 16.48 and 16.91 dollars per ton.

The situation in the Western Kentucky coal market is also complex, but not as complex as for Georgia. In the fifth NCM run, an 18 and 9 percent coal transport cost increase for Western Montana and Southwestern Wyoming, respectively, leads to a large shift from western coal sources to indigenous Western Kentucky coal. A slight lowering of rates from the fifth to the sixth run reverses the pattern.

As noted above, the pattern in the Midwestern and Southwestern demand regions is similar to that of the South Atlantic region. The market share of Northern Great Plains coal depends strongly on transport rates in both of these regions.

Since the NCM flows showed persistent oscillations in both scenarios, we decided to let the last NCM run made in each scenario serve as that scenario's coal market forecast. The scenario comparison to follow is based on the results obtained in the sixth NCM run of Scenario 1 and the fourth NCM run of Scenario 2.

SCENARIO RESULTS COMPARISON

We next compare conditions in the U.S. coal market under the two scenarios simulated in CRA's study. In the first scenario, coal transport rates were set equal to fully allocated costs. Although lower rates are to be expected in some cases, DOE and CRA agreed that the initial scenario

should assume that full transportation costs will be recovered. In the second scenario, coal transport rates are set equal to 180 percent of variable costs. As we explained above, we believe that an important result of the Staggers Rail Act of 1980 will be that many coal transport rates for new unit train service will be below the second scenario rate.

The results of this part of the analysis are forecasts of 1990 coal consumption, production, and prices at the DOE region level. Our findings are that Western Northern Great Plains coal production would be 87 million tons per year (19 percent) lower if all rates were set at 180 percent of variable costs as compared to a situation in which all rates are set at fully allocated costs. Furthermore, delivered price and mine prices would be 5.4 and 4 percent higher, respectively, under the 180 percent of variable cost scenario.

Table 4 shows the impacts that a shift of transport rates from fully allocated costs to 180 percent of variable costs would have on delivered coal prices. On average, delivered coal prices rise 8 cents per million Btu or 5.4 percent.

The relative regional increases shown in Table 4 are proportionate to transport distances and thus seem intuitively plausible. Thus, delivered prices rise by 13 and 14 cents per million Btu for the New England and Northwest demand regions, respectively. These regions are located at considerable distances from major coal supply regions. In contrast, delivered prices rise by only 4 cents per million Btu in New York/New Jersey and the Mid-Atlantic States. Both of these regions are situated close to the Appalachian producing districts.

Table 5 is the NCM forecast for regional coal production and mine prices under Scenario 1 and 2. The table reflects an overall 4 percent or 5 cent per million Btu mine price increase. The reason for the increase is the regional production shifts. In Scenario 2, less western and more eastern and midwestern coal is mined in response to the generally higher rail rates prevalent in Scenario 2. Eastern plus midwestern production totals rise from 608 to 672 million tons while western totals decline from 717 to 623 million tons. The most striking result reflected in Table 5 is the large difference in the forecast of Northern Great Plains coal production (461 million tons versus 374 million tons). This difference confirms the result found in the oscillation analysis that the market penetration potential for Northern Great Plains coal is extremely sensitive to transport rates. An important qualification of this result stems from the fact that in the NCM, total electricity demand is a point estimate input. If the NCM electricity demand was price sensitive, our run results would show a greater fall in coal usage and smaller coal price increases.

A possible corollary to the large Scenario 1 to Scenario 2 shift from western to eastern coal production is that fears about uncontrolled escalations in western rail rates may be somewhat unfounded. Such rapid increases, if attempted, would lead in the long run to a large loss of potential future market share for western coal. It is important to emphasize, however, that near-term rail investment needs and the coal type inflexibility that is characteristic of many boilers in current operation may negate this conclusion in the shorter run. It is also possible that some western railroads facing the large investments necessary to ship increased western production may determine that it is in their interests to slow the production and investment pace down through an aggressive contract rate negotiating strategy. To see clearly through these coal market/rail market interactive dynamics it would be necessary to perform a study of the investment needs of the western railroads and the implications that magnitude and timing of such investments would have on rail costs and rates.

CONCLUSIONS AND RECOMMENDATIONS

In our view the two most important results CRA's study has produced are:

- It has demonstrated the importance and usefulness of detailed, comprehensive and simultaneous analysis of coal markets and transportation markets in formulating coal transportation policy.

- It has demonstrated the interactive use of two powerful, user-oriented tools for examining the simultaneous determination of transportation rates and regional coal production and prices.

In addition, an analysis of the inter-NCM run oscillations of Northern Great Plains coal shipments to three DOE demand regions leads us to the following specific conclusions and recommendations:

- The market penetration potential of Northern Great Plains coal is extremely sensitive to transport costs (and therefore rates). This point has two possible corollaries. First, forecasts of substantial market power and rent capture opportunities available to western railroads may not materialize in the long run. Second, the geographic market penetration potential of competitively priced Northern Great Plains coal may extend as far as the South Atlantic region.

- In this analysis and other informal NCM output comparisons we have made, we note substantial volatility of forecasted coal flows at the NCM region level. While forecast volatility is not surprising, considering the substantial level of disaggregation of the NCM, it

should caution policymakers to keep in mind that NCM coal flows and price forecasts at the NCM region level probably have a large variance. Additionally, later forecast year flows in the NCM are usually restricted to simulate the effects of long-term contracts from earlier forecast years. Therefore, 1995 forecasts at the NCM region level may be substantially biased by 1985 flow and price forecast errors inevitable for some regions. Such forecast errors are likely because of the large forecast variance at the NCM region level. As with the use of any forecasting tool, more reliance can be placed on forecasts for more aggregated regions (e.g., DOE regions) than at the most disaggregated level in the forecasting system (e.g., the NCM region level).

- As indicated in the previous section, a key methodological assumption of CRA's study is that the necessary transportation infrastructure will be in place as needed to handle increases in coal flows. After several early TFM runs forecasted western origin transport costs which were too high to be consistent with this assumption, our subcontractor, CEXEC, Inc. expanded the capacity of the TFM network structure until the TFM cost curves became lower and flatter as a function of flow volume. However, even with these adjustments, the fifth NCM run suggests that the slope of forecasted transport costs out of Western Montana is still fairly steep in the model. The interpretation we place on this Northern Great Plains transport cost and production volume intraction is that coal market behavior will be very sensitive to the rate of transportation infrastructure investment. Therefore, we strongly recommend more research directed at forecasting the magnitude and timing of western rail investment needs and the impact that this will have on coal markets. Network models such as the TFM should be a valuable tool in performing these types of analyses.

Finally, the conclusions developed in the oscillation analysis at the NCM region level were reflected and reinforced at the DOE region level in the Scenario 1 versus Scenario 2 comparison of consumption, production, and prices. The main conclusions of this comparison are:

- 1990 Western Northern Great Plains production is 87 million tons (19 percent) less under Scenario 2. This region must ship longer distances than competing regions and therefore is more affected by the higher rail rates in Scenario 2.

- All other factors remaining constant, a change of transport rates from rates that are universally equal to fully allocated cost, to rates that equal 180 percent of variable costs will increase 1990 delivered coal prices by 5.4 percent and mine prices by 4 percent.

REFERENCES

1. Charles River Associates. An Analysis of the Interaction of the Coal and Transportation Industries in 1990. Prepared for the Coal and Electric Power Branches of the Energy Information Administration, U.S. Department of Energy under Contract Number DE-ACO 1-79EI-1 06 03. Boston, Mass: CRA. September 1981.

2. ICF Incorporated. Coal and Electric Utilities Model Documentation. Third Edition. Washington, D.C.: ICF. March 1979.

3. Bronzini, Michael S., and CACI, Inc. Freight Transportation Energy Use. Final report prepared for the U.S. Department of Transportation. July 1979.

4. Bronzini, Michael S. "Evolution of a Multimodal Freight Transportation Networks Model." Paper presented at the Transportation Research Forum. Philadelphia, Pennsylvania: TRB. October 27-29, 1980.

5. U.S. Department of Transportation and U.S. Department of Energy. National Energy Transportation Study. Preliminary Report. Washington, D.C.: U.S. DOT. July 1980.

6. Murphy, John F. Railroad Cost Modeling: Rail Freight Operations Cost Methodology. Cambridge, Mass.: U.S. Department of Transportation Transportation Systems Center. November, 1976.

Table 1

NCM RAIL COST EQUATION
(1975 Dollars)

Appalachia	TC = 4.4 + 0.0081M
Midwest	TC = 1.8 + 0.0061M
West of the Mississippi	TC = 0.6 + 0.0074M
West Crossing the Mississippi	TC = 3.1 + 0.0074M

Note: TC = Train Cost

M = Mileage

SOURCE: NCM Documentation, p. III-121.

Table 2

SCENARIO 1: INTER-NCM RUN
NORTHERN GREAT PLAINS COAL FLOWS TO DOE REGIONS
(1990 Flows -- Million Tons)

NCM Run	DOE Market Region		
	South Atlantic	Midwest	Southwest
3rd	17.0	58.7	97.0
4th	41.3	93.7	99.3
5th	17.1	79.8	63.3
6th	40.1	91.3	99.6

SOURCE: Charles River Associates, September 1981.

Table 3

1990 COAL FLOWS AND FULLY ALLOCATED TRANSPORT COSTS TO GEORGIA

NCM Run	Southwest Virginia MM tons	Southwest Virginia $/ton	Eastern Kentucky MM tons	Eastern Kentucky $/ton	Illinois MM tons	Illinois $/ton
3rd	2.8	7.63	22.6	5.68	0	6.64
4th	5.7	7.87	13.0	5.72	4.4	6.62
5th	0	7.77	6.0	5.68	3.6	6.60
6th	5.4	7.71	6.3	5.75	4.4	6.66

	Western Kentucky MM tons	Western Kentucky $/ton	Western Montana MM tons	Western Montana $/ton	Southern Wyoming MM tons	Southern Wyoming $/ton
3rd	10.9	5.37	0	24.02	0.5	17.17
4th	10.9	5.34	6.4	18.83	0.6	16.91
5th	10.9	5.34	0	24.08	16.7	16.48
6th	10.9	5.37	6.4	18.51	12.4	16.22

SOURCE: Charles River Associates, September 1981.

Table 4

1990 COAL CONSUMPTION AND DELIVERED PRICES BY DOE DEMAND REGIONS

REGIONS	ELECTRIC UTILITY SCENARIO 1 QUADS	$/MMBTU	ELECTRIC UTILITY SCENARIO 2 QUADS	$/MMBTU	ELECTRIC UTILITY BASELINE QUADS	$/MMBTU	TOTAL COAL SCENARIO 1 QUADS	$/MMBTU	TOTAL COAL SCENARIO 2 QUADS	$/MMBTU	TOTAL COAL BASELINE QUADS	$/MMBTU
NEW ENGLAND	0.185	2.03	0.185	2.16	0.186	1.80	0.280	2.07	0.280	2.21	0.281	1.92
NEW YORK/NEW JERSEY	0.539	1.80	0.538	1.84	0.546	1.88	0.853	1.84	0.852	1.90	0.860	1.94
MIDDLE ATLANTIC	1.940	1.68	1.938	1.72	1.927	1.81	5.085	1.81	5.084	1.86	5.072	1.97
SOUTH ATLANTIC	3.774	1.80	3.760	1.87	3.762	1.85	5.230	1.78	5.216	1.85	5.218	1.83
MIDWEST	4.319	1.52	4.315	1.61	4.339	1.61	7.283	1.61	7.278	1.70	7.303	1.68
SOUTHWEST	2.011	1.01	2.001	1.09	2.039	1.05	4.038	1.17	4.029	1.25	4.067	1.27
CENTRAL	1.405	1.24	1.402	1.38	1.404	1.33	1.790	1.29	1.787	1.42	1.790	1.38
NORTH CENTRAL	1.456	1.02	1.448	1.13	1.456	1.01	2.395	1.02	2.386	1.11	2.395	1.04
WEST	0.713	1.42	0.712	1.50	0.727	1.38	1.025	1.49	1.024	1.59	1.038	1.47
NORTHWEST	0.089	0.97	0.089	1.09	0.089	1.17	0.366	1.26	0.366	1.32	0.366	1.36
*** TOTAL UNITED STATES	16.431	1.48	16.389	1.56	16.476	1.54	28.345	1.55	28.302	1.62	28.390	1.63

Note: The sixth NCM run is used in Scenario 1 and the fourth NCM run is used in Scenario 2. The baseline run is the first NCM run of the first scenario. It contains the NCM transport cost algorithms presented in Tables 3.4 and 3.5. Prices are expressed in 1979 dollars.

SOURCE: Charles River Associates, September 1981.

Table 5

1990 COAL PRODUCTION AND MINE PRICES BY MEFS COAL REGION

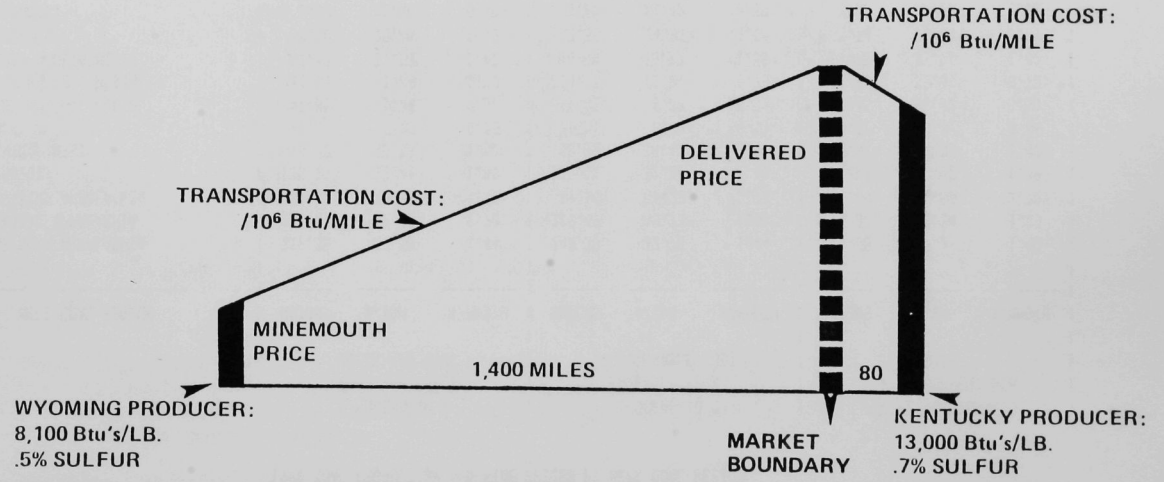
MEFS COAL REGION	SCENARIO 1 RATE=TFM FULLY ALLOCATED COST			SCENARIO 2 RATE=TFM 180% OF VARIABLE COST			BASELINE SCENARIO RATE=CURRENT NCM RATE		
	MMTONS	$/TON	$/MMBTU	MMTONS	$/TON	$/MMBTU	MMTONS	$/TON	$/MMBTU
NORTHERN APPALACHIA	217.35	37.58	1.44	244.38	37.78	1.44	221.85	37.26	1.42
CENTRAL APPALACHIA	199.01	47.79	1.78	219.47	48.73	1.81	214.87	48.54	1.80
SOUTHERN APPALACHIA	19.33	49.51	1.90	19.60	51.28	1.96	14.64	46.36	1.78
MIDWEST	155.59	32.44	1.40	170.01	32.30	1.40	169.73	32.12	1.39
CENTRAL WEST	16.72	35.68	1.50	18.92	34.42	1.48	15.87	34.32	1.48
GULF	77.57	7.22	0.53	76.51	6.94	0.51	100.62	8.97	0.66
EAST NO. GT. PLAIN	49.85	6.74	0.51	49.85	6.77	0.51	50.45	6.62	0.50
WEST NO. GT. PLAIN	461.01	12.64	0.72	374.35	12.91	0.73	441.48	12.61	0.72
ROCKY MOUNTAINS	59.52	34.58	1.42	54.84	33.77	1.38	60.95	33.96	1.40
SOUTHWEST	65.38	25.61	1.12	63.39	24.85	1.09	35.74	20.04	0.89
NORTHWEST	3.67	12.80	0.79	3.67	14.42	0.89	3.98	17.06	1.03
ALASKA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL UNITED STATES	1325.00	26.25	1.23	1294.99	28.00	1.28	1330.20	26.33	1.23

Note: The sixth NCM run is used in Scenario 1 and the fourth NCM run is used in Scenario 2. The baseline run is the first NCM run of the first scenario. It contains the NCM transport cost algorithms presented in Tables 3.4 and 3.5. Prices are expressed in 1979 dollars.

SOURCE: Charles River Associates, September 1981.

Figure 1

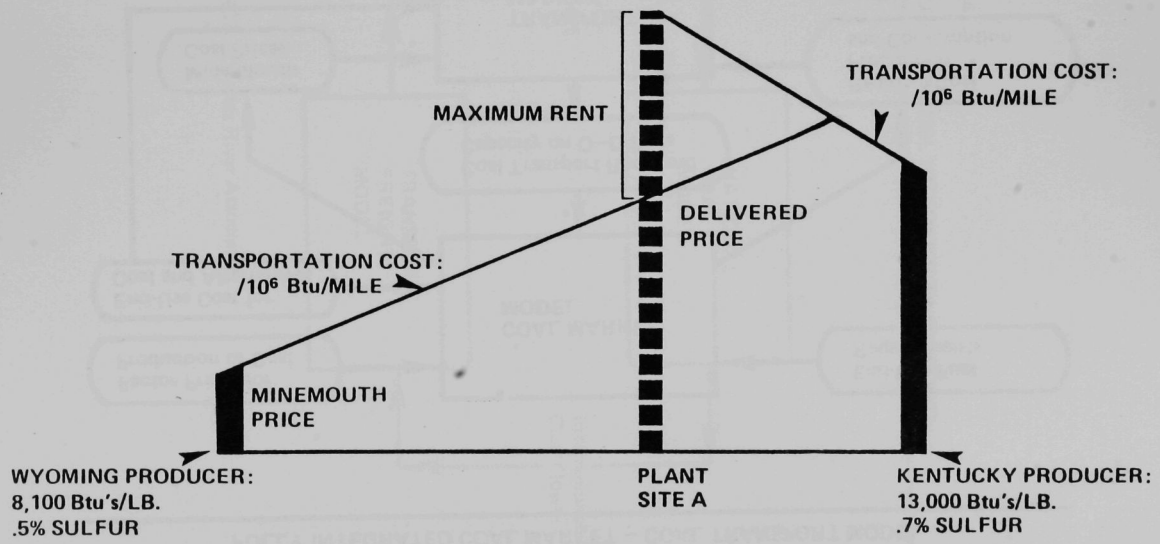
TRANSPORTATION RATES AND MARKET AREAS



SOURCE: Charles River Associates.

Figure 2

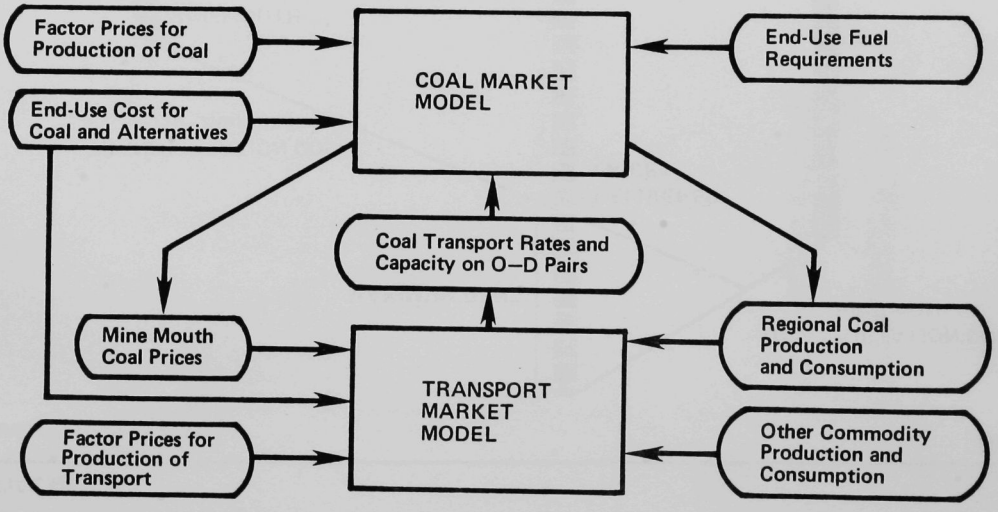
POTENTIAL RENTS



SOURCE: Charles River Associates.

Figure 3

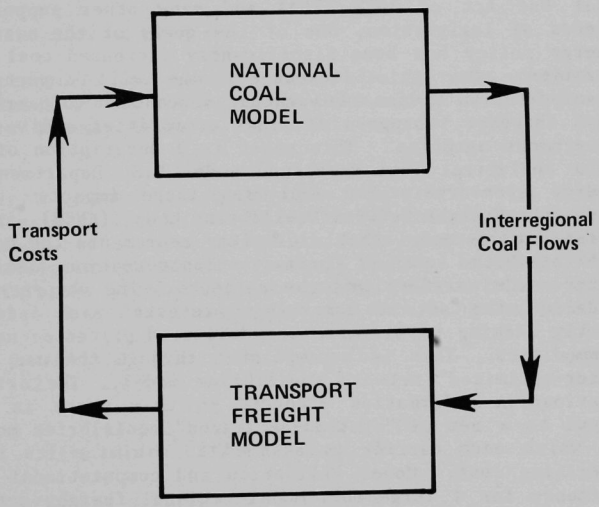
FULLY INTEGRATED COAL MARKET – COAL TRANSPORT MODEL



SOURCE: Charles River Associates.

Figure 4

SIMULATION MODEL INTERACTION ACHIEVED



SOURCE: Charles River Associates.

A NEW MODEL AND EFFICIENT COMPUTATIONAL PROCEDURE FOR DETERMINING MULTIMODAL FREIGHT NETWORK EQUILIBRIUM

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Abstract

With the adoption of the Powerplant and Industrial Fuel Use Act of 1978 (FUA) and many other supporting pieces of legislation, one of the goals of the national energy policy has been significantly increased coal utilization. How this increased usage will impact the transportation system is a matter of concern to carriers, coal shippers, shippers of other commodities, and various government agencies. This paper is a description of the main analytical tool developed under U.S. Department of Energy sponsorship for analyzing these impacts. That tool, the Freight Network Equilibrium Model (FNEM), is the first network model that explicitly represents the behavior of both sets of primary transportation decision makers--the carriers and the shippers. The shippers are modeled as a set of competing interests, each independently seeking to minimize the delivered prices of needed commodities. This is accomplished through the use of a "user-optimized" network equilibrium model. The origin-destination information produced in this phase is then input to a set of "systems-optimized" equilibrium models in which each carrier is assumed to minimize its total operating cost. Model validation and computational performance for a large multimodal regional freight network (9,799 links, 2,258 nodes and 10,920 origin-destination pairs) are reported.

INTRODUCTION

In the traditional user-optimized network equilibrium problem, the problem is to find the traffic pattern, such that for each origin-destination (O-D) pair, no user acting unilaterally can find a shorter path than the one already being used. This is equivalent to saying that

$$C_{p_1}(h) = C_{p_2}(h) = \ldots = C_{p_\ell}(h)$$
$$\leqq C_{p_{\ell+1}}(h) \leqq C_{p_{\ell+2}}(h) \leqq \ldots \leqq C_{p_n}(h) \qquad (1)$$

if $h_1, h_2 \ldots h_\ell > 0$ and $h_{\ell+1}, h_{\ell+2} \ldots h_n = 0$.

where $C_p(h)$ = the function expressing average travel cost on path p for flow vector h and

h_i = the flow on path i.

Since this pattern results from the independent actions of many users, each trying to minimize travel costs, it has been widely adopted for analyses of urban passenger highway networks where this type of behavior is assumed to occur.

In freight systems controlled by a single authority, such as the rail network of a single railroad, and where the O-D demands are already known, the modeling approach has been to assume that the controlling authority (the carrier) is attempting to minimize overall costs. In this case a system-optimized equilibrium problem is encountered. The solution to a systems-optimized problem is a set of flows that for each O-D pair satisfies

$$C'_{p_1}(h) = C'_{p_2}(h) = C'_{p_3}(h) \ldots = \ldots C'_{p_\ell}(h)$$
$$\leqq C'_{p_{\ell+1}}(h) \leqq C'_{p_{\ell+2}}(h) \leqq \ldots \leqq C'_{p_n}(h) \qquad (2)$$

if $h_1, h_2, \ldots h_\ell > 0$ and $h_{\ell+1}, h_{\ell+2}, \ldots h_n = 0$,

where $C'_p(h)$ = the function expressing marginal travel cost on path p for flow vector h.

Since for each O-D pair the marginal cost of any path used does not exceed the marginal cost of any other path (used or unused), total system cost cannot decrease with a transfer of flow. This clearly implies the state of minimum total cost.

When dealing with more general freight networks in which the user (shipper) O-D demands have not already been determined, the question arises as to which approach, user- or systems-optimized, is more appropriate. Clearly, the behavior of the many individuals and firms that make up the group of shippers is analogous to that of the highway users. They are all acting independently to achieve the cheapest cost transportation route (which includes

mode) possible. An equilibrium will exist when no shipper acting independently can improve its travel cost. On the other hand, the carriers are faced with the problem of how to satisfy the shippers' decisions, and each will do so in a cost-minimizing manner.

Typically, the approach that has been used to model these freight networks has been to ignore the behavior of the carriers and adapt one of the urban highway user-optimized models to the needs of the shippers (e.g., Ref. 10). This approach is a substantial simplification of the freight system decision-making hierarchy. It is no more realistic than would be the use of a system-optimized model that captures the carriers' behavior but ignores the actions of the shippers (Ref. 1). The model presented here is a computationally tractable model that explicitly accounts for the interaction between shippers and carriers rather than the behavior of just one of these groups. The model was developed as a means of analyzing the transportation impacts of increased coal usage. As such, it has the consignees (the users of coal--primarily electric utilities) making decisions about where to purchase and how to ship the freight. These utilities are the shippers in this model. It would be easy, however, to reformulate the model to account for consignor, rather than consignee, decision-making.

MODEL DESCRIPTION

To represent the behavior of shippers and carriers accurately, the FNEM is divided into two submodels that are applied sequentially. The shippers' submodel is a simultaneous distribution, modal split, and traffic assignment model. It is applied first to produce a user-optimized equilibrium flow and modal split. This application defines a set of origin-destination demands and a general routing pattern, which are then used as inputs to the carriers' submodel. The carrier's submodel is then applied to determine a system-optimized equilibrium flow for each carrier. An overview of this process is illustrated in Figure 1. Descriptions of each submodel follow; for theoretical, mathematical and algroithmic details, the reader is referred to References 2 through 4.

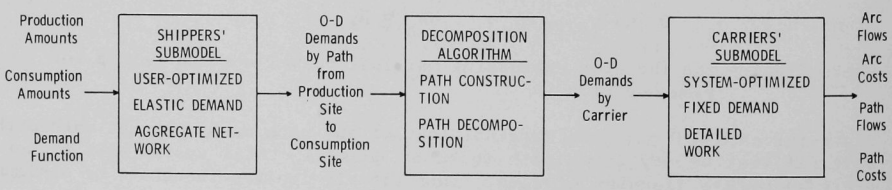
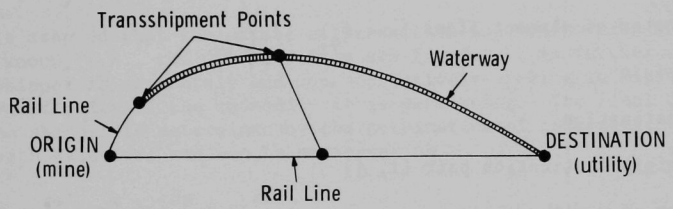


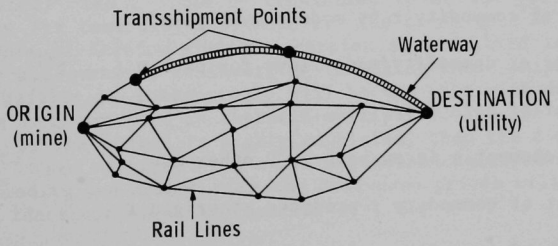
Figure 1. Overview of Freight Network Equilibrium Model

Shippers' Submodel

Description. The shippers' submodel routes traffic over an abstract aggregate representation of the rail transportation network. This aggregate network includes only the modes that might realistically be considered by shippers. Although the aggregate network varies from application to application, its nodes include all potential origins, destinations, transshipment sites, and inter-carrier transfer points (gateways). In addition, locations such as major points of transportation activity that might be of special interest can be added. An example of this aggregation for the shipment of coal is given in Figure 2. This aggregate network is used instead of the real network because it is this representation of the transportation system that the shippers actually "see" when making routing choices. Shippers are concerned with, and have the power to determine, the O-D pairs, mode(s) used; the location of transshipments (if any); and, to some extent, a general routing pattern. Unless private carriage is used, they neither have information about, nor control over, the detailed routing choices with which the carriers are faced.



AGGREGATE NETWORK



DETAILED NETWORK

Figure 2. Network Aggregation

To facilitate discussion of how the shippers will distribute their traffic over this aggregate network, the following notation is employed:

e = an element of the network (either an arc or a node)

E = set of all elements

r = commodity

s = mode

t_e^{rs} = travel time using element e for commodity r transported by mode s

c_e^{rs} = cost of the carrier of using element e to transport commodity r by mode s

f_e^{rs} = flow of commodity r transported by mode s over element e

f_e = vector of commodity/mode flows for element e = $(\ldots,f_e^{rs},\ldots)$

f = vector of element flows $(\ldots,f_e,\ldots)$

i = origin

j = destination

w = origin-destination pair (i, j)

W_i = set of w with origin i

W_j = set of w with destination j

p = path

P_w^{rs} = set of paths between O-D pair w with commodity r carried by mode s

h_p^{rs} = flow of commodity r by mode s over path p

h_p = vector of commodity/mode flows for path p $(\ldots,h_p^{rs},\ldots)$

h = vector of path flows $(\ldots,h_p,\ldots)$

δ_{ep} = 1 if element e is on path p, 0 otherwise

O_i^r = amount of commodity r produced at origin i

D_j^r = amount of commodity r demanded at destination j

m_i^r = purchase price of commodity r when purchased at origin i

z_w^{rs} = base transportation rate for commodity r by mode s between O-D pair w

T_w^{rs} = demand for commodity r by mode s between O-D pair w

T_w = vector of commodity/mode demands $(\ldots,T_w^{rs},\ldots)$

T = vector of O-D demands $(\ldots,T_w,\ldots)$

M_w^{rs} = the fraction of commodity r transported by mode s between O-D pair w

t_p^{rs} = travel time for commodity r by mode s over path p

c_p^{rs} = cost to the carrier of transporting commodity r by mode s over path p

q_r = value of time ($/hr/unit shipped) for commodity r

ε_s = permeability factor for mode s (the fraction of the carriers' cost that is passed onto the shipper), and

DP_{wp}^{rs} = delivered price of commodity r by mode s between O-D by path p pair w.

This notation makes it possible to describe the assumptions made about shipper behavior and the basic relationships that must exist for any optimal pattern of flows.

It is assumed that the extent of production and consumption activity already is known, i.e., the O_i^r's and D_j^r's are fixed. It is further assumed that each shipper is separately and noncooperatively seeking to minimize the final delivered price of the commodity it is purchasing. The final delivered price to the shipper is determined by the combination of commodity, origin, mode, and path selected, and can be expressed as

$$DP_{wp}^{rs} = qt_p^{rs} + m_i^r + z_w^{rs} + \varepsilon c_p^{rs} \quad . \tag{3}$$

It should be noted that the actual money expended on transportation is expressed by the third and fourth terms only. It is assumed here that this amount is equal to some base rate plus a specified percentage of the actual cost of shipment. This formulation is most appropriate if the transportation industry is tightly regulated. The z_w^{rs} can be considered to be the posted tariff between O-D pair w for commodity r by mode s. The ε can then be adjusted to represent the degree of freedom that the carrier is permitted to vary from this tariff given the costs it is incurring in making these shipments. If a market situation exists, as increasingly will be the case with deregulation, the ε term can be reinterpreted as a profit multiplier, and the z_w^{rs} term can then be deleted. If the market is highly regulated, then the ε is set equal to zero and the z_w^{rs} term retained. In a user-optimized solution it is expected that for each commodity and demand site the delivered prices will replace the more general cost functions given in Equation 1, i.e.,

$$DP_{wp_1}^{rs} = DP_{wp_2}^{rs} = \ldots = DP_{wp_\ell}^{rs} \leqq DP_{wp_{\ell+1}}^{rs} \leqq DP_{wp_{\ell+2}}^{rs} \leqq \ldots \leqq DP_{wp_n}^{rs} \quad \forall w \varepsilon Wj,\ s \tag{4}$$

if $h_1, h_2, \ldots, h_\ell > 0$ and $h_{\ell+1}, h_{\ell+2}, \ldots, h_n = 0$.

The demand and modal split may be determined directly from Wardrop's first principle in a way that total commodity production and attraction constraints are satisfied without the model user having to articulate a functional form for demand. Alternatively, the user may specify a particular demand law. This feature will become clearer when the equivalent optimization problem on which the model is based is presented (below). It is important to realize that the multimodal nature of this problem together with the fact that demand is described through the variables T_w^{rs} results in a modal split:

$$M_w^{rs} = \frac{T_w^{rs}}{\sum_m T_w^{rm}} , \tag{5}$$

and so by determining the T-variables one also determines the modal split.

Keeping the solution requirements (Eq. 4) in mind, the following equivalent optimization problem is formulated:

$$\text{Minimize } Z = \sum_e \sum_r \sum_s \oint_0^{f_e} \left[q_r \cdot t_e^{rs}(y_e) + \varepsilon_s c_e^{rs}(y_e) \right] dy_e + \sum_w \sum_i \sum_p \sum_r \sum_s \left(m_i^r + z_w^{rs} \right) h_p^{rs} + \psi(T) \tag{6}$$

subject to

$$f_e^{rs} = \sum_p \delta_{ep}^{rs} h_p^{rs} \tag{7}$$

$$G_w^{rs} = T_w^{rs} - \sum_{p \varepsilon P_w^{rs}} h_P^{rs} = 0 \qquad \forall\ r,w,s \tag{8}$$

$$E_i^r = \sum_s \sum_{w \varepsilon W_j} T_w^{rs} - O_i^r = 0 \qquad \forall\ i,r \tag{9}$$

$$F_j^r = \sum_s \sum_{w \varepsilon W_i} T_w^{rs} - D_j^r = 0 \qquad \forall\ j,r \tag{10}$$

$$T \geqq 0 \tag{11}$$

$$h \geqq 0 \ . \tag{12}$$

The function $\psi(T)$ in Eq. 6 is selected to correspond to the particular demand law or functional form for Eq. 5 that one desires to enforce. The constraint set specified the various relationships that must exist for any feasible flow pattern. The path and arc flows are related in Eq. 7, the path flows and O-D demand in Eq. 8, and the production and consumption

constraints in Eqs. 9 and 10, respectively. Constraints 11 and 12 are the nonnegativity constraints. By analyzing the Kuhn-Tucker conditions, the optimization problem (Eqs. 6-12) can be shown to be fully equivalent to the user-optimized flow pattern (Eq. 4), provided the cost functions are positive and monotonic and the line integral in the objective function is path-independent. A condition both necessary and sufficient for path independence is that the Jacobian matrix of element costs (consisting of $K_e^{rs} = qt_e^{rs} + \varepsilon_s c_e^{rs}$) is symmetric. If we call each mode-commodity combination a user class, this matrix says that the change in the cost of any user class on a particular network element experienced as a result of a change in flow of a different user class on that element must be the same as the influence that the second one has on the first. Although this symmetry assumption sounds quite restrictive, there are many types of freight analyses where it will apply. For instance, if different freight modes never share any network elements (railroads on rail links, trucks on highways, etc.) and if different commodities on the same mode are treated similarly by the carrier, then the symmetry assumption will be valid. Sometimes, however, different commodities are given different priorities by the carriers. In this case, the model can be used sequentially: first for the highest-priority goods, then for the next-highest-priority (taking into account the previous link loadings), etc.

Solution Algorithm. Since the shippers' submodel might easily include thousands of variables and constraints when being applied to a typical regional freight network, the algorithm used to obtain its solution must be as efficient as possible. In particular, the enumeration of paths that can easily number in the millions must be avoided. Fortunately, the shippers' submodel, although nonlinear in the objective function, has only linear constraints. There are solution techniques for mathematical programs of this type which, when properly applied, can eliminate the need for path enumeration. The particular algorithm chosen for solution of the shippers' submodel is the Frank-Wolfe algorithm, frequently used for urban traffic equilibrium problems (see Ref. 5). The use of this algorithm for the shippers' submodel requires the solution of a shortest path problem and a special type of linear program known as a Hitchcock or transportation problem, together with a one-dimensional line search at each iteration. The shortest path problem is solved by Dijkstra's method (see Ref. 6) and the Hitchcock problem is solved by the out-of-kilter procedure (Ref. 7). Greater efficiency could be achieved by replacing the out-of-kilter procedure with one of the generalized network codes presently available commercially. The line search is performed using a binary search routine.

Carriers' Submodel

Description. Given the values of demand and flow (T_w^{rs}, f_e^{rs}) produced by the shippers' submodel, the carriers' submodel predicts the detailed routing assignments made by the carriers. As such, it uses a detailed description of the transportion network. For modes that control their own right-of-way, such as railroads, the model treats each carrier individually. For the modes that operate on rights-of-way they do not control, such as barges on inland waterways and trucks on highways, the model assumes that the individual carriers that make up the mode behave as a single carrier and that single carrier is then in control of the corresponding portion of the network.

In order to predict an individual carriers' traffic assignment, it is required that the origin-destination demands be known for that portion of the network that the carrier controls. Since the demand from original production origin to ultimate consumption destination, the set of paths that will be used between each O-D pair, and how much of the demand will flow on each path are known from the shippers' submodel, all that is needed is to decompose these paths into the portions used by each carrier. A typical path p_k^r will be of the form

$$p_k^r = (i, n_1, n_2, \ldots, g, n_\ell, n_{\ell+1}, \ldots, g, n_v, n_{v+1}, \ldots, j) , \tag{13}$$

$$p_k^r = p_k^{rs_i} + p_k^{rs_\ell} + p_k^{rs_v} \tag{14}$$

where i is the production origin,

n is a node,

g is a transshipment point,

j is the consumption destination, and

$p_k^{rs_i}$ is the portion of the path p_k^r that involves only carrier s_i.

If we define

$h_{p_k^r}$ as the flow on path p_k^r,

$T_w^{rs_i}$ as the demand for commodity r between the terminal points w of carrier s_i, and

P_{ws_i} as the set of all paths that contain O-D pair w as terminal points for carrier s_i,

then

$$T_w^{rs_i} = \sum_{p_k^r \varepsilon P_{ws_i}} h_{p_k^r} .$$

These $T_w^{rs_i}$ then form the carrier-specific origin-destination demands that enable us to compose a systems-optimized traffic assignment problem for each carrier. If N_{s_i} is the subset of the network controlled by carrier s_i, this can be expressed by the following math program for carrier s_i:

$$\text{Minimize } Z = \sum_{e \varepsilon N_{s_i}} \sum_r c_e^{rs} (f_e) \cdot f_e^{rs} = \sum_{p \varepsilon P_{ws_i}} \sum_r c_p^{rs} \cdot h_p^{rs} \tag{15}$$

subject to

$$\sum_{p \in P_{ws_i}} h_p^{rs} = T_w^{rs_i} \qquad \forall\ (w,r) \tag{16}$$

$$h_p^{rs} \geq 0 \qquad \forall\ (w, p \in P_{ws_i}, r). \tag{17}$$

Solution Algorithm. Although the carriers' submodel is articulated in terms of path flows, it is possible, as was the case with shippers' submodel, to avoid path enumeration. Once again, the Frank-Wolfe algorithm is applied. The main difference between the use of this algorithm for the carriers' submodel and for the shippers' submodel is that the presence of fixed demands for the carriers' submodel requires only that shortest path calculations and one-dimensional line searches be performed.

OTHER CONSIDERATIONS

As described above, transshipment of freight between modes must be considered as a separate mode. However, transshipment can more easily be handled in the actual computer code by including in the network a set of dummy transshipment links with associated cost functions. Any shipment of freight that travels over a transshipment link from mode a to mode b will be considered to be traveling by the combination mode a/b. When enumerating modes to determine modal split, the combination mode is counted separately. Transshipment links can also be used as "interline links" to restrict movements between carriers of the same mode. These links connect carriers at possible interline points and have cost functions representing interline penalties.

It should also be mentioned that back-hauling may be accommodated in the theoretical structure in a number of ways. The most straightforward approach to doing this is to assume that the empty cars will be returned over the same paths used in the fore-haul, and to adjust the flow levels accordingly. This would be especially appropriate for unit train movements. Another approach is to model general-purpose rail cars as separate commodities, with supplies and demands for empties being generated by demands and supplies of those commodities requiring the rail cars.

Finally, considerations of fleet capacity may also be accommodated in a number of ways. The simplest of these is to incorporate appropriate logic in the decomposition algorithm software to prevent the determination of carrier specific O-D demands that would exceed any carrier's fleet capacity.

APPLICATION OF THE MODEL

The original impetus for the model described in the previous two sections was the need to develop a tool for analyzing the congestion impacts resulting from increased coal haulage in the northeastern United States. In particular, the model may be used to ascertain the differential congestion associated with governmental policies and incentives, such as the Powerplant and Industrial

Fuel Use Act of 1978 (FUA) for the converting of utilities and major fuel-burning installations from predominantly oil-based to predominantly coal-based. This is done by first developing data pertaining to the productions and attractions of noncoal commodities. This information, with appropriate cost functions, is input to the model in what is called the preloading phase. The arc flow levels from this phase are used to adjust the congestion on each arc prior to application of the model to a data base of productions and attractions for multiple coal types; this second phase is called the loading of the primary commodities. This approach of preloading other commodities and then assigning coal yields a worst-case assessment of the congestion impacts arising from the regulatory policy considered. The model output indicates arcs with substantial flow increases and cost-of-flow increases as a result of the regulation; these are flagged and pointed out to the user as potential bottlenecks.

One of the networks studied with the model is a modified version of the FRA rail network coupled to a newly designed waterway network for the northeastern United States. That network consists of 9,799 links, 2,258 nodes, and 10,920 origin-destination (O-D) pairs. Due to a number of practical considerations concerning the availability of data and the computational burden involved, some modifications of the general model described earlier (Model Description) were made. In particular, for the preloading phase the model was run for only one aggregate commodity. Moreover, considering this high level of aggregation, a separable negative exponential demand function was selected and calibrated using information about mean trip cost. For these circumstances, the general model (Eqs. 6-12) can be specialized by letting

$$\breve{\psi}(T) = \sum_w \sum_r \sum_s \gamma \; T_w^{rs}(\ln T_w^{rs} - 1) \quad .$$

To solve this specialized model the Frank-Wolfe algorithm discussed in the previous section was used with one modification: a doubly constrained gravity model was solved instead of a Hitchcock problem to improve the computational efficiency (Ref. 8). For the loading of the primary commodities, no demand function is necessary; coal movements are based entirely on delivered price. The equivalent optimization problem has the same form as Equations 6 through 12 except that the term $\psi(T) = 0$. Another modification to the general model concerns interlining between rail carriers. For this application, the shortest path routine has been modified so as to minimize the extent of interlining among rail carriers between each O-D pair. The cost functions used to represent delay and carrier operating cost were taken from the National Energy Transportation Study (NETS) (Ref. 9) and are based on the average physical attributes of arcs of the freight network and the results of simulation models. These cost functions are such that the equivalent otpimization problem (Eqs. 6-12) yields a unique user equilibrium (see Ref. 3). Following solution of the shippers' submodel, the paths were decomposed to obtain fixed O-D demands by carrier. These, in turn, were used in the carriers' submodel to find the final arc flows over the detailed network.

Results of this initial application are very encouraging. The model took slightly less than 14 CPU minutes on a IBM 3033 to solve the large Northeast network. The link loadings produced by the model have been compared against the historical usage of the link. The historical usage is derived

from the density code assigned to the link by the Federal Railroad Administration (FRA). The FRA density codes are:

Code	Annual Gross Tons (millions)
1	1 - 1
2	1 - 5
3	5 - 10
4	10 - 20
5	20 - 30
6	30 +

Table 1 exhibits the cumulative frequency distribution of the differences between the FRA historical data and the computed density codes produced by FNEM and also those produced by another recent attempt to model large scale multicommodity freight movements, an early version of the Multimodal Network Model (MNM) (Refs. 10 and 11). The MNM used an aggregate version of the FRA network with seven density codes.* As can be seen from these results, for one aggregate commodity FNEM predicted almost half of the link loadings correctly and nearly three-fourths within one density code difference. This is substantially better than the results produced by MNM.

The FNEM predictions in which 15 commodity groups were solved simultaneously on a more aggregate network than used for the one commodity case are also shown. The disaggregation by commodity significantly improves the predictions.

Table 1. Differences between Predicted Railroad Link Traffic Densities and FRA Estimates

Density Code Difference	Cumulative Percentage of Links		
		FNEM	
	MNM	1 Commodity	15 Commodities
0	21	43	56
± 1	55	74	76
± 2	76	84	92
± 3	90	92	97
± 4	97	96	98
± 5	99	100	100
± 6	100	-	100

*In that application the network density code 6 represents 30-40 million tons and density code 7, greater than 40 million tons.

DISCUSSION AND EXTENSIONS

The FNEM model appears to be a more accurate predictor of freight network flows than the one other model (known to the authors) for which accuracy tests have been made. This improvement in results probably is due to the separation of shipper and carrier routing decisions and the different criteria employed by each.

However, the flow predictions still deviate more than desirable from observed flows, suggesting that further changes will be necessary to improve predictions. Of course, some of the error surely is due to faulty data and the high degree of aggregation. But even with better or even ideal data, troublesome errors could remain. These probably would result from the highly idealized treatment of the supply side. In particular, consideration of the fleet and reorganization of train/yard operations as freight traffic varies are absent from the model, even though these appear to be crucial to understanding of costs as well as transit times. But including relevant features of these operations will be difficult, as abstraction from detailed operation plans will be necessary. There also needs to be considerable work on the cost and travel time functions themselves. Also, the means of treating carriers in a very competitive industry like trucking is an open question; perhaps a game-theoretic approach would be worthwhile.

REFERENCES

1. T.L. Friesz and E.K. Morlok, "Recent Advances in Network Modeling and their Implications for Freight Systems Planning," Proceedings of the Transportation Research Forum, 21(1):513-520 (1980).

2. T.L. Friesz and J. Gottfried, "A Freight Network Equilibrium Model, Report of the Northeast Transportation and Fuel Availability Study," Report No. CUE-FNEM-1981-8-2, University of Pennsylvania (August 1981).

3. T.L. Friesz, J. Gottfried, R.E. Brooks, R.L. Tobin, and S.A. Meleski, "The Northeast Regional Environmental Impact Study: Theory, Validation and Application of a Freight Network Equilibrium Model," ANL/ES-120, Argonne National Laboratory, Argonne, Ill. (1981).

4. T.L. Friesz, J. Gottfried, and E.K. Morlok, "A Freight Network Equilibrium Model," paper presented at the International Symposium of Transportation Supply and Equilibrium Models, University of Montreal (November 11-13, 1981).

5. N.H. Gartner, "Analysis and Control of Transportation Networks by Frank-Wolfe Decomposition," Proc. 7th International Symposium on Transportation and Traffic Theory, Kyoto, Japan, pp. 591-623 (1977).

6. N. Christofides, Graph Theory: An Algorithmic Approach, Academic Press (1975).

7. E. Minieka, Optimization Methods for Networks and Graphs, Marcel Dekker (1978).

8. S. Evans, "Some Models for Combining the Trip Distribution and Traffic Assignment Stage in the Transport Planning Process," Traffic Equilibrium Research Forum, Springer-Verlag (edited by M. Florian) (1974).

9. CACI, Inc., "Transportation Flow Analysis, National Energy Transportation Study," Report Nos. DOT-OST-P-10-29 through -32, U.S. Department of Transportation, Washington, D.C. (1980).

10. M.S. Bronzini (1980a), Evolution of a Multimodal Freight Transportation Network Model, Proceedings of the Transportation Research Forum, 21(1): 475-485.

11. M.S. Bronzini (1980b), Evolution of a Multimodal Freight Transportation Network Model, mimeo.

THE USDA-EPA ECONOMIC IMPACTS OF COAL DEVELOPMENT ON NATURAL RESOURCES PROJECT

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ABSTRACT

The EPA-USDA Economic Impacts of Coal Development on Natural Resources Project is jointly funded by the EPA's Office of Research and Development and USDA's Economic Research Service to develop and maintain a data storage, retrieval, and analysis system capable of characterizing and analyzing coal and other natural resource market and nonmarket factors. The approach is to simulate the current and recent historical coal network, extrapolate that network in the short run, and build a long run optimization capability. Data files describing coal reserves, mining, cleaning, transportation, and utilization have been obtained and are being integrated in a data base management system. Two models have been developed to use the data and perform analysis. The integrating model is the Interregional Coal Analysis Model, a modular linear programming formulation used as an accounting suboptimization tool to replicate historic coal network characteristics. The second model is the Transportation Analysis System, an engineering cost, transportation network optimization formulation incorporating the entire railroad, waterway and coal pipeline network in the U.S.

INTRODUCTION

Since the early 1970s it has been obvious that an increasing portion of our Nation's energy requirements will be directly or indirectly provided by coal. However, numerous uncertainties persist concerning future demand/supply conditions of domestic and export coal. The impact of such uncertainties may not appear to cause significant changes in coal demand and supply on a regional or industry-wide basis but they do influence the decisions of the firm (producer, carrier, consumer, etc.) and can pose serious problems for those communities which experience coal and related energy development activities. Serious market and socioeconomic problems have already been observed resulting from energy development activities in the West.

Appropriate public decisionmaking requires identification and segregation of causal factors that influence market and nonmarket activities associated with coal production, distribution, and utilization.

A research project was therefore formulated in 1975 to characterize these relationships. The objective of this project is to develop and maintain an efficient data storage retrieval, and analysis system (model) capable of characterizing and analyzing existing coal and other natural resource market and nonmarket factors. Models developed by this research will describe short and long run firm decisionmaking, socioeconomic impacts resulting from energy project development, and effects of alternative public policy decisions. This project is jointly planned and funded by the U.S. Environmental Protection Agency (EPA) and U.S. Department of Agriculture (USDA). Program coordination is provided by EPA's Office of Research and Development and USDA's Economic Research Service.

The objective of this paper is to present information concerning the approach, data, and modeling activities that have been undertaken by the EPA-USDA energy/environmental research project. An integral part of this project is the development of a transportation networking model that characterizes coal and other energy product flows via alternative modal/intermodal techniques.

APPROACH

Market and related nonmarket investigations of coal and energy development activities typically rely on aggregated data to empirically derive causal relationships. Models developed using such data are generally underspecified and are subject to significant aggregation bias. Moreover, most models that have been developed require significant post-model disaggregation of results to estimate specific impacts on any selected group of firms or communities. In short, most studies attempt to use macro data to characterize micro relationships rather than accumulate those data at the most disaggregated level, characterize individual firm (or community) behavior, and aggregate while accounting for new interrelationships that arise at the industry or regional level.

Investigation of existing and potentially available data early in the project (1976) suggested that, given certain resources, a system of data and analytic programs could be developed to support an interregional competitive analysis at the county level. However, because of the magnitude of the data required to develop and exercise such a modeling system and the need for acquiring and validating data, a significant portion of the project resources had to be devoted to developing a state-of-the-art data base management system for maintaining public and private data.

Therefore, the objective became to build an integrated set of data bases and analytical models to support intercounty competition analysis of alternative coal-related policy scenarios. The approach was to simulate the current and recent historical coal network (mine to power plant), extrapolate that network in the short run (ten years), and build a long run optimization capability. Decisionmakers could thus observe the current situation, understand the market and institutional rigidities along the network in the short run, see how modeled optimization would change current commodity flows, and assess impacts on rural counties and communities.

The approach taken is somewhat different than that normally followed by modelers. Instead of developing a theoretical structure and a sophisticated framework to support a model, we first decided to build a set of data bases capable of supporting analysis at the county and/or firm level. Once that system of data bases was in place, it would be much easier to choose or build a model capable of performing a wide range of policy analysis over the entire coal network, i.e., we chose to spend 70 percent of our time developing a data base and 30 percent developing a model and performing policy analysis rather than the normal opposite ratio.

THE DATA BASE

The primary concern in obtaining and integrating individual data files is to maintain the greatest possible level of disaggregation. Therefore, whenever possible, data were obtained describing activities of individual firms and aggregated only because of proprietary restrictions or computer capacity and cost constraints.

Data files describing coal reserves, mining, cleaning, transportation, and utilization have been obtained and are now being integrated into a data base management system. Examples of these data files are: the USGS National Coal Resources Data System (1981 version); MSHA, OSM, and EIA mine production files (annual 1977 through 1980); cleaning plant files developed from several sources; transportation network capacity and physical characteristics and flow patterns by commodity; utility and industrial coal utilization files including Form 423 and Form 67; TVA contract and spot coal deliveries; GURF; NEDS; etc. A major subobjective of the project has been the determination of individual mine suppliers of coal-fired power plants each year from 1975 through 1980. This data base, when combined with files describing current plans for new coal-fired units and conversions, can be used to perform short run analyses of coal market behavior resulting from demand by the electric utility industry.

THE INTERREGIONAL COAL ANALYSIS MODEL

Data from those files described above provide input (directly or via empirical manipulation) to a linear programming (LP) model called the Interregional Coal Analysis Model (ICAM). The ICAM is currently formulated for use as an accounting tool to replicate, through simulation, historic coal network characteristics. Coal production, transportation, and consumption components are analyzed in a modular fashion. Each module is constrained, by restrictions concurrently applied in the other modules, but is also capable of independent optimization for performing sensitivity analyses.

A LP technique was selected over alternative analytical tools for several reasons. Primary among them is the ability to force the model to adequately reflect real world coal network activities while maintaining the ability to parameterize certain relationships for performing sensitivity and optimization analyses. A LP formulation is readily applicable to an interregional competitive analysis and interpretation of results is relatively straightforward. Although the linearity restriction associated with LP does not allow accurate depiction of all activities, it was decided that

the bias associated with the linearity restriction was not sufficient to warrant use of a more sophisticated and costly technique.

As exercised, the ICAM is primarily demand driven. Coal-derived electricity demand, developed from an inventory of power plant fuel consumption characteristics, determines how much coal is required from producers and the corresponding demand for transport services. The ICAM minimizes production, transportation, and conversion costs unless constrained to reflect current coal network flow patterns. Activities are defined to reflect specific origin/destination flow patterns at the firm level and aggregation to the county or multicounty level is performed primarily for reporting purposes.

Given an optimal set of feasible movements to meet a selected demand scenario, resource utilization and cost characteristics are used in combination with estimated coefficients to determine externalities and nonmarket impacts of interest to EPA and USDA. Several coefficients necessary for performing detailed analyses of secondary impacts on land, water, labor, capital availability, price, environmental quality, socioeconomic and institutional infrastructures, etc. resulting from regulatory or public policy decisions are still under development.

As mentioned earlier, the ICAM is comprised of three modules: the mining module, the transportation module, and the utilization module. Each of these modules is briefly discussed in the following sections.

THE MINING MODULE

The mining module determines individual county production characteristics (historic and projected) for supplying coal to an originating point of transport. Production is accumulated in thousands of tons at the county level using current mine production data. The cost assigned to production in each county is the market selling price of coal obtained from regionalized price equations having the following national form:

$$P = -30.79 + 0.014X_1 - 11.07X_2 - 0.006X_3 + 6.98X_4 + 13.30X_5$$

where

P = price in cents per million Btu,

X_1 = Btu content (mmBtu/lb),

X_2 = sulfur content (weight percent, as received),

X_3 = quantity of coal in thousands of tons (ttons),

X_4 = number of years projecting into the future, and

X_5 = dummy variable depending on the number of UMW contract renewals occurring in the projection period.

The total county reserve base is incrementally depleted for each county depending on the ratio of underground (2.00 tons per ton of production) and strip (1.15 tons per ton of production) mining. However, since the ICAM currently is used only for short run modeling, the depletion procedure merely tracks cumulative production. Depletion is not currently a significant factor in county production or price schedules.

A Western States prototype ICAM included coefficients describing the number of acres requiring reclamation. However, sponsor interest in this area has waned and therefore those coefficients do not reside in the current national version of the ICAM. Land and water use coefficients are of current interest to the USDA and will be developed for the mining module if time permits. It should be noted that water use coefficients are of far greater importance in the utilization module.

THE TRANSPORTATION MODULE

The transportation module moves coal (on a Btu basis) from each origin point specified in the mining module to a destination point defined in the utilization module. Transportation of coal is allowed to occur only between those producing counties and utilization points which have been identified from historical data. In addition, announced intentions for new plants and their sources of coal (county) are added. Costs for each movement are obtained from the North Dakota State University Transportation Analysis System. The conversion from thousand tons to mmBtu is based on the quality of coal reported for each movement obtained from historical data files. The amount of coal allowed to be transported is also constrained using historical data files.

Obviously, if the ICAM included a full transportation matrix allowing flows from every county capable of producing coal to every power plant capable of burning it, the fully formulated problem would probably be too large and expensive to run. Therefore, a contract was awarded to the Engineering Experiment Station at North Dakota State University (Kenneth A. Ebeling, Industrial Engineering Department) to build a network analysis and engineering costing capability to fully describe the flow and cost of delivering coal from any mine to any power plant via rail, barge, and/or pipeline. The resulting Transportation Analysis System (TAS) simulates the entire railroad, waterway, and slurry pipeline network in the U.S. (more than 20,000 nodes). Each node has been recoded to make it compatible with FIPS place and ZIP codes so that population census data can be integrated and analyzed. The TAS is capable of moving coal from any mine to any power plant over the combined network using alternative constraints including capacity limitations for individual links while simultaneously building an engineering cost for the movement. Computer graphics have been utilized to display results of individual route characterization. An interactive capability is also available.

THE UTILIZATION MODULE

The utilization module receives coal from the transportation module and converts it to produce specified outputs (ex., electricity to meet a reported demand). Currently, steam electric power plants are the only

class of consumers residing in the utilization module. These power plants utilize coal to produce electricity measured in millions of kilowatt hours. The output from each plant for any forecast year is primarily determined by the plant capacity factor, an index of the actual energy produced by a plant during a period with respect to its potential.

Plant capacity factors are projected using the following equation:

$$PCF = 82.5 - 0.0048(HR) - 0.0020(NONF) - 0.0074(GC) + 0.115(CUSE)$$

where

PCF = plant capacity factor (annual percent),

HR = input/output ratio or heat rate (mmBtu/kWh),

NONF = nonfuel operating cost ($/mmkWh),

GC = generation capacity (Mw), and

CUSE = coal use (annual percent of total energy input provided by coal).

It should be noted that certain parameters in the above equation are stochastic and require separate estimation, particularly heat rate. Both statistical and trend analysis were used to estimate the plant factor parameters. However, careful inspection of each projection is necessary to prevent inconsistent results. The heat rate (conversion efficiency) is also instrumental in determining each power plant's demand for coal.

Land and water use coefficients for each plant have also been developed for use with the ICAM. The relevant water use coefficient depends on the cooling method used. Land use also depends upon cooling method but is relatively insignificant.

RIGHT-HAND-SIDE CONSTRAINTS

Right-hand-side constraints are necessary for tracking reserves in each county, the capacity for each transportation connection, and the kWhs of electricity each plant can produce. The right-hand-side constraints force the model to replicate historical coal network patterns and will be used later to selectively optimize according to the policy scenario defined.

The reserve constraints are obtained from the 1981 National Coal Reserves Data Base System available from the U.S. Geological Survey. Work is currently underway to segregate reserves according to 21 categories of sulfur dioxide chosen by the EPA funded Universities Research Group on Energy (URGE). A concurrent study concerning coal and coal ash quality impacts on supply functions has also been initiated.

The constraints for each transportation connection are obtained from the TAS and were originally derived from historical coal network patterns

and new capacity tables. The power plant production capacity constraints were obtained from the plant capacity factor analysis discussed earlier.

Other constraints and/or more detailed constraints will be added as resources permit. Examples of constraints which may be added include water availability and reserves characterization according to quality, quantity, and cost of extraction.

OPTIMIZATION

The linear programming formulation was originally designed and is usually used as a global optimization technique. Constraints are always present but are usually sufficiently relaxed to allow all activities (columns) significant latitude in choosing the level at which they will operate. This is not true in the problem the ICAM characterizes. We have initially constrained the ICAM so that power plants can generate and transport only at levels and with sources observed from historical information. We intend to partially, not globally, relax those constraints based on the details of the policy scenarios which are to be formulated.

A question therefore arises concerning the effect of partial optimization on the overall system. Discussion with Marc Kaplan, who will later be summarizing all the models presented at this Workshop, suggests the conflict is based on the age-old differences between predictive (our approach) vs. prescriptive (global) models. The EPA-USDA Project is building a model which attempts to predict, as accurately as possible, real-world (utility) responses to selective and industry-wide environmental and other regulations. The Project is attempting to translate those selective and industry-wide regulations into county and community impacts which can realistically indicate to federal, state, and local planners the magnitude of problems which must be addressed in order to efficiently accommodate predicted levels of development.

EPA's Office of Research and Development recognizes the difference between predictive and prescriptive models and is attempting, in their funding of research projects, to develop interactive, responsive models which perform both global and predictive optimization. The URGE Project, also funded by EPA's Office of Research and Development, is currently revising the Teknekron Utility Simulation Model. This model is a utility dispatch model which allocates or builds capacity as consumer demand warrants. When revised, the utility dispatch model will include state level demand, unit dispatch, utility finance, transportation, and coal supply modules which can be interactively accessed by EPA analysts.

SUMMARY

The EPA-USDA Economic Impacts of Coal Development on Natural Resources Project continues to work toward the completion of a system that can accurately describe the existing coal network, analyze historical relationships and institutional arrangements, make short run projections of the current situation, suboptimize over the longer run, and make comparisons between multiple optimal utility networks. The Project will concentrate on

impacts to rural communities and the agricultural sector following satisfactory characterization of the coal network and market and nonmarket cause/effect relationships. Analyses being contemplated include inter-commodity competition for transportation resources between agricultural commodities and coal, synfuels development and its competitive position with the agricultural sector, air and solid waste pollution impacts on agricultural production, and labor impacts in rural communities.

THE PORT EXPANSION SYSTEM: APPLICATIONS AND EXTENSIONS

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ABSTRACT

A multiobjective programming model, the Port Expansion System (PES), was originally developed to aid in the planning for the reuse and redevelopment of marine transport networks. The multiobjective framework allows for the simultaneous consideration of different planning objectives. In this paper PES is extended to consider sulfur dioxide emissions at power plants. Three objectives are considered, minimizing costs; comprised of coal purchase and transport costs as well as SO_2 control costs and fixed opening and operation and maintenance costs for handling facilities at both ports and power plants, maximizing system efficiency as measured by coal handling times and minimizing sulfur dioxide emissions. By varying the importance of the objectives the tradeoffs between them are explicitly presented. In addition to this data, the hierarchial location model also provides the following information:

- How much, what type, how and by which routes coal is shipped from mines to utilities.
- The size and location of new coal handling facilities.
- The allocation of coal to handling facilities at ports and power plants.

1. INTRODUCTION

The Energy Supply and Environmental Coordination Act of 1974 (P.L. 93-379) and the Power Plant and Industrial Fuel Use Act of 1978 (P.L. 95-620) were two attempts by the Federal Government to stem the use of oil and natural gas for generating electricity in the U.S. These acts banned the use of natural gas in all electric generating plants after 1990 and forbid any new plants from using gas or oil. They also empowered the Secretary of Energy to prohibit certain existing plants from burning oil. Prohibition orders have been issued for sixteen electric utilities in New England.

The New England plants that have been directed to convert, entirely or in part, from oil to coal have a total generation capacity of 3,740 megawatts of electricity. All but four of the plants are on the seacoast or on adjacent estuaries or navigable rivers. Few of the affected plants

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or on adjacent estuaries or navigable rivers. Few of the affected plants have as yet made a move toward coal conversion beyond engineering and feasibility studies.

This report presents some results of the project which consisted of two major phases. The first phase, an inventory of coal unloading facilities in the New England region, including those specifically built to service such large coal-consuming industries as electric utilities, was developed. A general status report was prepared on each facility still standing, whether in use or not. While general port coalhandling facilities may have virtually disappeared, larger electric generating plants, many built on salt water to receive waterborne coal, still possess usable or restorable coal handling wharfage and equipment.

The second major phase of this project was the formulation of a mathematical programming model called the Port Expansion System (PES) that can determine the least cost location, number, and activity levels of coal handling facilities, the mine origin and types of coal that are to be shipped and the transport modes and routes needed to adequately serve New England utilities that are to convert to coal. The results of the phase one inventory are incorporated into the model as constraints (such as site availability, depth of harbor and railroad links among others) that will ultimately determine the size of coal handling facilities for each port as well as the feasibility of locating new facilities at those sites.

2. MATHEMATICAL STRUCTURE

PES is a mixed integer mathematical programming model designed to find optimal routes and modes for transporting coal to coal demand sites and optimal locations and activity levels for coal handling facilities at receiving and shipping nodes on a transportation network. The model is solved so as to minimize the total cost function $Z_1(\overline{X},\overline{W})$. The optimal choice of route, mode, location and activity levels provided in the solution to the model represent the least total cost of coal delivery attainable given the assumptions and data input to the system.

Three types of decision variables are used to designate the different choices that are made within the model. The flow decision variables have the general structure X^{v}_{ijq} and represent the tons of coal quality type q transported by mode v from origin node i to destination node j. The $X_{r\ell j}$ variables represent the allocation of coal to an "open" handling facility type r at subnode ℓ within node j. Zero-one integer variables, $W_{r\ell j}$, determine whether or not machine type r is open (operating) at subnode ℓ in node j.

PES is actually two linked models, a transportation/transshipment model defined for the network and a location/allocation model defined for the potential locations of coal handling facilities within receiving and shipping nodes of the network. The location/allocation model is nested

within the transportation model. In the transportation/transshipment, component, node j is treated as a single entity, with transportation arcs of the network originating or terminating at node j. Within node j coal handling facilities can be located at any of the appropriate subnodes (potential sites). Incoming or outgoing coal shipments are simultaneously allocated within the model to open handling facilities at these sites.

Solution procedure

All functions of continuous (non-integer) variables are linear allowing for a relaxed linear programming* representation of the system to be solved with standard solution packages such as the IBM MPSX software. Optimal integer solutions for the PES can then be found by using standard integer programming routines. The current version of the system has been solved by the SESAME program developed at the Massachusetts Institute of Technology. Integer values are obtained by use of a "branch and bound" routine that follows the solution of the relaxed L.P.

The linear form for the relationships developed in the Port Expansion System will facilitate performing post optimally sensitivity analysis for the solution. Since there is some degree of uncertainty surrounding many of the data inputs to the model, the range of values that various parameters in the system can take on and still keep the current solution optimal can be derived. This is also an option available on most standard mixed integer programming software packages. The PES program, when set up with the basic data described in Section 3, has 406 functional constraints (320 inequalities and 86 equalities) and 2284 variables which include 2046 flow variables (X_{ijq}), 119 allocation variables ($X_{r\ell j}$) and 119 zero-one machine location variables ($W_{r\ell j}$). The relaxed linear program solves in approximately 120 seconds of CPU time. Using the outputs of the relaxed L.P. and analysis of the concave cost functions of coal handling facilities only two additional runs were needed. The solution to the mixed integer program achieved in this way was only 3.19% larger than the optimal solution to the relaxed L.P. Thus a good integer solution was obtained in less than six minutes of CPU time.

3. DATA INPUT DESCRIPTION

The data needed to run the PES includes sources of coal (mines), the locations of coal demanding power plants and the existing transportation and material handling infrastructure that includes railroads, ports, and water modes that could be used to transport coal.

Data associated with each coal producing node are the price, Btu and sulfur qualities of the coal, and the quantities of each coal type

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* The relaxed linear program allows all variables to be continuous, thus, $0 \leq W_{r\ell j} \leq 1$ for the relaxed L.P.

that are produced. There is a continuous range of qualities by sulfur and Btu content, in order to use this information in the model, coal quality was reduced to 9 discrete representative types.

Coal demand was estimated for the 17 power plants in the study, from the rated megawatt capacity of each of these units as published by the Federal Energy Administration (11).

At each of the nodes that are to handle coal (transshipment ports and power plants) there may be a number of candidate sites (subnodes) for the location of coal handling equipment. For transshipment ports and the Brayton Point power plant (RA) the type of equipment to be located (a decision made within the PES) will be chosen to perform a specific transfer function; rail to water, water to rail, or water to water. Equipment to be located at subnodes within power plant nodes will serve only to unload coal from incoming water or rail modes.

An inventory of New England port capacities was compiled for the project from Army Corps of Engineers publications (33, 34). Information on the depth of channel, depth at berth, size of berth, rail connections, existing handling facilities and potential storage capacities for most subnodes at ports and power plants served by water modes is provided. The mode and type of vessel that can be accommodated by either a port or a power plant is determined from the information in the inventory. The existence of rail connections to subnodes provides for the potential rail movement of coal to or from that subnode. Harbor depths greater than 40 feet will allow 60,000 dead weight ton (dwt) freighters to potentially use a port. Twenty-five foot and 15 feet harbor depths permit the potential use by 25,000 dwt and 15,000 dwt vessels respectively.

The capacity of a transshipment node or a power plant node to handle coal is determined by the type, size and number of vessels it can accommodate, and the capacity of the coal handling equipment that ultimately locates there. (A subnode is able to accommodate only one machine type consisting of a specific configuration of equipment.) Eight types of machines have been identified for coal handling. The types are identified by their funciton and capacity where functon is determined by the modes accommodated (rail or water) and capacity is limited by space availability at a subnode. Fixed costs for each machine type are amortized daily at an 11.5 percent interest rate over 25 years (1). It is assumed that the capacity of a machine type is the total quantity of coal it can handle duirng a 16 hour period.

Table 1 shows the capacity and fixed and variable costs for each machine type used. Machines 1 through 3 are capable only of unloading coal and therefore will only locate at power plants. For power plants served by water routes only, machine types 1 and 2 are the only options. Where a power plant only has a rail connection, it is restricted to machine type 3. Machine types 4 through 8 have the capacity to unload and load coal and are the types of machines tht can locate at transshipment nodes. Machines of type 4 and 5 can be located in ports restricted to water bourne nodes; machines of type 6 are for

Table 1: Coal Handling Machine Costs

1 period = 16 hours

Coal Handling Facility Component	FIXED COST: Total Cost	FIXED COST: Per Period Amoritization (Per Day)	Capacity Tons Per Hour (TPH)	VARIABLE COST: Manpower Requirements Per Day	VARIABLE COST: Energy Requirements Per Day	VARIABLE COST: $ Per Ton
1) Clam Shell[c]	$6.0x10^6$	$2003	1200	2 @ $9/hr.	1 mw-hr.	.0439
2) Ladder Bucket [a,e]	$8.4x10^6$	$2803	2500	1 @ $9/hr.	1.742 mw-hr.	.0278
3) Rotary Dumper [a,b,e]	$3.7x10^6$	$1635	2000	2 @ $9/hr.	.660 mw-hr.	.0205
4) Clam Shell Stacker Reclaimer [c,d,e]	$7.9x10^6$	$2638	1200	3 @ $9/hr.	1.884 mw-hr.	.0770
5) Ladder Bucket [a,e] Stacker Reclaimer	$10.5x10^6$	$3506	2500	2 @ $9/hr	2.626 mw-hr.	.0436
6) Rotary Dumper [a,b,e] Stacker Reclaimer	$7.3x10^6$	$2438	2000	3 @ $9/hr.	1.544 mw-hr.	.0403
7) Clam Shell Rotary Dumper Stacker Reclaimer [a,b,c,d,e]	$11.4x10^6$	$3807	1200	5 @ $9/hr.	2.544 mw-hr.	.1111
8) Ladder Bucket [a,b,d,e] Rotary Dumper Stacker Reclaimer	$14.0x10^6$	$4675	3000	4 @ $9/hr.	3.6160	.0538

a) McDuffie Island [1,16]

b) Lockhead Report [9]

c) Personal Conversation with Bud Tracy, Northeast Utilities

d) Northeast Utilities Coal Conversion Plan-Norwalk [22]

e) United Engineers, Boston, MA [30,31,32]

transshipment nodes rstricted to rail shipments into the nodes; and machines of type 7 and 8 are for nodes capable of accommodating both rail and water modes in and out of the node.

4. MULTIPLE OBJECTIVE EXTENSIONS

Multiobjective programming techniques are currently being used to modify the model described in the previous sections to add flexibility to its prescriptive analysis capabilities. While cost minimization is often used as the evaluative criteria for analyses of this type, a more realistic description of the decisions to be made in the coal handling and transport system revitalization plan may be obtained by simultaneously optimizing conflicting objectives such as; cost, coal handling efficiency and emissions reduction.

For the multiobjective analysis handling efficiencies are measured by the fraction of coal handling equipment capacity utilized at any transshipment node. To operationalize this the following set of constraints need to be added to the model:

1) $X_{r\ell j}/B_{r\ell j} \leq H \qquad \forall \; r\varepsilon\ell, \ell\varepsilon j, j\varepsilon Y$

The objective function $Z_2(\overline{X},H)$ measures the maximum fraction of capacity utilized for any "open" handling facility in the system. By minimizing $Z_2(\overline{X},H)$ the unloading burden will be equalized throughout the Network.

The Multiobjective Port Expansion System has been run with test data for a sample problem. Figure 1 is a schematic of the nodes and transport links of the system used. For the example there are two coal mines, DU and JE, each providing a different quality of coal which vary by Btu content and price. The coal mines are directly connected by rail to two power plants, QA and PB, and two transshipment nodes, SB and SN. The transshipment nodes are connected to two of the power plants, PD and PA, by water routes. Three power plants are respresented in the problem: QA with rail connections only, PD with water connections, and PB with the capability of being served by both rail and water.

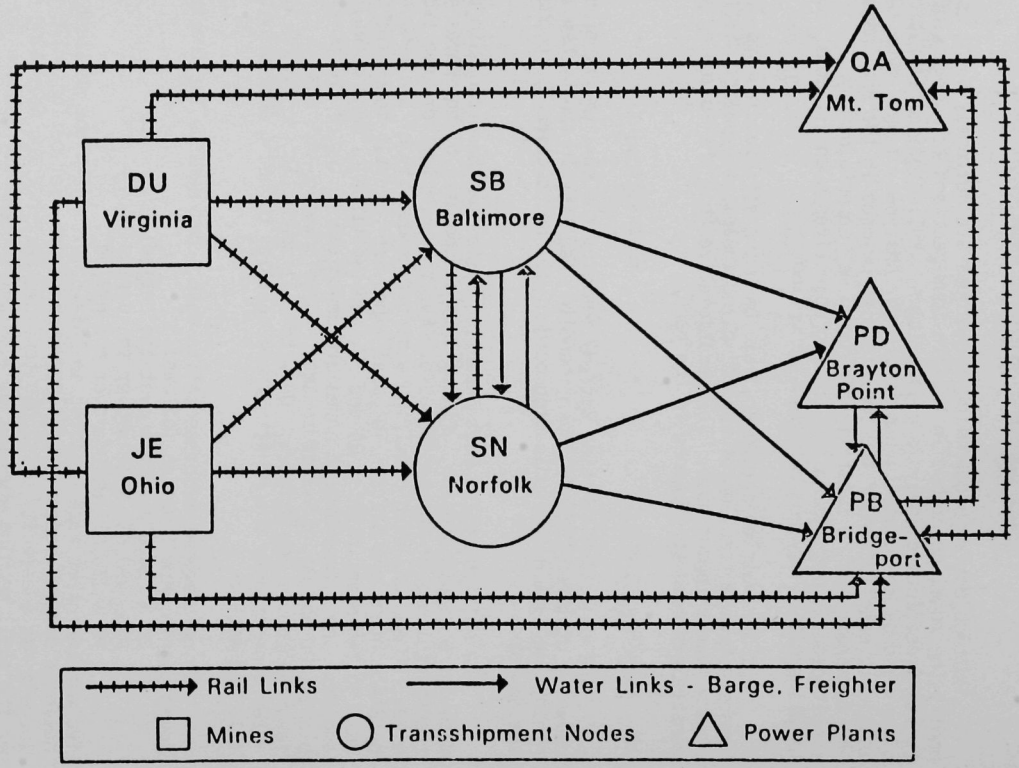
Using somewhat respresentative data, coal demands for the three power plants were input as follows:

QA = 26,874 MBTU's over the period
PD = 229,611 MBTU's over the period
PB = 130,811 MBTU's over the period

Two machine sizes were utilized in this problem with the smallest having a maximum capacity of 6,000 tons of coal per period while the largest has a capacity of 12,000 tons per period. The operating costs of the small machine were put at $.65 per ton and $.5 per ton for a larger machine. Investment cost for small machines are $550 compared to $1650* for large machines.

FIGURE 1

SAMPLE PROBLEM



Five multiobjective runs were made with the data for the sample problem. Objective $Z_1(\overline{X},\overline{W})$ was optimized with $Z_2(\overline{X},\overline{H})$ constrained to be less than or equal to the values of 1.000, .750, .500, .425 and .350. Table 2 summarizes the results (with $Z_1(\overline{X},\overline{W})$ = MINCSTOT and $Z_2(\overline{X},H)$ = MINMAXUT) of the five runs, A through E. The trade-off between minimum total cost and maximum unloading time (system efficiency) is displayed on the graph in Figure 2.

Since the two objectives conflict, decreasing the maximum unloading time increases total costs. A decrease of 50% in the maximum unloading time objective (1.000 to .500) requires an added total expenditure of $5,728 or less than 1% of the total minimum cost. Another 30% reduction in the maximum unloading time objective (.500 to .350) would cost $14,611 which represents an additional 2.4% to the minimum total cost. The tradeoff of cost and system efficiency exhibits decreasing marginal returns to expenditures.(Table 2).

Movement along the multiobjective tradeoff curve from solution A to D shows similar changes in the component costs for objective Z_1 $(\overline{X},\overline{W})$. Investment (TOTINCST) and coal purchasing (TOTCLCST) costs increase while operating (TOTOPCST) and transport costs (TOTRNCST) decrease. The total number of coal handling facilities increase, due to large capacity (12,000 tons/period) machines (2 used in solution A while 6 are used in D) replacing small capacity machines (3 used in A, only 1 used in D). Solution E represents a break from these monotone patterns for investment and transport costs. Total investment in machines decreased from the previous solution while the cost of transport, that had been decreasing, goes up. The use of small machines increases dramatically, from 1 to 6, as the use of large machines decreases from 6 to 3. There is a decline in the total amount of coal transported throughout the five solutions.

We are currently formulating the mathematical structure for the environmental objective. Data on pre-combustion alternatives (such as coal cleaning), combustion process changes (such as fluidized bed boilers) and post combustion removal technologies (such as flue gas desulfurization processes) is being gathered. It is anticipated that with this additional capability, the composition of changes in emissions patterns and coal use by type can be compared to the total cost and to cost components.

A simple procedure for calculating costs and emissions was developed to test the feasibility of additional sulfur emissions constraints and objectives. Two new sets of constraints were added to PES, represented by the following generic equations:

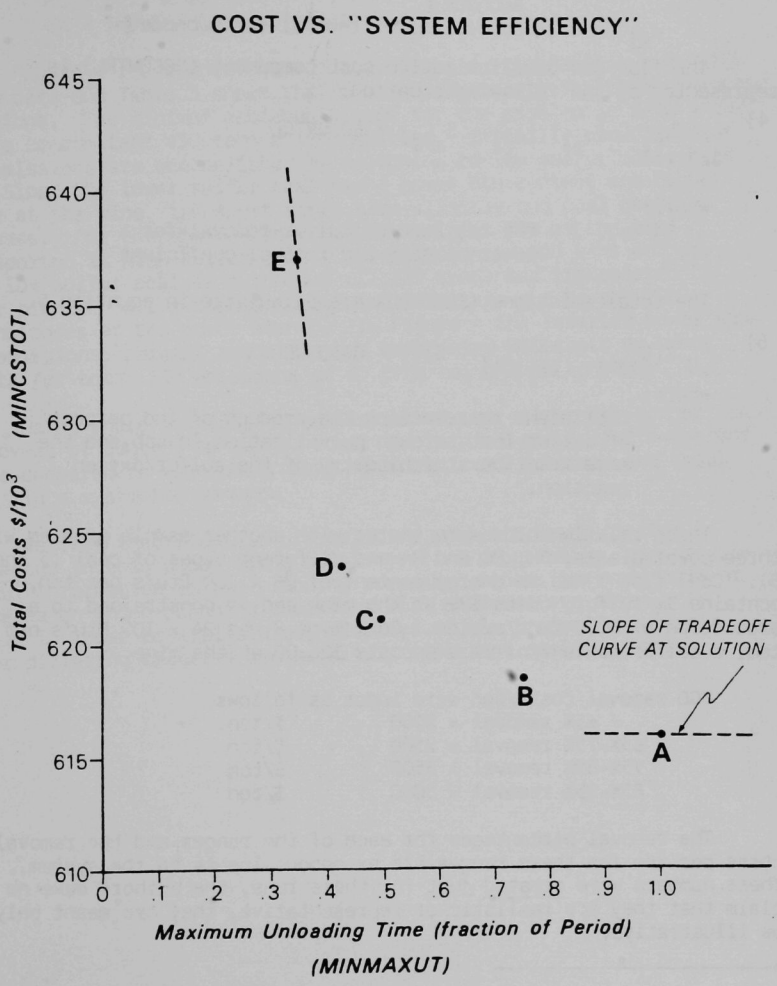
2) $S_{oo,j} = \sum_q a_q \sum_{i \in N_j} \sum_v X_{ijq} Y_{ijq} \qquad \forall\ j \in U$

3) $(1-\alpha_{\ell,j})\ S_{\ell,j} \geq S_{\ell+1,j} \qquad \forall\ \ell \in j,\ j \in U$

TABLE 2 A COMPARISON OF SOLUTIONS

Objective Component / *Solution	MINCSTOT	MINMAXUT	TOTINCST	TOTOPCST	TOTRNCST	TOTCLCST	No. of Machines 1	No. of Machines 2	Tons On Rail	Tons On Barge
A (15,872)	616,731	1.000	4950	16,707	118,890	476,184	3 (5)	2	15,872	14,771
B (15,872)	618,323	.750	7,700	15,548	118,890	476,184	2 (6)	4	15,872	14,771
C (15,462)	622,459	.500	9,350	15,527	110,348	487,234	2 (7)	5	15,462	14,361
D (15,372)	623,571	.425	10,450	14,987	108,469	489,664	1 (7)	6	15,372	14,271
E (14,862)	637.070	.350	8,250	13,230	112,195	503,394	6 (9)	3	14,862	8,400

FIGURE 2.


COST VS. "SYSTEM EFFICIENCY"
645
640
635
630
625
620
615
610
Total Costs $/10^3 (MINCSTOT)
E
D
C
B
A
SLOPE OF TRADEOFF CURVE AT SOLUTION
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Maximum Unloading Time (fraction of Period)
(MINMAXUT)

where:

$S_{oo,j}$ = Total amount of sulfur entering the power plant each period.

$S_{\ell,j}$ = Total amount of sulfur entering treatment subnode ℓ.

$\alpha_{\ell j}$ = Coeficient of removal for subnode ℓ.

The flue gas desulfurization cost component (SOCONTRL) is represented by the following equation:

4) $$\sum_{j \varepsilon U} \sum_{\ell \varepsilon j} C_j(\alpha_{\ell j}).(\alpha_{\ell j} \cdot S_{\ell ij}) = \text{SOCONTRL}$$

where:

$C_j(\alpha_{\ell j})$ = The cost/ton of sulfur removal for power plant j and removal coeficient .

The total emissions (EMSOTWO) are calculated in equation 5.

5) $$\sum_{j \varepsilon U} K(S_{ooij} - \sum_{\ell \varepsilon j} \alpha_{\ell ij} \cdot S_{\ell j}) = \text{EMSOTWO}$$

where:

K = coeficient representing the product of the percent of sulfur lost through pulverization, in ash, and the mole fraction stoichiometry of the sulfur/oxygen reaction.

These relationships were tested with another sample problem with three power plants, PK, PC and RA and different types of coal (5 and 8). Coal type 5 has an energy content of 26 x 10^6 Btu's per ton, contains 3% sulfur, costs $22 at the mine and is constrained to a production of 8000 tons/period. Coal type 8 has 24 x 10^6 Btu's per ton, a sulfur content of 1% and costs $26.00 at the mine.

FGD removal costs/ton were input as follows

65% removal	= 2000	$/ton
65%-75% removal	= 2500	$/ton
75%-85% removal	= 3500	$/ton
85%-95% removal	= 5000	$/ton

The removal percentages for each of the ranges and the removal costs per ton for these ranges are exogenous inputs to the system. These numbers were created just for these runs, the authors make no claim that they are realistic or representative, they are meant only to be illustrative.

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* These investment costs represent the per period amoritization of capital expenditures for the coal handling facilities.

The demands for the three power plans are as follows:

PK = 21.6 x 10^9 Btu's/period
PC = 65.5 x 10^9 Btu's/period
RA = 180.3 x 10^9 Btu's/period

Figure 4 represents the results of the multiobjective runs with these data and Table 3 shows the detailed components for three selected solutions. The minimum achievable cost for the problem is \$376 x 10^3 with a concomitant 450 tons of SO_2 emitted. Initially reductions of SO_2 emissions are accomplished by switching to low sulfur coal (type 8). Since the lower sulfur coal has a lower Btu content and higher price at the mine, transport costs rise slightly and coal costs increase. For the minimum cost solution almost 70% of the coal transported is high sulfur coal. At emissions of 200 tons per day, only low sulfur coal is purchased (11,139 tons) and transported to power plants. All subsequent cost increases are due to the FGD technologies at the power plants. In Figure 4 the inserted boxes show the emissions, percent reduction and associated FGD costs by power plants for total SO_2 emissions of 65 tons/day and 30 tons/day.

Using these multiple objective techniques allows for comparisons of levels of control by plant, costs for control and sulfur emissions to be compared to transport, coal handling, coal purchase and total costs in a systmatic manner.

We feel that flexible prescriptive analysis, such as that presented in this paper using multiobjective programming, can provide useful information to the planning process. Since, the rationale or criterea on which planning decisions will be based are often only partially known or articulated, displays of the tradeoffs inherent under differing criterea can be a very important decision tool.

FIGURE 3

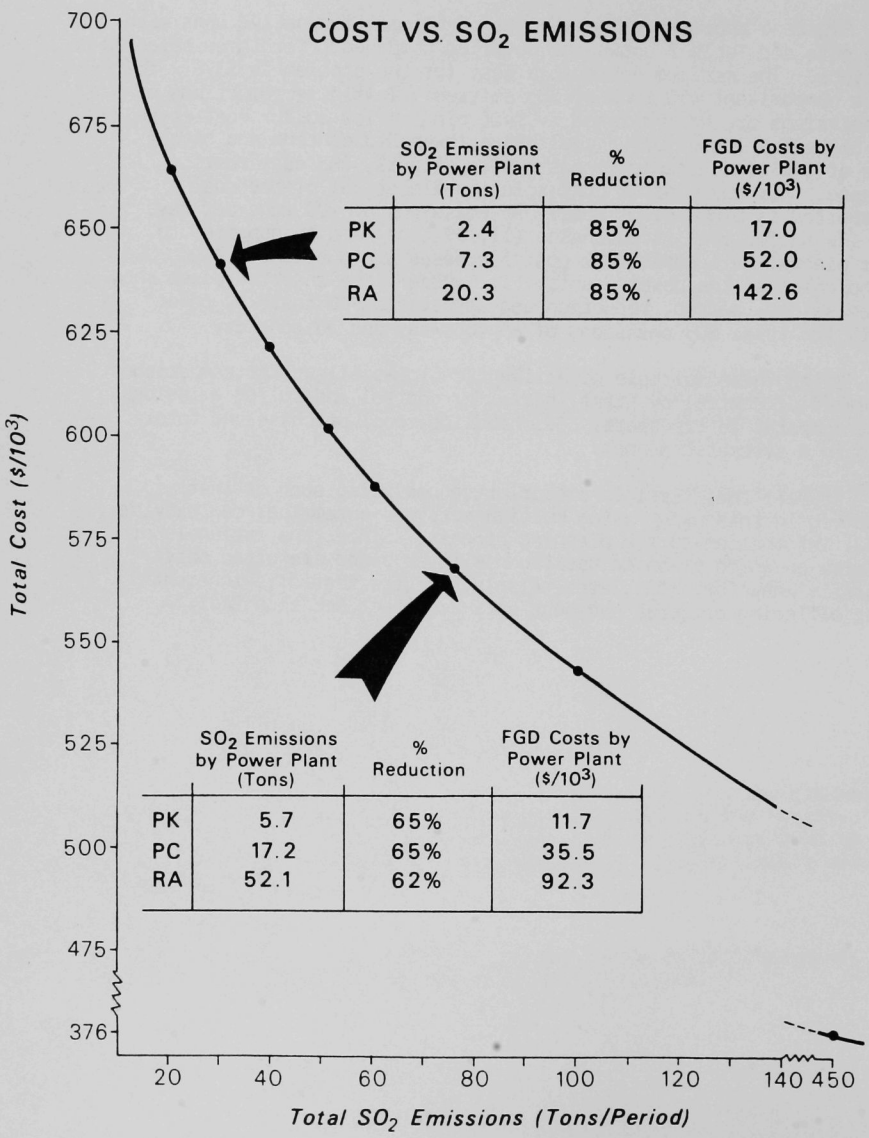
COST VS. SO_2 EMISSIONS
700
675
650
625
600
575
550
525
500
475
376
Total Cost ($/10^3)
20
40
60
80
100
120
140
450
Total SO_2 Emissions (Tons/Period)
SO2 Emissions by Power Plant (Tons)
% Reduction
FGD Costs by Power Plant ($/10^3)
PK 2.4 85% 17.0
PC 7.3 85% 52.0
RA 20.3 85% 142.6
SO2 Emissions by Power Plant (Tons)
% Reduction
FGD Costs by Power Plant ($/10^3)
PK 5.7 65% 11.7
PC 17.2 65% 35.5
RA 52.1 62% 92.3

TABLE 3. A Comparison of Solutions

Objective Component / Solution	Total Emissions of SO_2/day (Tons)	SO_2 Emissions by Power Plant	Per Cent Reduction by Power Plant	Flue Gas Desulfurization costs by Power Plant	Tons of Coal Shipped by Sulfur Content	Total Cost ($\$/10^3$)	Transport Costs ($\$/10^3$)	Coal Handling Costs ($\$/10^3$)	Coal Purchase Costs ($\$/10^3$)
D (10,899)	300	28.7 136.0 135.2	0 0 0	0 0 0	2884 (3%) 8015 (1%)	407	115	15	277
H (11,139)	75	5.7 17.2 52.1	65% 65% 62%	11.7 35.5 92.3 139.5	0 (3%) 11,139 (1%)	569	118	15	296
J (11,139)	40	2.4 7.4 80.2	85% 85% 76%	17.0 52.0 123.3 192.3	0 (3%) 11,139(1%)	621	118	15	296

REFERENCES

1. Alabama State Docks Department, McDuffie Coal Terminal Report, Mobile, Alabama, 1981.

2. Beckmann, M., and Marschak, T. "An Activity Analysis Approach to Location Theory." Kyklos, 1955, 8, 128-141.

3. Charnes, A. and Klingman, D. "The Distribution Problem with upper and Lower Bounds on the Node Requirements." Management Science, 1970, 16, 638-642.

4. Cohn, Jared L. Multiobjective Programming and Planning. New York: Academic Press, 1978.

5. Davis, F., and Ray, T. "A Branch-Bound Algorithm for the Capacitated Facilities Location Problem," Naval Research Logistics Quarterly, 1969, 331-344.

6. Efroymson, M., and Ray T. "A Branch-Bound Algorithm for Plant Location." Operations Research, 1966, 14, 361-368.

7. Hill, M. Planning for Multiple Objectives: An Approach to the Evaluation of Transportation Plans. Regional Science Research Institute, Philadelphia, PA 1973.

8. Rietveld, P. Multiobjective Decision Methods and Regional Planning. North-Holland, Amsterdam, 1980.

9. U.S. Army Corps of Engineers, The Ports of Southern New England Port Series No. 4. Revised 1976, (Washington, D.C.), U.S. Government Printing Office, 1977.

10. U.S. Army Corps of Engineers, The Port of Portland and Searsport Maine and Portsmouth, New Hampshire, Port Series No. 1. Revised 1976. (Washington, D.C.), U.S. Government Printing Office, 1977

11. U.S. DOE, Bituminous Coal and Lignite Production and Mines Operations - 1978, Energy Data Report, (Washington, D.C.), EIA, 1980.

WORLD COAL DISTRIBUTION ANALYSIS

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ABSTRACT

Data Resources, Inc. (DRI) has developed a modeling system designed to determine levels of steam coal trade among countries over the next two decades. The analysis considers economic (industrial growth by country), energy (fuel use by sector and type), coal supply (available reserves by exporting nation), and transportation (domestic and oceangoing) factors. A special feature of the models is an explicit consideration of the many qualitative factors, such as political risks, labor problems, and the possibility of an OPEC III, that will affect world coal trade patterns in the future.

The modeling system is an agglomeration of a number of specific DRI analysis capabilities: international economic forecasts, world energy use projections, oceangoing vessel analysis, domestic transportation constraints, coal reserves and production by country, and physical distribution management analysis. These are combined in a World Coal Distribution Model, which produces estimates of country-specific coal imports and/or exports by destination nation through the year 2000.

DRI has used the model to evaluate optimal coal resource investment strategies, transportation constraints in moving coal to U.S. ports, alternative competitive strategies of coal producers in the world markets, new U.S./foreign port investment requirements, new coal bulker requirements analysis, possible location of inland coal consolidation facilities within the U.S. and abroad, levels of steam coal trades for Europe and the Far East, world coal port development needs, among other issues.

OVERVIEW

Coal now supplies 25% of the world's energy. Recent DRI estimates indicate that coal will have to supply between one half and two thirds of the additional world energy requirements through the year 2000. This implies that world trade in steam coal will have to grow almost tenfold over 1979 levels by the end of the century. By 1990, DRI estimates that Europe will import over 110 million metric tons of steam coal, a 100% increase over 1979 levels. Far Eastern demand for steam coal imports is expected to jump to 67 million metric tons by 1990, a net increase of 54 million tonnes over 1979. In total, world steam coal trades are projected to grow from 70 million metric tons in 1979 to 214 million by 1990, for a compound annual growth rate of 9.4% per year.

U.S. coal producers, exporters, and transportation companies should all benefit from the increased demand for coal, as 31% of the world's recoverable coal reserves are located within this country. Although the U.S. is expected to be a major supplier of coal to the world market in the 1980s, many international coal distribution problems have to be overcome to assure reliable delivery in consuming nations.

The coal distribution system among countries is currently the chief constraint to increased steam coal trade growth. Delivery systems are strained to the limit for some trade routes but tremendously underutilized on others. With a continuing "boom-bust" cycle for world coal demand in the 1980s, disruptions in coal movements among countries will exist well into the decade. Coal exporters seeking to develop new markets abroad as well as service existing contracts will need more complex planning tools to avoid distribution problems in the next decade.

In order to help coal companies, railroads, ports, exporters, and foreign consumers better plan for the volatile export coal markets of the 1980s, DRI has developed a World Coal Distribution Model. The modeling system is structured to provide planners with both short- and long-term transportation strategies for world coal trades in the future. In particular, the models suggest optimal distribution arrangements (coal port ownership, contract rate potentials, optimal coal reserve locations, etc.) to help companies best serve the growing world markets for steam coal.

The following sections describe the major components of the DRI World Coal Distribution analysis, including a full discussion of how the model combines all the information to determine world coal trade pattern forecasts. The final section describes a number of typical analyses DRI has performed with the World Coal Distribution Model.

MODEL INPUTS

The World Coal Distribution Model draws on a number of DRI economic, energy, and transportation models for its primary information inputs. Consistency in forecasts by country, industry sector, or energy demand is guaranteed by the use of common forecasts for world economic activity. In this manner, forecasts of world steam coal trades will be determined from a set of globally consistent international economic projections. Figure I details the analysis procedure.

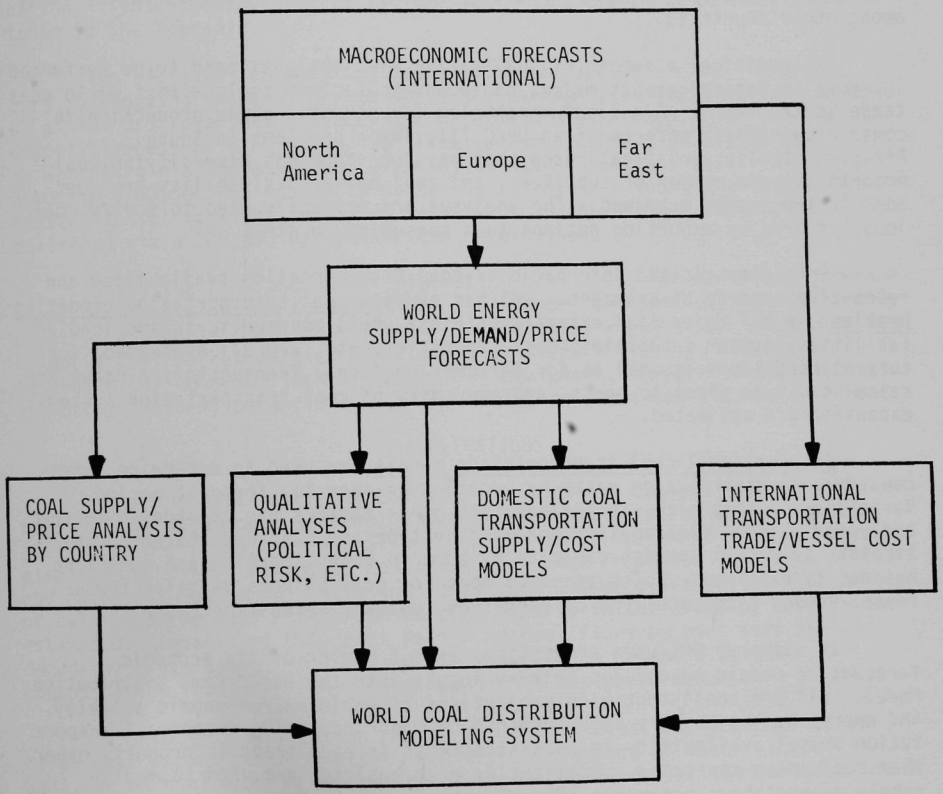
The world economic environment is first forecast by a set of international macroeconomic models. All major industrialized nations in North America, Europe, and the Far East are analyzed, with forecast updates provided on a quarterly basis. For each country, the models cover: final demands (for example, durable consumption, inventories), monetary and fiscal policy, prices, wages, incomes, exchange rates, industrial production by sector, petroleum market conditions, external trade flows, among other factors. Thus, complete information on the underlying economic factors that affect energy use by country are projected for both short-term and long-term scenarios. In general, a number of alternative forecasts are available for each country, reflecting different qualitative (political, social, and other) risks to the nation's internal and external environment.

The next step in the process of evaluating world coal distribution patterns over the coming years is to analyze worldwide energy developments. For all major world energy-consuming nations (over 35 in all), DRI has created an econometric model of energy supply, demand, and price relationships. The models are specified in terms of dynamic disequilibrium and take into account the simultaneous effects of: interfuel substitutions, conservation, price elasticities, supply conditions, and government policies. In all, demand for

FIGURE I

DRI MODEL FOR

WORLD COAL DISTRIBUTION ANALYSIS



14 fuel products in each of 7 sectors (energy users), including steam and metallurgical coal consumption, is determined for each country. Production and imports by fuel type, as well as world trade patterns for energy products, are also forecast by country. The models provide detailed information on expected energy imports by country on a year-by-year basis through the end of the century.

Once steam coal import requirements are known by country, a number of other analyses must be performed to determine actual country-to-country coal trade flow projections. First, a detailed study of major world coal exporters must be made in order to determine exportable reserves, possible production levels, transportation or other constraints, prices, vessel loading capabilities, among other factors. DRI has carried out this analysis for: the United States, Canada, Alaska, Colombia, the PRC, the USSR, Australia, South Africa, Indonesia, the United Kingdom, France, Germany, Belgium, Poland, Spain, Italy, among other countries.

In addition, a number of qualitative risk analyses need to be performed in order to determine what major, non-economic factors could affect world coal trade in the 1980s. A nuclear moratorium for domestic power production in certain countries, effects of an OPEC III, labor problems in South Africa/Australia, political risks that may come from not diversifying coal imports among a number of suppliers, and coal bulker availability are just some of the issues examined. The analyses are primarily used to modify coal import shares by exporting nations to a consuming country.

Both domestic and international coal transportation availability and rates also need to be examined. DRI has studied coal transportation exporting problems in all major coal export countries. Rail movements, inland loading facilities, system capacities, port capacities, etc. are all evaluated, for current conditions as well as for forecast periods. Transportation rates are calculated from mines to ports, and new costs of coal transportation system expansion are estimated.

International coal transportation models are used to determine inter-country coal distribution costs by vessel type over the forecast period. Variations in ship size, technology, and other factors are considered in the analysis. Vessel availability analyses by type are also undertaken. Constraints on vessel loading capacity by port in both exporting and consuming nations is examined. Costs are developed for coal bulkers by major trade route, vessel size, and type of operation (charter versus spot market).

In summary, DRI uses projections from a number of its economic forecasting models to develop primary inputs into the World Coal Distribution Model. All are consistent with projections of world macroeconomic activity, and energy use by country is determined by major consuming sector. Transportation vessel availability is consistent with foreign trade in products other than coal among countries. Qualitative risk analyses are used to modify purely quantitative estimates of world steam coal trades.

WORLD COAL DISTRIBUTION MODEL

The World Coal Distribution Model is used to combine all inputs to generate final levels of coal imports by country by export source. In all

cases, trade route specific analyses (e.g., mode congestion costs, port problems, vessel availability, etc.) can be performed.

The modeling system generates delivered prices of U.S. coal at importing country ports, delivered prices of competitive coal, available supply by coal type/country, U.S. coal exports by port, vessel/rail requirements by coal exporter/importer -- based on a decision process involving both quantitative considerations (delivered price, available supply/demand) and qualitative factors (existing long-term contracts, political risks, etc.).

The analysis uses a combination of econometric (demand analysis) and programming methods (supply analysis, transportation) to generate final outputs. As many as 10 separate economic, energy, and transportation models may be used in generating a solution for a single coal exporting or importing nation. Typical output tables for the World Coal Distribution Models are found in the Appendix.

The distribution analysis can be used for specific mine, railroad, port, oceangoing vessel, foreign port, and foreign facility studies. As many or as few U.S./overseas linkages can be examined as needed. For example, the competitiveness of U.S. steam coal (low sulfur, 12,000 BTU/lb., 8% ash) mined in West Virginia and moved to Europe by an N&W RR contract rate via Hampton Roads in a 60,000 DWT bulker to Rotterdam and distributed via a 30,000 DWT coastal vessel to final consumers relative to South African steam coal delivered via a 100,000 DWT bulker can be examined.

Using the rich amount of information available, the model can generate a number of alternative forecasts for coal import demands, export supplies by country, and world coal trade flows. In addition, a number of strategies used by world coal market participants can be examined. Finally, impacts of technological changes (such as new mining equipment, improved vessel designs and other factors) on world coal distribution patterns can also be developed.

APPLICATIONS

Over the past year, DRI has used the model to analyze the competitiveness of U.S. steam coal in foreign markets for both pricing and contract analyses. Decisions on new U.S. coal export port investment by coast have also been studied. Potential constraints on coal shipments for South Africa and Australia due to political and labor problems were evaluated. The effect of a European nuclear moratorium on coal imports in the 1980s by country was estimated. Impacts of U.S. port delays on coal flows by port over the next decade were evaluated. A location analysis for an inland U.S. coal consolidation facility in Northern Appalachia was performed.

A principal application of the World Coal Distribution Model is to allow coal export participants to evaluate the impact of "other-actor" behavior on coal exports by country or port. For example, the introduction of N&W RR contract rates on U.S. port export shares for steam coal can be studied. Impacts of other coal exporters lowering their delivered price in Europe on U.S. steam coal market shares by country can be determined. The effect of larger oceangoing vessels on relative coal exporter competitiveness can also be studied.

In summary, the DRI World Coal Distribution Model was developed to answer some fundamental questions about international steam coal trades. Effects of coal prices, transportation rates, port constraints, political risks, oceangoing vessels, changing energy demand/supply conditions, among other factors on world coal distribution patterns can be analyzed. Users include coal producers, modes, port authorities, vessel operators, and foreign importers/exporters of coal. The model allows detailed studies of specific mine-to-overseas steam coal user distribution systems that will exist in the 1980s.

APPENDIX

WORLD COAL DISTRIBUTION MODEL OUTPUT TABLES

1. European Economic Forecasts
2. Coal Use by Country
3. Coal Imports by Country
4. U.S. Regional Coal Production/Prices
5. U.S. Coal Export Price Forecast - Hampton Roads
6. Australian Coal Production/Exports
7. Australian Coal Export Price Forecast - Newcastle
8. Steam Coal Export Forecasts by Country
9. U.S. Coal Export Port Capacities to 1990
10. Delivered Coal Prices - Europe by Country of Origin
11. U.S. Steam Coal Exports by Country of Destination
12. Overseas U.S. Coal Exports by Port

TABLE 1

Data Resources, Inc.
Forecast of Major European Economies
(Seasonally adjusted at annual rates)

	1980		1981				1982		Years				
	III	IV	I	II	III	IV	I	II	1979	1980	1981	1982	1983
REAL GDP GROWTH *													
West Germany...	0.2	-1.6	1.4	-2.7	-2.2	-0.2	2.5	5.0	4.4	1.8	-1.2	1.8	3.3
France.....	2.0	0.0	-3.4	3.9	3.7	2.1	6.5	0.8	4.0	1.5	0.7	3.3	2.4
United Kingdom.	2.2	0.7	-3.2	-4.0	-0.7	3.5	2.2	1.3	1.4	-1.4	-1.8	1.5	2.7
Product Basis.	-6.5	-5.9	-1.5	-2.3	0.4	4.1	2.2	1.3	2.1	-2.8	-2.9	1.9	2.7
Italy.....	-10.5	8.4	2.3	-3.4	2.1	1.5	0.8	1.4	4.9	4.0	0.2	1.2	2.0
GROWTH IN INDUSTRIAL OUTPUT													
West Germany...	-5.9	-7.2	9.1	-1.3	-4.7	-0.1	2.4	6.8	5.3	-0.1	-1.4	2.1	4.0
France.....	-2.2	-7.7	-16.2	-2.4	5.2	10.5	8.5	8.0	2.7	-0.2	-5.6	7.0	3.8
United Kingdom.	-11.8	-10.4	-3.9	-2.5	6.4	1.4	3.0	3.0	2.5	-6.6	-4.9	2.8	4.0
Italy.....	-27.0	22.7	2.7	-9.1	-12.1	3.7	1.9	4.1	6.7	5.5	-3.3	0.8	3.1
The Netherlands	-13.6	13.5	-3.6	-11.0	-1.5	-0.2	3.0	5.2	3.3	-0.1	-3.1	1.6	2.9
Belgium.....	-16.1	-14.6	7.3	10.7	-2.2	7.8	2.1	0.2	0.3	-0.2	-2.6	3.1	3.0
CONSUMER PRICE INFLATION													
West Germany...	5.0	5.3	6.1	6.0	6.4	3.8	4.5	2.1	4.1	5.5	5.7	3.8	2.8
France.....	12.8	12.7	13.0	13.2	16.6	14.4	13.6	15.1	10.7	13.5	13.5	14.3	14.5
United Kingdom.	11.0	9.7	9.2	17.0	9.5	10.3	9.6	9.3	13.4	18.0	11.8	9.8	9.3
Italy.....	21.8	20.7	21.3	19.6	22.1	17.7	16.1	18.5	14.8	21.2	20.4	19.3	19.1
The Netherlands	6.5	5.3	8.0	6.3	6.5	5.2	4.8	4.8	4.2	6.5	6.6	5.2	5.0
Belgium.....	7.3	8.8	7.5	5.5	12.2	7.7	7.3	7.2	4.5	6.7	7.8	7.9	6.9
UNEMPLOYMENT (000)													
West Germany...	909	985	1075	1206	1359	1485	1551	1549	872	892	1281	1540	1525
France.....	1458	1478	1610	1781	1854	1946	1914	1917	1349	1447	1798	1983	2051
United Kingdom.	1699	2020	2304	2506	2627	2742	2783	2811	1302	1648	2545	2832	2951
Italy.....	1734	1708	1718	1917	1930	1987	1976	2070	1697	1697	1888	2013	2060
The Netherlands	257	292	328	378	394	421	424	420	210	248	380	416	392
Belgium.....	330	352	365	392	410	431	438	441	294	322	400	442	453

* Real GNP Growth in West Germany

TABLE 2

Coal Use Forecasts
(Hard and Brown)
West Germany
(Million metric tons)

	1979	1985	1990	% Growth 79-85	% Growth 85-90
Consumption	217.7	220.6	250.0	0.2	2.5
Steam	183.6	183.1	210.0	-0.1	2.8
Metallurgical	34.1	37.5	40.0	1.6	1.3
Total Imports	9.9	11.5	16.1	2.5	7.0
Energy Consumption Shares (%)					
Coal	29.6		32.5		
Natural Gas	15.7		16.2		
Oil	50.2		42.2		
Nuclear and Hydro	4.6		9.2		

Source: DRI/EML World Energy Model (June 1981).

TABLE 3

Total Coal Import Forecasts By Country
(Million metric tons)

	1979	1985	1990	% Growth 79-90
Europe				
Austria	2.8	5.8	8.4	10.5
Benelux	9.9	9.1	10.1	0.2
Denmark	7.6	12.6	15.9	6.9
Finland	4.8	5.5	6.2	2.4
France	27.2	13.6	13.3	-6.3
Greece	0.6	0.7	0.9	3.8
Ireland	0.8	0.8	0.8	-
Italy	14.1	24.5	38.4	9.5
Netherlands	6.2	6.8	10.4	4.8
Norway	0.7	0.9	1.1	4.2
Spain	4.2	14.1	22.3	16.4
Sweden	2.1	2.2	2.5	1.6
United Kingdom	4.4	4.4	4.4	-
West Germany	9.9	11.5	16.1	4.5
Comecon**	34.3	36.3	39.8	1.4
Total, Europe	129.6	149.2	190.6	3.7
Far East				
Japan	59.4	65.5	83.6	3.2
South Korea	6.3	15.9	25.9	13.7
Taiwan	5.4	8.9	12.6	8.0
Other	7.1	8.3	17.6	8.6
Total, Far East	78.2	98.6	139.7	5.4
North America	17.6	17.8	17.8	0.1
Latin America	4.4	11.0	17.2	3.2
Africa	3.1	5.8	9.5	10.7
Other***	-	6.0	13.0	-
Total, All Countries	232.9	288.4	387.8	4.7

*Includes brown coal (1.5 Mmt).

**Includes intra-Comecon movements, approximately 94.5% in 1985 and 86.2% in 1990.

*** Primarily Israel.

Source: DRI/EML World Energy Model (June 1981).
DRI estimates.

TABLE 4

U.S. Regional Coal Production
and Mine Mouth Prices
(Millions of metric tons, nominal $/ton)

	1980	1985	1990	% Growth
Northern Appalachia				
Low Sulfur[1]				
Production	16.2	19.6	20.1	2.2
Mine Mouth Price[4]	$36.72	$77.80	$129.00	13.4
Medium Sulfur[2]				
Production	71.7	73.5	94.5	2.8
Mine Mouth Price	$32.01	$66.22	$110.58	13.2
High Sulfur[3]				
Production	79.6	79.4	119.0	4.1
Mine Mouth Price	$25.15	$54.29	$ 94.15	14.1
Southern Appalachia				
Low Sulfur				
Production	139.3	129.9	133.7	-0.4
Mine Mouth Price	$32.48	$90.45	$146.12	16.2
Medium Sulfur				
Production	91.4	101.3	91.9	0.5
Mine Mouth Price	$29.97	$65.95	$126.93	15.5
High Sulfur				
Production	7.2	14.2	32.6	16.3
Mine Mouth Price	$23.70	$67.88	$97.23	15.2
Midwest				
Low Sulfur				
Production	2.6	2.6	2.5	-0.4
Mine Mouth Price	$32.77	$74.70	$124.42	14.3
Medium Sulfur				
Production	8.2	40.1	54.6	20.9
Mine Mouth Price	$31.31	$59.12	$109.01	13.3
High Sulfur				
Production	115.2	101.6	141.2	2.1
Mine Mouth Price	$28.03	$47.61	$85.80	11.8

[1] Low Sulfur: Less than 1.04% sulfur.

[2] Medium Sulfur: 1.05% to 2.24% sulfur

[3] High Sulfur: Greater than 2.25% sulfur.

[4] Mine Mouth Price includes a 10% rate of return to produce investments.

TABLE 5

U.S. Coal Export Price Forecasts - Hampton Roads
($/ton, F.O.B. Pier)

Cost Indexes (1980 = 1.0)	1980	1985	1990	% Growth
Mine Mouth (74)[1]	1.00	2.03	3.53	13.4
Transportation (25)[2]	1.00	1.88	3.07	11.9
Port Charges (1)[3]	1.00	1.69	2.85	11.0
Export Price ($/ton)[4] Hampton Roads	$49.19	$97.83	$167.62	13.1

[1] Assumes underground, low sulfur (less than 1.04%) steam coal mining in Northern Appalachia.

Number in parantheses is % of total cost related to this component of export coal prices.

[2] General increases of 12% per year in coal rates, with 13.4% per year growth to 1985, and 10.3% per year to 1990.

[3] Assumes no additional port charges, such as deep-draft user charges in the 1980s.

[4] Assumes mine mouth cost of $33.28 per metric ton, a transportation rate of $15.46 per metric ton and 45¢ per metric ton dumping charge.

TABLE 6

Australia
Coal Forecasts
(Million metric tons)

	1978	1985	1990	% Growth 78-85	% Growth 85-90
Production	101.5	176.9	247.4	8.3	6.9
Steam	58.3	107.9	169.5	9.2	9.5
Metallurgical	42.5	69.0	77.9	7.2	2.5
Exports	37.9	73.7	102.2	10.1	7.1
Steam	4.0	14.8	36.5	20.6	19.8
Metallurgical	33.9	58.9	65.7	8.2	2.2
Exports as % of Production	37	42	41	1.8	-0.5

Source: World Coal Study and Data Resources estimates.

TABLE 7

Australian Coal Price Forecasts
(F.O.B. Pier, Port)

Cost Indexes (1980 = 1.0)	1980	1985	1990	% Growth
Mine Mouth (62)[1]	1.00	1.92	3.26	12.5
Transportation (28)[2]	1.00	1.73	3.54	13.4
Port Charges (10)[3]	1.00	1.71	2.87	11.1
Export Price ($/ton)[4] Newcastle	$45.50	$83.98	$150.12	12.7

[1]Based on U.S. mine cost inflation for open pit operations (low sulfur steam coal) in West. Number in parantheses represents % of total costs of this component in export prices.

[2]Assumes a 20 year cost recovery period for new rail investments, charged back to coal operators.

[3]Based on state construction of new port facilities (piers, channels, etc.) with investment charged back over 30 year horizon at low capital recovery rates (less than 10% interest charges).

[4]Less than 1% sulfur, 12,000 Btu./lb. steam coal.

TABLE 8

Steam Coal Export Forecasts
(Millions of metric tons)

	1978	1985	1990	% Growth
European Markets				
Poland*	30.0	32.0	31.0	0.3
South Africa	12.7	46.1	50.0	12.1
Colombia	0.0	4.5	11.0	-
USSR	2.5	0.0	0.0	-
West Germany	4.3	0.0	0.0	-
United Kingdom	2.0	6.0	7.0	11.0
Zimbabwe	0.0	1.0	1.0	-
Far East/European Markets				
Australia*	4.0	12.9	31.0	18.6
Canada	1.3	4.4	16.0	23.3
Far Eastern Markets				
USSR	0.0	0.0	1.0	-
China	0.0	2.5	3.0	-
Total				
European Markets	51.5	89.6	100.0	5.7
Far East/European	5.3	17.3	47.0	20.0
Far East Only	0.0	2.5	4.0	-
All exporting countries, excluding the United States	56.8	109.4	151.0	8.5

*Uses constrained output forecast.

Source: DRI estimates WOCOL study.

TABLE 9

Annual Coal Export Capacity by Port
Stated Capacity
1980-1990
(Millions of tons)

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
New York/New Jersey	0	3.0	3.0	3.0	3.0	8.0	13.0	13.0	13.0	13.0	13.0
Philadelphia/Wilmington	3.5	8.5	18.5	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Baltimore	13.9	13.9	13.9	35.9	35.9	35.9	45.9	45.9	45.9	45.9	45.9
Hampton Roads	50.5	50.5	50.5	65.5	81.5	106.5	106.5	106.5	106.5	106.5	106.5
Wilmington/Morehead City/ Radio Island	0	3.0	3.0	3.0	3.0	20.0	20.0	20.0	20.0	20.0	20.0
Charleston	0	0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Savannah/Brunswick	0	1.0	1.0	9.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0
Mobile	5.2	8.0	8.0	8.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
New Orleans/Baton Rouge	7.5	13.5	13.5	29.0	35.0	45.0	50.0	50.0	50.0	50.0	50.0
Total	80.6	101.4	115.4	182.4	228.4	285.4	305.4	305.4	305.4	305.4	305.4
70%	56.4	71.0	80.8	127.7	159.9	199.8	213.8	213.8	213.8	213.8	213.8
Coastwise	4.5	4.8	5.4	5.9	5.8	6.7	7.5	8.2	8.8	9.4	9.9
Cross-Gulf	5.1	5.6	5.8	5.9	6.5	7.7	8.4	9.2	10.3	11.0	11.8
Export Capacity	46.8	60.6	69.6	115.9	147.6	185.4	197.9	196.3	194.7	193.4	192.1

TABLE 10

Export Coal Delivered Prices
($/mmBTU)

		1980	1985	1990
Europe (Dunkirk)				
From:	Hampton Roads	2.48	4.39	7.40
	Mobile	2.18	4.72	7.73
	Baltimore	2.12	4.23	7.03
	Newcastle	2.23	3.94	6.86
	Gdansk	1.97	3.98	7.00
	Richards Bay	2.01	3.84	6.59
	Cartegena	-	4.24	7.12
Hampton Roads as % of:				
	Newcastle	111	111	108
	Gdansk	126	110	106
	Richards Bay	123	114	112
	Cartegena	-	104	104

TABLE 11

U.S. Steam Coal Exports
Baseline Scenario
(Millions of metric tons)

	1979	1985	1990
Europe			
Austria	0	0	0
Benelux	0.2	1.9	2.5
Denmark	0.1	3.6	5.4
Finland	0	1.1	1.6
France	0.2	1.4	1.3
Greece	0	0	0
Ireland	0.1	0.1	0.1
Italy	0	4.9	10.5
Netherlands	0.1	1.2	2.6
Norway	0	0	0
Spain	0.2	5.2	8.0
Sweden	0	0	0
United Kingdom	0	0.5	0.5
West Germany	0.6	2.0	3.8
Total, Europe	1.5	21.9	36.3
Far East			
Japan	0.4	1.0	3.0
South Korea	0	0.2	0.3
Taiwan	0	0.9	1.3
Other	0	0	0
Total, Far East	0.4	2.1	4.6
North America	10.6	10.8	10.8
Latin America	0.1	1.2	2.1
Africa	0.2	1.6	3.4
Other	0	2.4	5.2
Total, All Countries	12.8	40.0	62.4

TABLE 12

Overseas U.S. Exports by Port
Baseline
(Millions of metric tons)

	1979	1985			1990		
	Actual	Low*	Base*	High*	Low*	Base*	High*
Philadelphia (5%)**	0.1	3.7	4.3	4.9	4.5	5.6	7.1
Baltimore (19%)	8.3	14.0	16.2	18.7	17.0	21.4	26.9
Norfolk (42%)	20.8	30.9	35.7	41.2	37.7	47.3	59.6
Newport News (24%)	8.1	17.7	20.4	23.6	21.5	27.0	34.0
Mobile (6%)	2.6	4.4	5.0	5.8	5.4	6.8	8.6
New Orleans (3%)	1.3	2.2	2.5	2.9	2.7	3.4	4.3
Other (1%)	0.2	0.1	0.9	1.0	1.0	1.3	1.4
Total	41.4	73.6	85.1	98.2	89.7	112.5	141.8

*U.S. coal export scenario.

**Estimated port share of overseas exports.

Note: Components may not add to total due to rounding.

APPENDIX A:
WORKSHOP PARTICIPANTS

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APPENDIX B:
WORKSHOP AGENDA

AGENDA

COAL TRANSPORTATION MODELING WORKSHOP

Jointly Sponsored By
Electric Power Research Institute and U.S. Department of Energy

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue
Bldg. 3, Three-Way Conference Room (#256)
Palo Alto, California

December 3 and 4, 1981

THURSDAY, DECEMBER 3, 1981

9:00 AM	Registration	
9:30 AM	EPRI Welcome and Opening Remarks Director, Energy Analysis & Environment Division, EPRI	René Malès
9:45 AM	DOE Welcome and Opening Remarks Director, Office of Energy Supply Transportation and Coal Exports, DOE	Mario Cardullo
10:00 AM	Workshop Objectives Project Manager, Supply Program, Energy Analysis Department, EPRI	Edward G. Altouney
10:15 AM	Refreshment Break	
10:30 AM	Workshop Operation Project Manager, Center for Transportation Research, Argonne National Laboratory	Kenneth M. Bertram
10:45 AM	Presentations on Transportation Models by Their Authors	
	Vice President Data Resources, Inc.	David L. Anderson
	Vice President Manalytics, Inc.	Bertram E. Rifas
	Operations Research Analyst U.S. Department of Energy	William Orchard-Hays
12:15 PM	EPRI Hosted Lunch	

AGENDA (Cont'd)

THURSDAY, DECEMBER 3, 1981

1:00 PM Presentations on Transportation Models by Their Authors (Cont'd)

Senior Planner COMSIS, Inc.	David Rubin
Director, Transportation Program Princeton University	Alain L. Kornhauser
Senior Consultant/Professor CACI, Inc./University of Tennessee	Michael S. Bronzini
Senior Research Associate Charles River Associates, Inc.	Thomas P. Egan

3:00 PM Refreshment Break

3:15 PM Presentations on Transportation Models by Their Authors (Cont'd)

Economist U.S. Department of Agriculture Colorado State University	John W. Green
Professor Boston University	Samuel J. Ratick
President TERA Consultants, Inc.	Robert E. Brooks
Transportation Systems Engineer Argonne National Laboratory	Roger L. Tobin

5:15 PM ADJOURN

FRIDAY, DECEMBER 4, 1981

9:00 AM Presentations of Transportation Models by Their Authors (Cont'd)

Vice President Data Resources, Inc.	David L. Anderson
Transportation Systems Engineer Center for Transportation Research Argonne National Laboratory	Marc P. Kaplan

10:00 AM Workshop Instructions — Kenneth M. Bertram

AGENDA (Cont'd)

FRIDAY, DECEMBER 4, 1981

10:15 AM	Refreshment Break
10:30 AM	Breakout of Two Workshop Groups: 1) Domestic Energy Transportation Models -- Emphasis on Utility Coal Supply Systems 2) Domestic Plus International Energy Transportation Models -- with Emphasis on U.S. Coal Export Systems
12:15 PM	ERPI Hosted Lunch
1:00 PM	Workshop in Session
2:45 PM	Refreshment Break
3:00 PM	Summaries of Results by Each of the Workshop Breakout Groups
3:30 PM	Discussions of Alternative Modeling Approaches Devised by the Different Working Groups, with Needs for Future Research Defined
4:00 PM	Workshop Wrapup -- Ken Bertram and Ed Altouney
4:15 PM	ADJOURN

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