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FREIGHT TRANSPORTATION ENERGY USE
Volume II-Methodology and Program Documentation

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16. Abstract

The structure and logic of the transportation network model component of the TSC Freight Energy Model are presented. The model assigns given origin-destination commodity flows to specific transport modes and routes, thereby determining the traffic load placed upon each network element, and produces transportation cost, transit time, and energy-use estimates at several levels of detail. User and programmer instructions, including input data formats, program computation methods, and program output descriptions and examples are provided. Other volumes of the report are:

Vol. I - Summary and Baseline Results, 62p.
Vol. III - Freight Network and Operations Database, 140p.
Vol. IV - Analysis of Selected Energy Conservation Options, 140 p.

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PREFACE

This study is one part of a larger Department of Transportation effort to examine transportation energy efficiency. The study was performed by CACI, Inc. - Federal for the DOT Transportation Systems Center. The TSC technical monitors were Dr. David Anderson and Dr. Russell Cherry. Their support, encouragement, and technical aid are gratefully acknowledged. Valuable guidance and assistance were also received from Paul Hoxie, Domenic Maio, and John Murphy of TSC. CACI participants in the study were Michael Bronzini, Roger Miller, John Sabo, Catherine Schourek, Conrad Strack, and Kenneth Wright. Both TSC and CACI also wish to acknowledge the cooperation of the Army Corps of Engineers, who made available for the study the multimodal network model and data developed under their inland navigation systems analysis program.

METRIC CONVERSION FACTORS

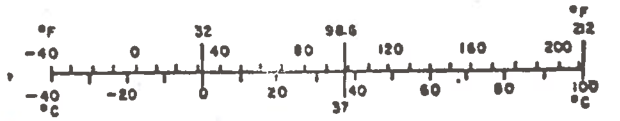
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

This report presents in great detail the design of a transportation network model to be used for assessing the impacts of energy conservation in U.S. intercity freight transportation. This model is the central analytical component of a comprehensive energy conservation impact assessment methodology, referred to as the "TSC Freight Energy Model." The overall structure and content of the Model are described in a companion volume (1).* The primary intent of the report is to document the transportation network model computer program. Various support models and other computer programs included in the TSC Freight Energy Model are also documented.

Figure 1-1 is a simple schematic of the TSC Freight Energy Model. The database includes representations of a multimodal intercity freight transportation network and the commodity flows which are to be shipped from origin to destination through the network. A set of modal simulators use portions of this data to develop estimates of modal cost, transit time, and energy-use characteristics for input to the transportation network model. The network model allocates the commodity flows to specific transport modes and routes, thereby determining the traffic load placed upon each network element, and produces transportation cost, transit time, and energy-use estimates at several levels of detail.

The next chapter presents an overview of the transportation network model, and covers the purpose, features, structure, and applications of the model in summary fashion. The intent of the chapter is to delineate the general problem area and scope for which the model is designed, and to introduce the model's conceptual framework and algorithmic processes.

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* References may be found in Appendix A.

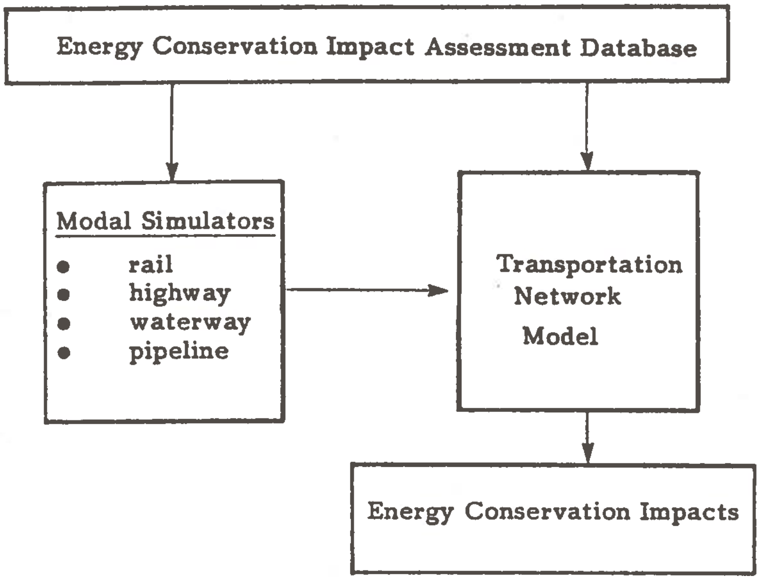


Figure 1-1. TSC Freight Energy Model

Chapter three is an in–depth treatment of the structure and logic of the transportation network model. The manner in which transportation networks are defined and represented is described, and the model's operating logic is presented. Emphasis is placed on documenting the mathematical structure of the model. Familiarity with set theory and discrete mathematics is assumed, but to aid comprehension the mathematical treatment is paralleled by intuitive and logical arguments.

Chapter four documents the computer program which implements the model's structure and logic. It is intended for the use of the programmer who will be charged with operating the model at a particular computer installation, modifying the program and documentation, correcting latent program errors, transferring the program from one computing environment to another, and so forth.

Chapter five provides instructions for using the transportation network model computer program. Input formats and data element descriptions are provided, and examples of program output reports are given.

Chapter six defines all meaningful symbols and arrays used in the program. Like chapter four, it is mainly of interest to programmers.

Throughout this report, it is assumed that the reader has a working knowledge of the U.S. freight transportation system, and that he/she is familiar with the basic concepts and techniques of transportation systems analysis. Some helpful review material along these lines appears in references (2, 3, 4, 5, 6, 7) and similar sources.

A suggested reading guide for users of this document with varying interests is offered below.

Chapter	2	3	4	5	6
Manager/Executive	X				
Transportation Analyst	X	X			
Program User	X	X		X	
Programmer	X	X	X	X	X

2. TRANSPORTATION NETWORK MODEL : OVERVIEW

This chapter presents an overview of the purpose, features, structure, and applications of the transportation network model. Detailed descriptions of the model's logic, programmatic constructs, data requirements and formats, and output formats are provided in succeeding chapters.

Purpose

The basic purpose of the transportation network model is to predict the impacts of various options for conserving energy in intercity freight transportation. Several types of impact measures are desired from the model, as follows:

- Estimates of energy savings achievable by new technology, new methods of operation, and network alterations.
- Modal investment in equipment and facilities required to implement various energy conservation options.
- The impact of energy conservation options on modal carrier costs, service levels, and shipper mode-choice decisions.

A second purpose is to provide a device for generating energy-optimal freight transport system configurations and for predicting the consequences of energy-use optimization.

Within these broad requirements, 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 must be sensitive to the primary variables and tradeoffs which dominate shipper decision-making, and must account for interactions among shippers in their joint use of transportation facilities. Further analytical specifications call for the model to approximate transportation market equilibrium, and to report on the performance of the elements of the transportation system and on the service rendered to shippers. Both system performance and shipper service are to be 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, in terms of assessing the impacts of energy-conservation options, the scope and purpose of the model are confined to measuring the system performance and shipper service which might be expected if particular options were to be implemented. It is the role of the analyst using the Freight Energy Model, of which the transportation network model is but one part, to design and execute model run sequences which allow testing, comparison, and evaluation of potential energy-conservation measures.

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 insure that an acceptable alternative is included in his 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 can provide no guarantee that the optimal strategy will be discovered.

Features

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 following features.

- Problem Size

The size of problem which the model can handle is subject only to computer limitations. There are no inherent restrictions on the number of network elements or commodity shipments.

- 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 are 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 "capacity functions," relate transit time to shipment volume, and "energy functions" relate energy use to volume. Cost, capacity, 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 specifications of historical or estimated modal-split percentages or desired route from origin to destination are also permitted. Commodity types are defined by two-digit classification, and by weighting factors specifying the tradeoff 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.

- 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.

- Shipment Routing

Least disutility (from the shipper's viewpoint) routes from origin to destination are found for all shipments. Disutility is defined as a linear combination of cost, transit time, and energy use, and is allowed to vary with shipment volume on each link and node.

- Programming Language

The transportation network model is programmed in SIMSCRIPT II.5. The main reasons for choosing SIMSCRIPT were its set processing features, its use of dynamic memory allocation, and the self-documenting nature of SIMSCRIPT source code, all of which simplify and shorten the computer programming task.

Structure

The transportation network model consists of a set of computer routines which may be divided into three functional categories as shown in Figure 2-1.

In the operation of the model, the input routines serve the purpose of extracting and translating data from input forms or preestablished files into formats and data structures needed for the model. General categories of data processed by the input routines are indicated in Figure 2-1. Also included in the input processing are data edit functions and printouts of the data used for a particular run of the model.

The main analysis routines accomplish the logical processes of the model. They include algorithms and procedures for selecting routes through the multimodal network for particular commodity shipments, determining disutility of such movements, assigning movements to particular routes in accordance with their relative disutilities, and collecting results of the allocations for presentation in output reports.

The output routines organize results of the model and present them in several types of reports. Included, in particular, are reports giving the allocations of movement requirements to the elements of the network and the cost, time, and energy use associated with such allocations. The output routines also produce several data files. The network file contains the network data plus the final node-and-link traffic allocations. The path file provides detailed path and disutility results for each shipment. The modal traffic file contains single mode origin-destination commodity flow tables for possible input to other models.

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.

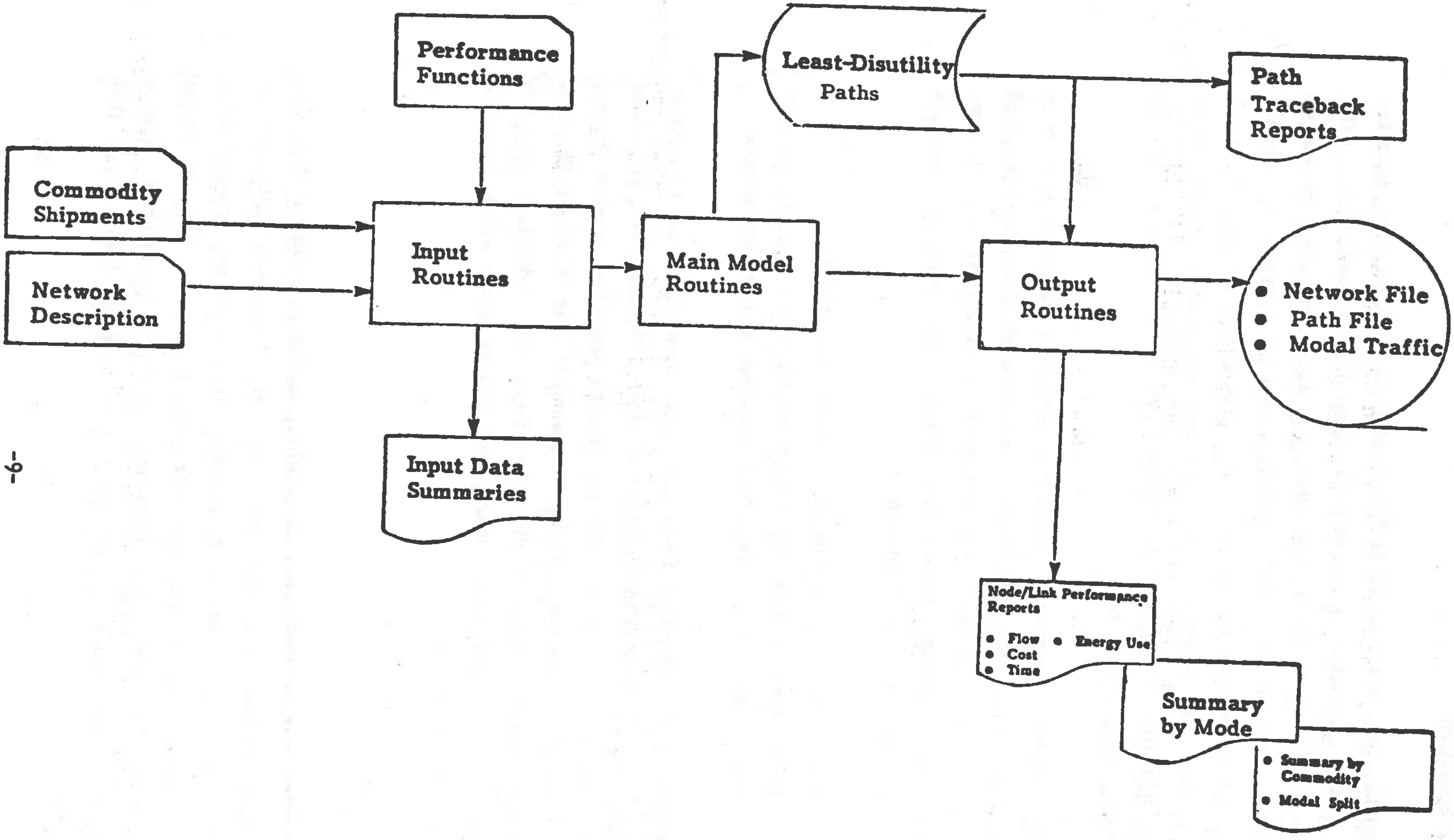


Figure 2-1. Overall Structure of the Transportation Network Model

- 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 capacity function
- energy use, as determined from the element's energy function.

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 global optima (paths which minimize total systemwide disutility).

- 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, non-petroleum products will not be shipped via 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.

- Circuity Constraint

To alleviate potential computational problems, a constraint is imposed on the number of routes considered in the path selection process. The method of doing this is quite simple. It assumes that the location of each node is given in terms of geographic coordinates. An ellipse of given eccentricity is then constructed about the origin and destination regions for a particular commodity movement, with the major axis of the ellipse being the straight line connecting the centers of the two regions. The path selection algorithm then considers only those routes between the two regions that lie totally within the ellipse. The algorithm permits the ellipse to automatically increase in size, according to specified criteria, to insure that at least one route is included. In effect this "inclusion ellipse" constitutes a circuity constraint which greatly shortens the amount of computer processing time required; the price paid, of course, is that circuitous routes which may be less costly than the selected route are ignored.

- Inertia Effect

An optional "inertia effect" is also included in the model, whereby a specified portion of any commodity shipment may be constrained to observe modal share percentages input by the user for that shipment. Least-disutility paths for the mode-constrained tonnage are built using only nodes and links of the specified mode. The balance of the shipment is free to select the optimal route. This feature is needed to reflect the realities of long-term shipper contracts and other commitments, and to smooth the model's response to small changes in modal cost and service levels from one run to another (or from one iteration to another; see the latter portion of Chapter 3 for further details).

- Assignment Algorithm

Equilibrium network flows are approximated by using an iterative procedure to assign shipments to the network. Link and node disutilities are initially set by entering the performance functions with flow volumes equal to each element's practical capacity (that flow volume for which delays are "normal") or some other user-supplied volume estimate. Shipments with fixed routes are assigned by increasing the loadings on each link and node in the route by the shipment amount. Shipments with a fixed mode choice are assigned using the path selection routine with the additional constraint that all elements in the path must be of the selected mode. All other shipments are assigned using normal minimum-path logic, and all link-and-node volume estimates are updated to reflect the total assigned traffic. This entire process is repeated in an iterative fashion, until assumed and final volumes agree within some specified tolerance. For time-series simulations, volumes from one period may be used as the initial volume estimates for the next period.

- 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 also 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 (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.

Applications

Within the context of the general scope and objective of the transportation network model as given above, several specific areas of application for the model may be identified. The following are suggestive as to possible uses of the model:

- Determine the direct net benefits and energy-use consequences of transportation investments.
- Compare the energy-use, cost, and service results of various energy-conservation options.
- Generate energy-minimizing network flow patterns and develop energy-optimal freight transportation system configurations.
- Quantify tradeoffs between transportation cost, shipper service, and energy use.
- Determine the effects of modal improvements on competing modes.
- Identify other transportation improvements needed to enhance the effectiveness of proposed improvements.
- Estimate modal shares of future commodity shipments.
- Analyze intermodal cost, service and energy-use differentials.
- Estimate interregional commodity transportation costs for use in commodity-flow forecasting.
- Analyze the impacts of preferential or nonnormative rate structures.
- Estimate shifts in transport utilization resulting from instituting or deleting government subsidies of transportation.
- Evaluate the ability of the transportation system to absorb temporary or long-term reductions of particular transportation services due to strikes, floods, bankruptcies, and so forth.
- Study the impacts of transportation innovations such as truck/rail intermodal service, landbridge, slurry pipelines, Lash/Seabee, and increased truck-size limits.
- Provide traffic-flow and energy-use data for input to environmental impact analyses.

It is important to realize that different applications require different networks and modal detail. For example, questions such as the proper level of investment in a single transportation link are too detailed to be addressed with this model at the national level. Such very specific applications require regional level modeling. The model itself can be used at the regional level, but with data inputs which are significantly more refined than those used for national level studies.

3. MODEL STRUCTURE AND LOGIC

This chapter sets forth the transportation system description and the network analysis techniques embodied in the transportation network model. The manner in which the essential features of multimodal transportation networks are represented in the model is taken up first. This is followed by a logical and mathematical statement of the model's computational procedures.

PART I: DEFINITIONS AND REPRESENTATIONS

The next section of this chapter describes the regional structure assumed in the model. This is followed by sections on transportation networks, performance functions, and commodity flows. A discussion on how changes in network structure and operations (such as energy conservation measures) can be modeled concludes Part one.

Regions

The geographic area containing the transportation system to be analyzed is represented in the model as a set of regions. These regions must be closed and nonoverlapping, and must collectively account for all of the economic activity and commodity flows to be included in the analysis. Commodity flows are input to the model by specifying their origin and destination regions. Hence the regions serve as sources and sinks of goods movements, and as the locations of economic activity which generate these movements.

Intraregional freight shipments are not included in the model. This obviously places some limitations on the regionalization scheme adopted; if the regions are made too large, significant loadings on linehaul transportation facilities may be "lost" in the analysis. On the other hand, if numerous small regions are used, a very detailed network will be required, and the computer resources needed to process the network and its large set of commodity flows will become burdensome.

The transportation network model was designed with the intent of using the 173 economic regions defined by the Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce, shown in Figure 3-1. The model itself is completely general, and some other suitable set of regions could equally well be used.

The only regional attributes represented in the model are the name of the region and the location (latitude and longitude) of its center. The location is used only for calculating route circuity constraints, as described later, and does not necessarily represent a point where all commodity flows are assumed to originate and terminate; that is, these regional centers are not necessarily equivalent to the "zone centroids" commonly defined for transportation network analysis. The distinction is a fine one, however, so the reader may find it convenient to adopt a zone centroid interpretation of the model's regional centers.

Transportation Networks

Transportation networks are represented in the model as connected sets of nodes and links. The following specific entities are included in the network representation:

- Nodes - intersections, terminals, link delimiters
- Linehaul Links - linehaul transportation facilities
- Access Links - local transportation, pickup and delivery
- Transfer Links - intermodal transfer facilities

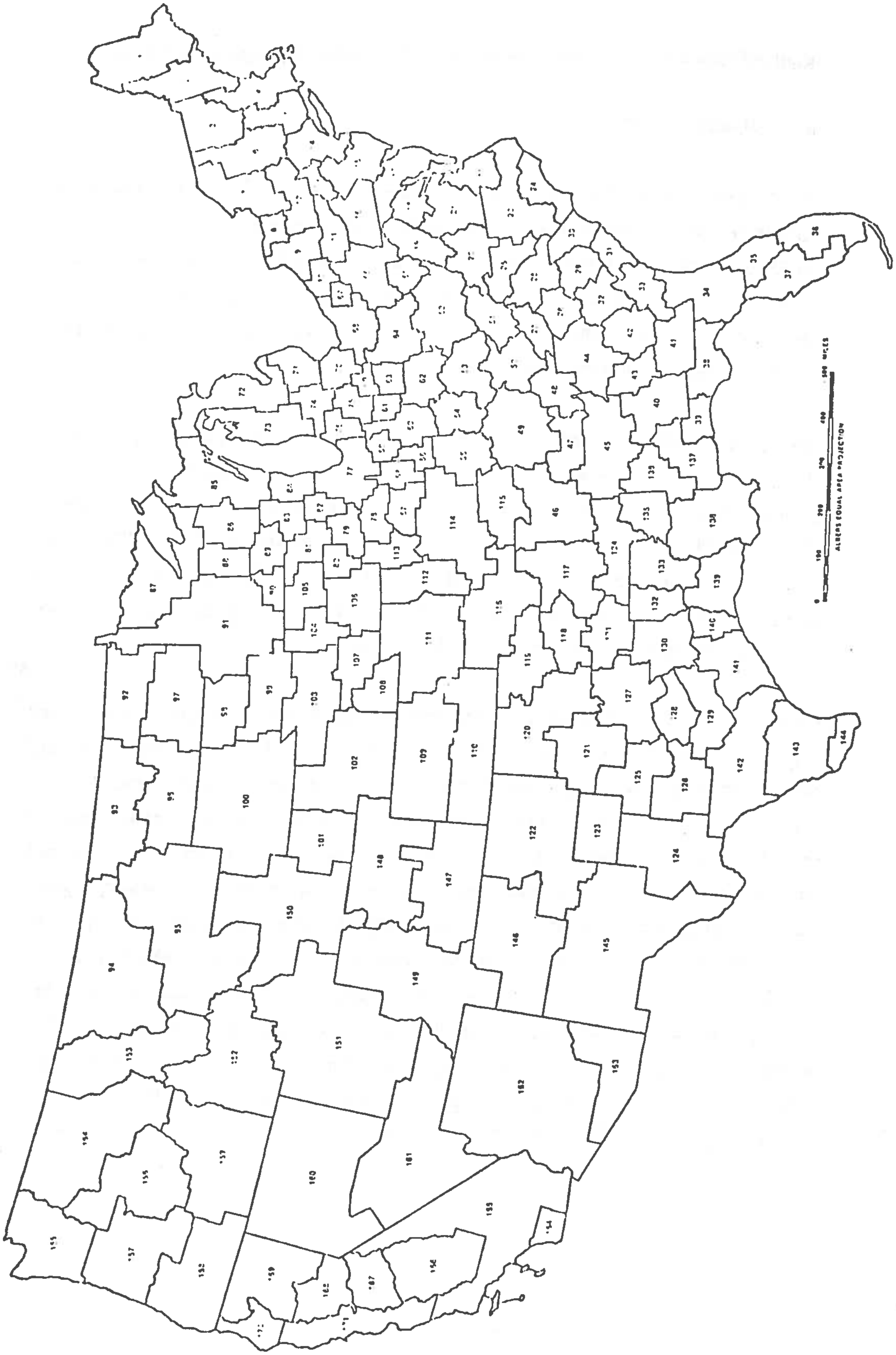


Figure 3-1. BEA Economic Areas

Each of these network entities is further defined and described below.

- Nodes

Nodes are numbered/named points in geographic space used to identify and locate transport facilities. Physically, nodes represent locations where linehaul transportation facilities intersect and traffic is permitted to switch from one facility to another, and/or locations where the characteristics of linehaul facilities change. Nodes are also used to identify points of access to the transportation network.

Consistent with standard transportation network analysis practice, nodes are the primary elements used to define the spatial organization of the transportation network. Most transportation operations occur on the links of the network, and nodes are used to specify the locations of link-end points, thereby identifying and delimiting the links. To fulfill this descriptive purpose, nodes are characterized in the model by their name, location (geographic coordinates), and transportation mode.

Nodes may also be used to represent transportation terminals and other types of transportation facilities, where intramodal switching, fleeting, direction changes, and other types of transport operations occur. Some typical facilities which may be represented as nodes in the model include junctions of rail lines, rail-classification yards, highway intersections and interchanges, truck terminals, locks, river ports, inland-waterway fleeting areas, and pipeline junctions and terminals. Another important use of nodes is to represent urban area and intraregional subnetworks which are too detailed to include in the network description, but which account for significant portions of transportation cost, delay time, and energy use. The operational aspects of nodes are represented in the model by the node class. The class, in turn, has performance functions associated with it, which define the node's operating characteristics.

- Linehaul Links

The linehaul transportation facilities which make up the multimodal network are represented in the model as linehaul links. These links are intended to represent homogeneous segments of intercity freight transportation facilities. A single link might thus represent a single-track or double-track rail line, a primary highway, a waterway, or a section of pipeline.

Linehaul links are identified by specifying the nodes at each end of a link. Attributes used to model link operations include length and link class. Different operating characteristics may be specified for each direction of travel on a link, if desired. One-way links may also be specified. The link class is used to associate appropriate performance functions with the link. The mode of transportation represented by a link is determined by the mode given for the nodes at the ends of the link; thus linehaul links may only connect nodes of a single mode. Further, only one link may directly join two nodes. If more than one physical facility connects two nodes, they must be combined and represented as a single link.

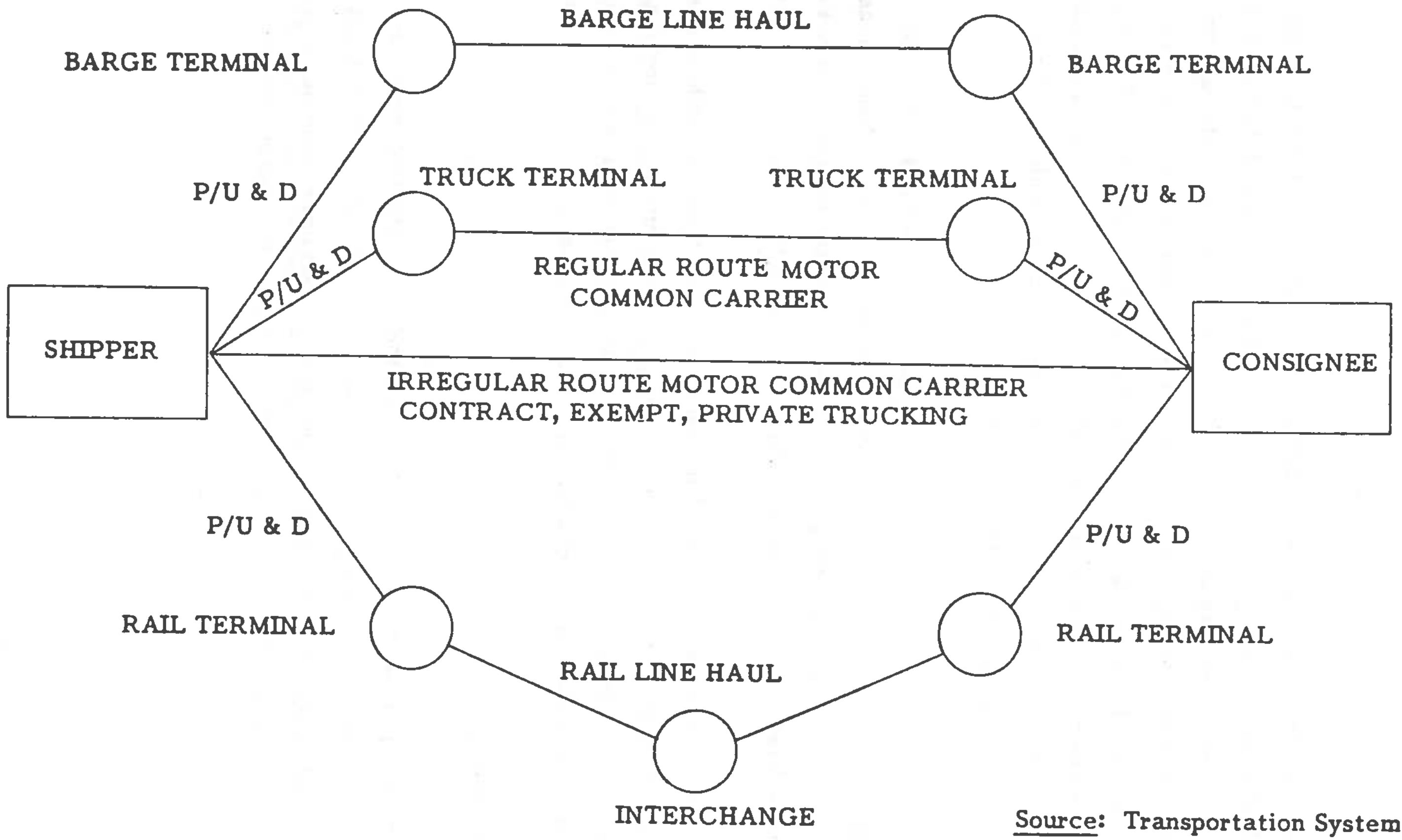
Numerous questions concerning level of detail arise in attempting to define the linehaul links to be used to represent a given transportation network. The model is completely general in this respect, and will accept either very coarse or very fine networks. For large systems such as those expected to be analyzed with the TSC Freight Energy Model, it is obviously impractical to include every individual transportation facility in the network. Doing so actually adds nothing to the analysis, since a high percentage of the secondary links would be assigned no traffic. Extremely coarse representations of the network can also be misleading, since essential link performance relationships may be obscured.

The challenge, then, is one of striking a proper balance between too much detail and too little. A useful approach to this problem is to define an initial network made up of all intercity trunk-line facilities known to carry significant amounts of freight, plus any secondary lines needed for network continuity and coverage. Preliminary model results will then indicate where the network needs to be pruned or expanded. Multilevel representations, where more detail is used in those areas of primary importance in a study, are also useful for many model applications.

- **Access Links**

The transportation operations represented by access links in the model are indicated schematically in Figure 3-2. The various types of transportation terminals, shown as circles in the figure, are represented as nodes in the network. The linehaul facilities connecting the terminals are represented as linehaul links (intermediate nodes, not shown in the figure, may also be needed). The lines labeled "P/U & D" (pickup and delivery) in Figure 3-2 are the conceptual equivalents of the access links included in the multimodal network.

In general, then, access links represent those transportation operations needed to move freight shipments from the shipper's dock to a point of access to the linehaul transportation network, and from the network to the dock of the consignee. The exact operation represented depends upon the transport mode used for the linehaul move, and, to some extent, upon the particular circumstances of each shipper/consignee. Local service trucking commonly provides pickup and delivery for barge and common carrier truck shipments, and for some rail shipments (those by shippers with no rail siding, those handled by rail freight forwarders, and TOFC/COFC or "piggy-back" shipments). Most rail shipments enter the rail network via industrial switching. Waterway shippers located directly on a waterway require no pickup and delivery service, except in congested ports and other special cases where service boats may be used to move barges to and from a barge line's terminal. Gathering and distribution lines are represented by access links for pipeline shipments. Although not shown in the diagram, direct dock-to-dock trucking also makes use of access links; in this case, the access links represent the local street and secondary road system connecting the shipper's dock to the primary highway system. (These are obviously the same physical facilities included in the access link representations of local service trucking, at least to the extent that truck terminals are located immediately adjacent to the primary highway system.)



Source: Transportation Systems Center,
U.S. Dept. of Transportation

Figure 3-2. Freight System Operations

It is neither possible nor necessary to represent every individual access arrangement by an access link in the network. Instead, a limited number of access links are required for each region, connecting the region to one or more nodes of each transport mode serving the region. Each access link, then, must represent the average access characteristics and arrangements of those shippers using the particular network node on the outbound end of the link.

A typical (hypothetical) schematic showing the relationship between regions, nodes, and access links is given in Figure 3-3. Commodity traffic originating within BEA region 16 may access the transportation network through nodes 820, 825, and 830 (note that an access link may connect a region to a node located outside of this region). Node 830 also provides access to BEA region 17. In this example, the analyst has determined that there is no significant pickup and delivery activity between BEA region 16 and node 815, hence no such access link in included in the network.

As shown in Figure 3-3, access links have only one fixed end -- the node to which they connect. The other end "floats" within the region; hence access links might be visualized conceptually as the "resultant vector" of a set of local transportation "access vectors" directed toward the node.

Access links have attributes which are very similar to those of linehaul links. They are described in the model by their region, node, and access link class. As with linehaul links and nodes, the class designation is used to point to performance functions which characterize link operations.

- Transfer Links

Transfer links provide connections between nodes of different modes in the multimodal network. They are used to represent intermodal transfer facilities, such as riverside coal transloaders, container terminals, grain elevators serving lengthy truck hauls, and all types of rail-barge, truck-rail,

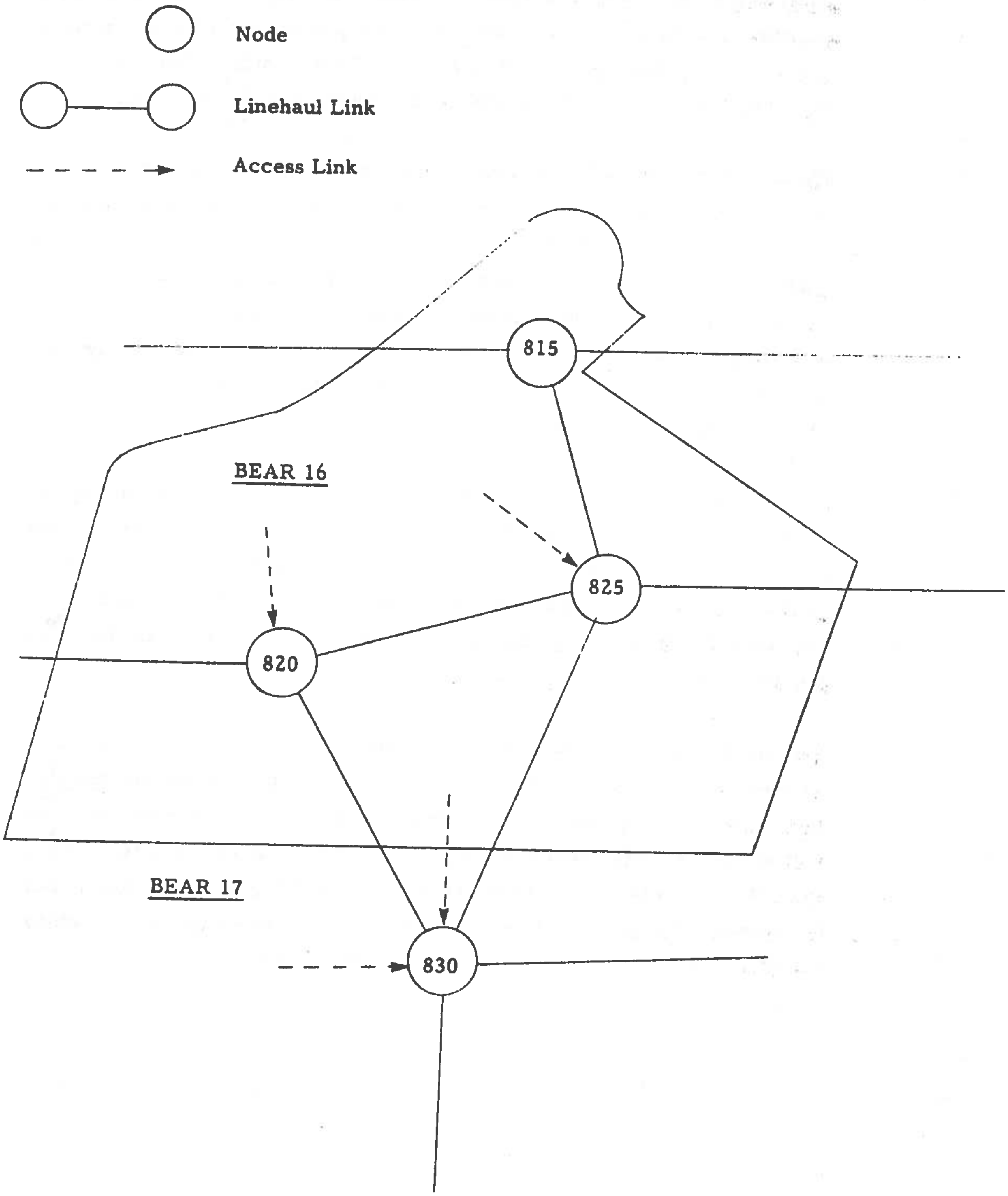


Figure 3-3. Access Link Schematic

truck-barge, and other interface terminals. Although represented as links, transfer operations are very similar to the types of activities occurring at nodes, as they take place within a rather limited area. Thus two nodes connected by a transfer link should be reasonably close to each other.

Figure 3-4 is a schematic showing the structural relationship between nodes, transport modes, and transfer links. Portions of two modal subnetworks are shown in the figure, and a transfer link connects node 825 of mode 1 with node 510 of mode 2. Suppose that mode 1 is rail and mode 2 is waterway. In this case, the transfer link represents a means for shippers not located near the waterway to gain access to water transportation via the rail system, assuming that the cost savings of water transportation more than offsets the extra handling costs incurred for switching modes.

It is useful to think of each modal subnetwork as lying in its own horizontal plane. The total transportation network would then consist of a set of these planes, stacked one on top of another. The transfer links can then be visualized as vertically inclined lines connecting these planes, which serve the purpose of stitching the modal subnetworks together to form an integrated multimodal network.

The attributes of transfer links are the same as those of the other types of network links, and include the nodes at each end of the link and the transfer link class. One exception is that transfer links are all one-way links, so bidirectional transfer facilities must be represented as two transfer links in the network. This directionality requirement is imposed to recognize that intermodal cargo handling facilities (such as rail-to-barge coal transloaders) are often designed specifically to serve one-way cargo flows.

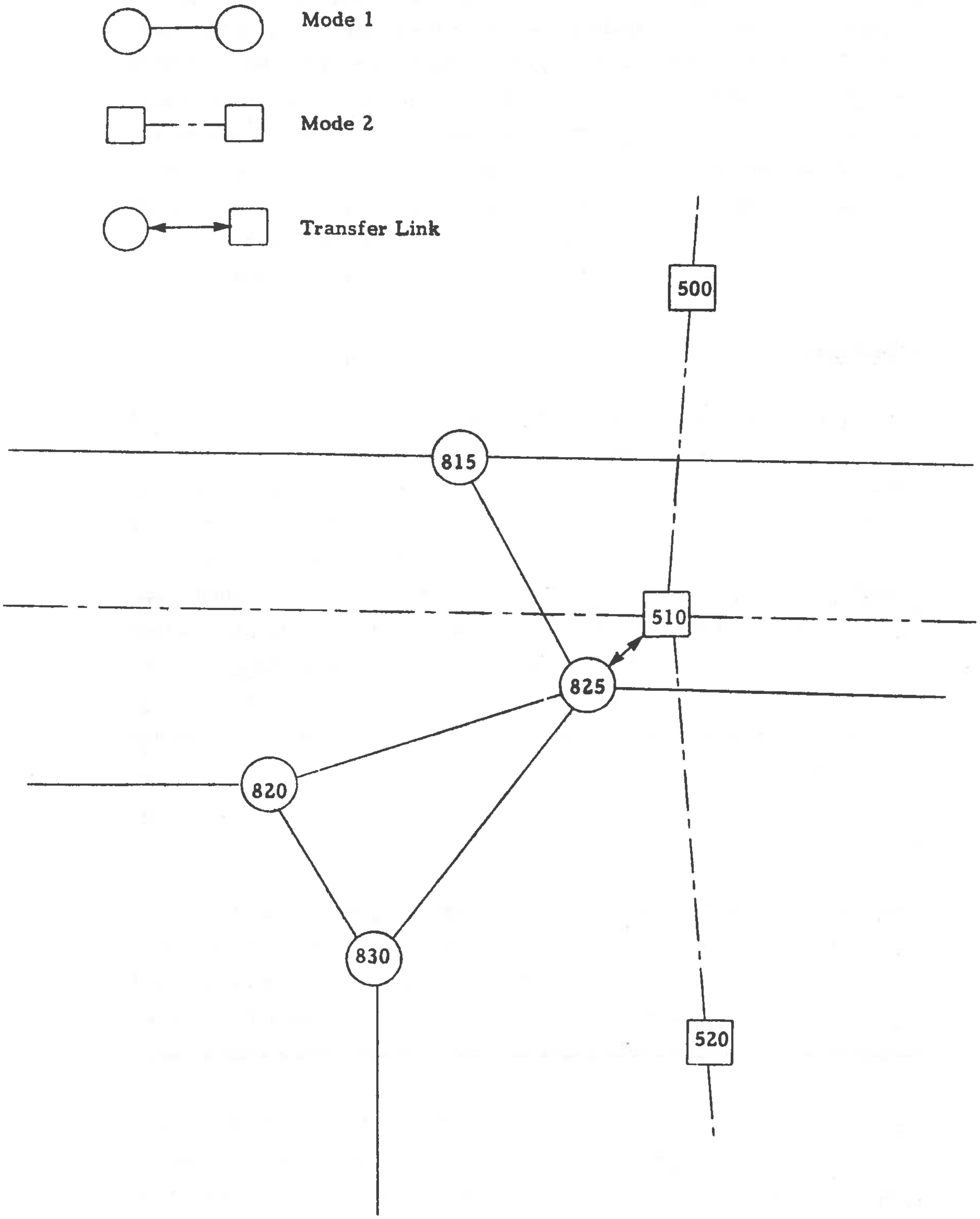


Figure 3-4. Transfer Link Schematic

- Summary of Network Geometry

In summary, each modal subnetwork is represented as a connected set of nodes and linehaul links. Nodes represent terminal and switching facilities, points of access to the transportation network, and other point-oriented transport processing locations. Linehaul links represent linehaul transportation facilities. The modal subnetworks are connected to the regions by access links, and to each other by transfer links. Each link and node is assigned to a class, and the class has associated with it three performance functions which define the operating characteristics of all links/nodes in the class. These performance functions are described in the next section.

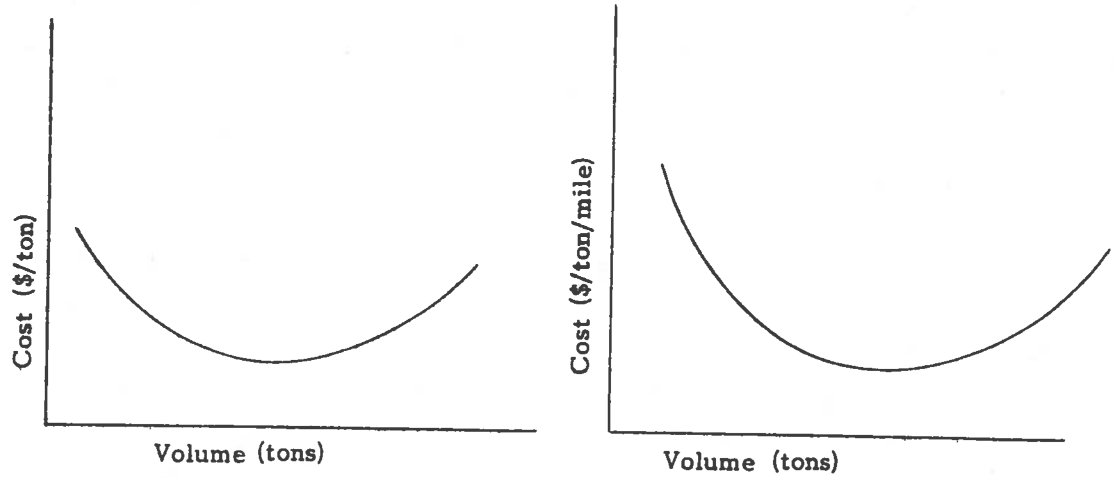
Performance Functions

The performance characteristics of transportation facilities are represented in the model by supply functions. These functions relate the unit "cost" or disutility of using a facility to the total amount of traffic which it carries. The theoretical bases for this representation are the diminishing ratio of fixed cost to total cost with increasing traffic, and the effects of congestion as traffic volume becomes closer to facility capacity. In the transportation network model a supply function is actually a composite of three other functions — a cost function, a time function, and an energy function. The model builds its supply functions internally, on the basis of facility cost, time, and energy functions supplied by the user. These three functions are further defined and described below.

- Cost Functions

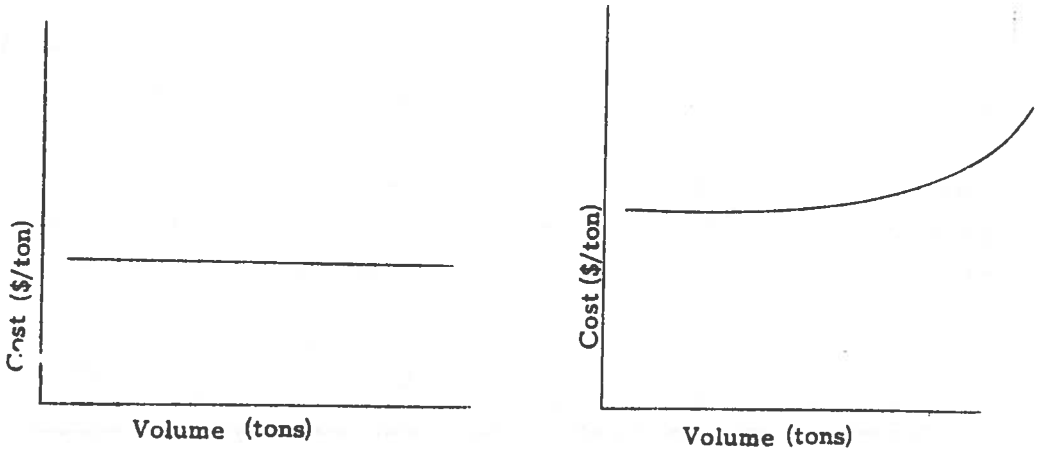
Some typical cost functions for various types of network elements are displayed in Figure 3-5. The use of these functions within the model is rather simple. The function is entered on the horizontal axis with the total volume of traffic which the node or link carries (or is expected to carry), and the corresponding unit-transportation cost is read from the vertical axis.

As noted previously, cost functions are not specified for individual links and nodes, but rather for classes of links and nodes which have similar operating characteristics. Of course, there is no inherent limit on the number of classes which may be defined by the user, so a user with sufficient patience and study resources could indeed provide a unique function for each link and node in the network.



a) Nodes

b) Linehaul Links



c) Access Links

d) Transfer Links

Figure 3-5. Cost Functions

However, small cost differences should not warrant creating separate facility classes, given the scope and purpose of the model. Thus all double-track rail lines in the eastern U.S. operated under central traffic control might form one class, those in the western U.S. another, and so on. Similarly, waterway nodes representing locks with one 1200 x 110-foot chamber and one 600 x 110-foot chamber might form one class, those representing locks with a single 600 x 110-foot chamber a second, and so on. In general, links and nodes with similar physical dimensions, topographic/regional attributes, and operating patterns, and hence similar cost structures, may be grouped together into a single class.

Two special considerations apply to cost functions for linehaul links. First, links which are virtually identical in all respects may have different lengths. For this reason, unit costs are specified on a per-mile basis for linehaul link classes (see panel b in Figure 3-5), and the function value is multiplied by the length of the particular link in the model's cost calculation routines. Second, cost is assumed to be a function of the total traffic in both directions. So for any types of linehaul links for which this is not true (e.g., single-running double track rail lines) the user must provide separate one-way links for each travel direction and structure the class and function data accordingly.

Given the model's use and interpretation of cost functions, an important question is: "Exactly what costs are the functions intended to represent?"

There is no simple and universally correct answer to this question. In general, the cost functions should be similar to short-run average cost (SAC) curves, as defined in microeconomic theory.* A short-run view is adopted

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* Annualized vehicle capital costs should be included in average variable cost, though economists would generally associate such costs with the investment in fixed plant. From the network viewpoint, vehicle-related costs are variable with traffic volume, since vehicles can be moved about the network in response to traffic fluctuations. Also, SAC generally includes the fixed facility investment for a given design capacity, whereas the model leaves the treatment of right-of-way costs to the user's discretion. The cost functions developed in Volume 3, for example, include fixed facility cost for rail and pipeline, transform it to a variable cost (as a fuel tax) for highway, and exclude it for waterways, which is roughly the way right-of-way costs are viewed by the respective carriers.

because the model is intended to be used to analyze the ability of a given transportation system to accommodate given interregional commodity flows at a given point in time. Within this framework, the transportation infrastructure is fixed, so average fixed cost declines as traffic increases. However, traffic volumes approaching capacity can be accommodated only by incurring the extra expenses due to traffic congestion, such as excess fuel consumption and reduced productivity (e.g., less ton-miles per hour) of vehicles and operators. Hence it is expected that the cost functions will be U-shaped, as depicted in Figure 3-5. (Note: access costs, being regional averages, are not very sensitive to these influences and might reasonably be assumed to be constant, as indicated in the figure.)

Of course, the model itself is completely general, and any set of cost functions defined by the user can be used. For example, it may be desirable to define costs as the transportation charges or rates paid by shippers for some model applications. In addition the cost functions may either include or exclude government expenditures.

These questions have been sources of controversy in transportation economics for many years, and cannot be settled here. It is the model's view that the relevant costs are those perceived by shippers. However, the exact definition of cost adopted for any model application depends upon the objectives and purpose of the analysis. The most important requirement to be observed is that costs must be defined consistently for all modes, to insure comparability. If this dictum is adhered to, the results produced by the model should be unbiased and should represent relative modal advantages fairly.

- Time Functions

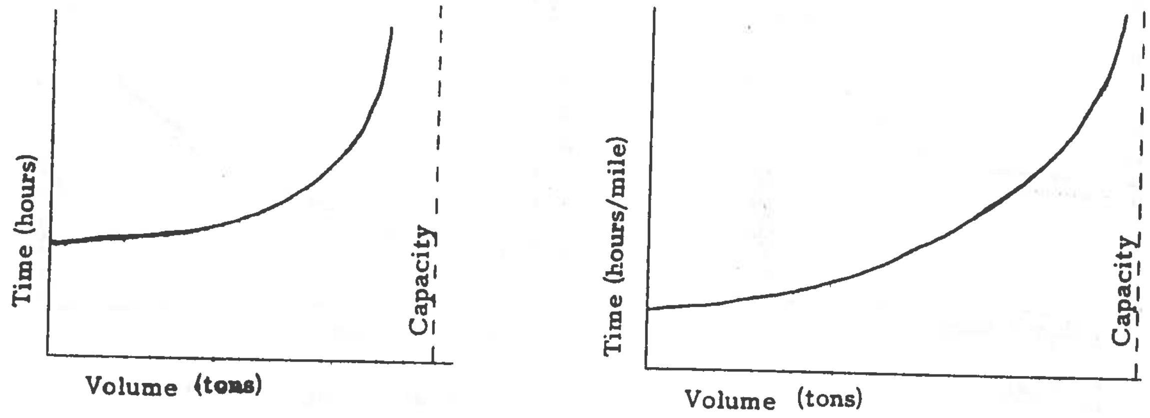
Virtually everything in the preceding section on cost functions applies equally well to time functions. These functions relate the average time required to travel through a link or node to the total volume of traffic which it carries (or is expected to carry). Some typical examples of time functions are provided in Figure 3-6. As shown, transit time is normally either constant or a monotonically increasing function of volume. As volume approaches the physical capacity of a node or link, transit time increases rapidly, due to the usual and familiar phenomena of congestion and associated delays. Transit time for linehaul link classes is specified on a per-mile basis, to account for different link lengths, and is a function of total two-way link volume. There are fewer problems associated with defining transit time than with defining cost, since transit time is a direct product of modal technology and operations.

- Energy Functions

Energy functions relate energy use per ton (or ton-mile) to the total volume of traffic which a facility carries. These functions are similar in shape to the time functions of Figure 3-6, as shown in Figure 3-7. The intercept of the energy function with the vertical axis corresponds to the energy required to move an empty vehicle (or group of vehicles). For modes such as highway where low volume operating speeds are high and generally less energy efficent than slower speeds at higher volumes, the initial slope of the function may be negative; that is, the function may exhibit energy returns to scale. Technological limitations and congestion effects will eventually cause the energy-use curve to rise. As with transit time, energy functions are derivable directly from modal technology and operations data.

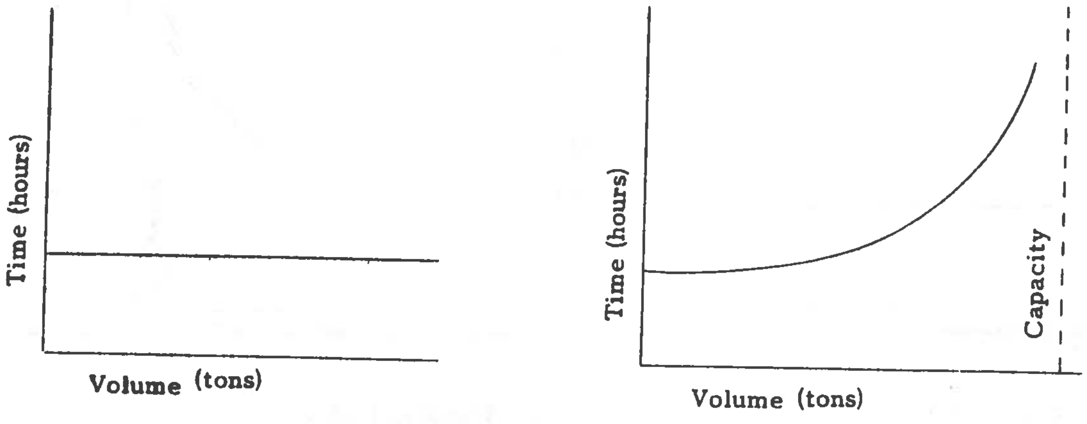
- Estimating Performance Functions

As noted in chapter one, the TSC Freight Energy Model includes a set of modal simulators which may be used to generate node and link performance functions. These simulators allow detailed representations of modal operating characteristics, vehicle load factors, empty vehicle redistribution, and so forth. Hence these simulators provide the necessary linkages between detailed transport operations data and the more abstract cost, time, and energy functions required for network analysis. They also provide a means for introducing into the network energy-conservation options such as technological innovations, new operating patterns, and other measures designed to reduce modal energy use. The modal simulators are the subject of Appendix E.



a) Nodes'

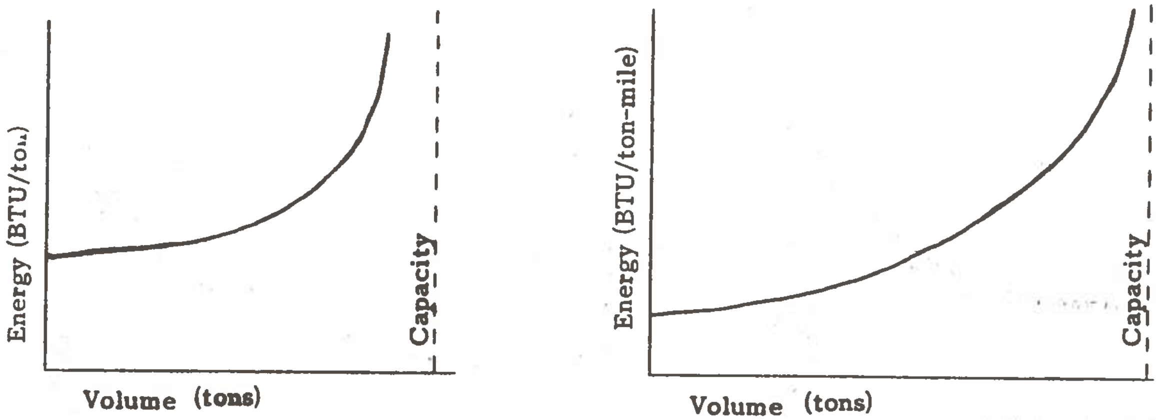
b) Linehaul Links



c) Access Links

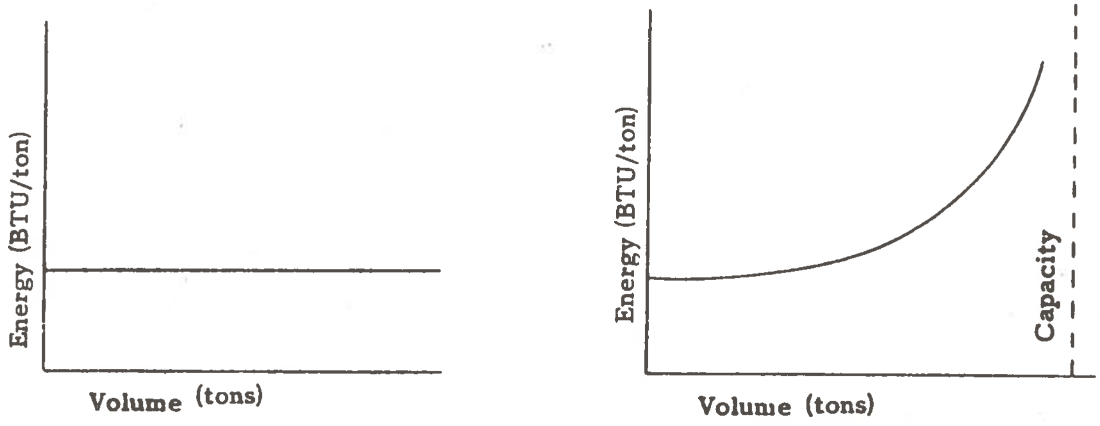
d) Transfer Links

Figure 3-6. Time Functions



a) Nodes

b) Linehaul Links



c) Access Links

d) Transfer Links

Figure 3-7. Energy Functions

The cost, transit time, and energy functions describing a transportation facility are not independent. The principal relationships between these functions are illustrated in Figure 3-8. Travel time is an important determinant of energy use, and time and energy use are both determinants of transportation cost. These relationships are either built into the modal simulators, or are accounted for by the sequence in which the functions are estimated.

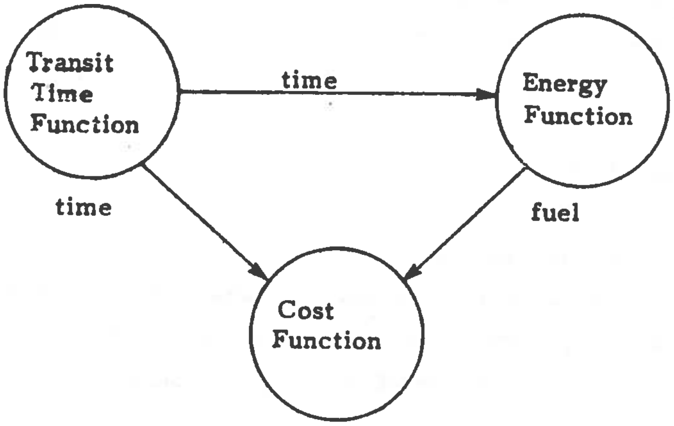


Figure 3 - 8. Relationships Between Performance Functions

- Additional Class Attributes

The main use of the "class" entity in the model is to provide a cross reference between individual nodes and links and their cost, time, and energy functions. That is, nodes and links with similar characteristics are grouped into classes, and performance functions are specified on a class basis.

Some additional performance attributes are also specified on a class basis. The first of these is capacity, the maximum flow which a node or link can sustain. For linehaul link classes a set of three impedance directional factors, one each for cost, time, and energy use are also specified. These factors allow the performance functions to be adjusted upward or downward to account for the influence of travel direction (e.g., upstream vs. downstream, upgrade vs. downgrade, etc.) on link impedance. Finally, a set of impedance commodity factors are used to adjust the functions for commodity-specific differences in cost, time, and energy use. These factors are defined for commodity class - facility class combinations, and are discussed further below.

Commodity Flows

As with most transportation network models, the commodity traffic to be shipped through the network drives the operation of the model. The general characteristics of commodities are represented by commodity classes; individual interregional commodity flows are represented as shipments.

- Commodity Classes

Commodity shipments to be assigned to the multimodal network must be grouped into a number of commodity classes, on the basis of similar physical, economic, and transportation characteristics. The following attributes of commodity classes are represented in the model:

- Two-digit commodity code
- Impedance weighting factors
- Allowable transportation modes
- Name
- Impedance commodity factors

Any two-digit commodity classification system may be used to define commodity classes. Of course, the scheme used for multimodal network analysis must be compatible with that adopted for commodity flow data collection and forecasting purposes.

The <u>impedance weighting factors</u> are used in the model to convert separate measures of transportation cost, transit time, and energy use into a single more generalized measure of shipper-perceived disutility. Hence the relative values of these weights indicate the tradeoffs which shippers are willing to make among the various components of transportation impedance. An additive utility function is assumed, as follows:

$$Z_k = A_k c + B_k t + W_k e \qquad (1)$$

where

Z_k = disutility for shippers of commodity k
c = transportation cost
t = transit time
e = energy use
A_k, B_k, W_k = impedance weighting factors for commodity k.

The values chosen for the impedance weights depend upon the units in which the impedance components are measured, the units in which disutility is to be measured, and the purpose for which the model is being used. Suppose, for example, that cost is measured in \$/ton, time in hours, and energy use in BTU/ton, and that disutility is to be measured in \$/ton (implying that the model is being used to generate minimum-cost network routings). Then impedance weights might be specified as follows:

$$A_k = 1.0$$

$$B_k = \left(\begin{array}{c}\text{commodity value}\\ \$/\text{ton}\end{array}\right) \times \left(\begin{array}{c}\text{inventory factor}\\ \%\text{ per hour}/100\end{array}\right)$$

$$W_k = \text{fuel cost, \$/BTU}$$

Note that B_k represents the shipper's unit cost of delay, in dollars per ton-hour, and thus provides an estimate of the value to the shipper of improved or expedited transportation service. Also, this weighting scheme implies that fuel costs must not be included in the value of c, to avoid double counting. (Alternatively, if fuel costs are included in c, then W_k should be set to zero.)

As another example, suppose it were desired to generate a set of network routings based on minimizing energy use. This could be accomplished with the following impedance weights:

$$A_k = 0$$

$$B_k = 0$$

$$W_k = 1$$

In this case, disutility would be measured as BTU/ton. This particular application is the prime motivation for including energy use as a separable component of impedance. In other applications, W_k values can be selected to simulate varying degrees of shipper/carrier sensitivity to fuel consumption (spurred by fuel rationing programs, for example), or to conveniently introduce fuel tax increases without reestimating all of the cost functions.

The allowable modes attribute is used in the model primarily to prevent illogical commodity-mode combinations from occurring in the network routing; for instance, agricultural commodities cannot be shipped through petroleum pipelines. The model only considers nodes of the allowable modes specified for a commodity class when finding least-disutility paths for shipments of that class.

The impedance commodity factors adjust the basic cost, time, and energy functions specified for a node or link class upward or downward to account for individual commodity effects. For example, TOFC trains and unit trains have different characteristics than manifest trains, although they all may use the same set of tracks. Similarly, integrated tows achieve higher speeds than nonintegrated tows. The impedance commodity factors incorporate such commodity related service differentials into the model's network performance data structure. These factors are specified for individual commodity class-facility class combinations, and separate cost, time, and energy factors are allowed. Thus a system with 10 commodities and 100 node/link classes could have as many as 3000 impedance commodity factors.

The roles played by the two types of adjustment factors specified for commodity classes are shown in Figure 3-9. A particular node or link belongs to a class, which references three performance functions. The values of cost, time, and energy use obtained from the functions are modified by the impedance commodity factors, which are indexed by commodity class and node/link class. These adjusted cost, time, and energy-use values are then weighted by the commodity's impedance weighting factors and summed to produce the final impedance or disutility value.

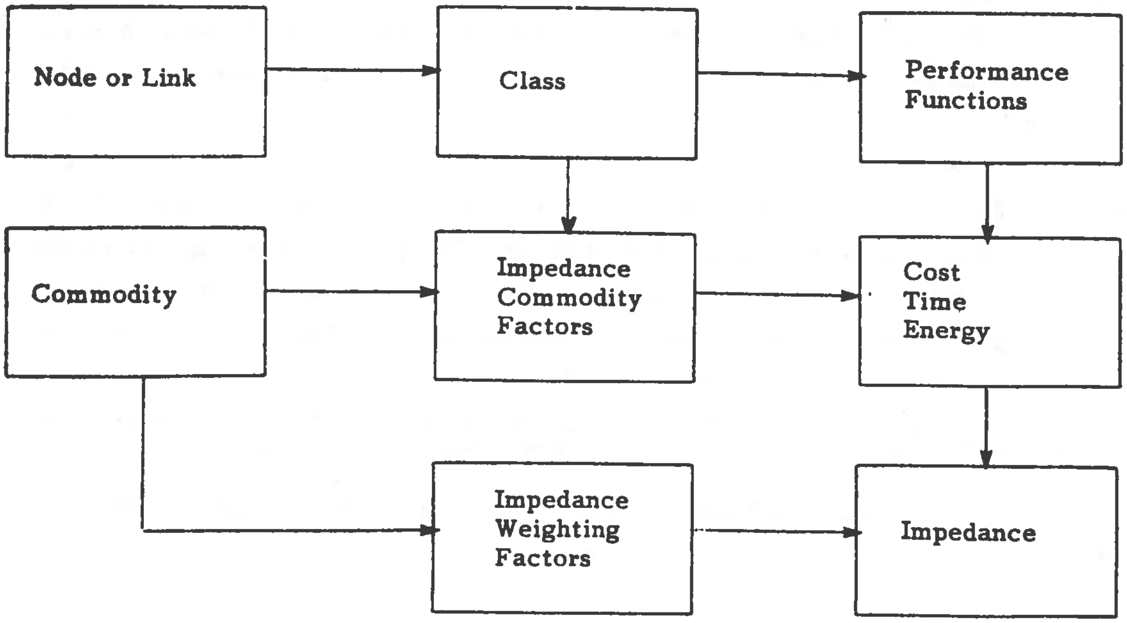


Figure 3-9. Computing Impedance

- Shipments

Commodity flows are represented in the model as shipments, each of which has the following attributes:

- Commodity class
- Origin region
- Destination region
- Quantity
- Impedance weighting factors (optional)

If impedance weighting factors are provided for a shipment, they override those in effect for the commodity class.

Each shipment may also have an optional specified route or an optional specified modal split. A specified route consists of the sequence of nodes to be followed from the origin region to the destination region. A specified modal split consists of: (1) the fraction ("inertia factor") of the total shipment which is constrained to observe the modal split; and (2) the shares (fractions) of the constrained tonnage to be allocated to each mode. This specified modal split feature is the model's operational representation of the "inertia effect" introduced in chapter two. Note that the inertia effect is specific to each shipment, rather than to entire commodity classes. If this option is selected and the inertia factor is less than 1.0, the balance of the shipment tonnage will be allocated to the least-disutility route in the normal fashion.

The inertia effect has been discussed a great deal but has not been included directly in prior freight transport models. It represents the long term nature of many commodity shipping arrangements. This influence, often treated as part of a nebulous set of "institutional factors," takes many shapes and forms and arises from a number of sources. One such source is a long-term contract between a shipper and a carrier, which effectively removes that shipper's goods from the arena of intermodal competition for the duration of the contract. Investments in long-lived capital goods designed to interface with only one transportation mode (e.g., rail spurs, barge transloading facilities, pipeline terminals, loading docks, stock-piling/warehousing facilities, etc.) are another. Reluctance of shippers to alter existing procedures, making them insensitive to small intermodal cost differentials, is a third source, and private ownership of transport fleets a fourth. Even something seemingly as readily changeable as a lack of knowledge of alternative transportation services can be a source of shipper rigidity. Legislative and regulatory activities and governmental taxation policies also contribute to this influence. Conceptually, factors of this type may be lumped together and treated as an "inertia effect" which limits the response of shippers to market forces. Inertia factors should be used when using the model for a sequence of runs representing consecutive future time periods. They are also a convenient means of conducting analyses under fixed modal share conditions.

For most model applications, the entire commodity flow from one region to another may be represented as a single shipment. However, if special study requirements dictate, the total flow may be divided into two or more shipments. This multiple-shipment representation may be needed, for example, if severe overloading of network elements occurs. This option should be used sparingly, however, because computer processing time is proportional to the number of shipments.

The model does not assume a time period for which shipment quantities are to be specified. Hence, the shipments could represent daily, weekly, monthly, quarterly, or annual flows, as required. In general, it is expected that the model will be used in conjunction with quarterly or annual data. A requirement implicit in the structure of the model is that the time base selected for specifying commodity flows must be used consistently throughout the data. In particular, the following attributes must all be specified with reference to a common time interval:

- Commodity flow tonnages
- Link and node capacities
- Performance functions

Modeling Transportation Options

The preceding sections have described in some detail how an existing transportation system is represented in the transportation network model. Given that a basic purpose of the model is to analyze potential changes in the transportation system, how are these changes represented?

The exact technique used to represent a transportation option depends upon the nature of the option. An addition to the network is represented by adding nodes and links representing the new facilities to the network description, and providing performance functions for the new nodes and links. Similarly, a deletion is accomplished by removing the appropriate nodes and links. An entirely new mode, such as coal slurry pipelines, can be represented by providing the requisite modal subnetwork and its attendant access links, transfer links, performance functions, and commodity "allowable mode" designations. An investment or an operating change designed to upgrade the capacity and performance of an existing node or link is represented by shifting its cost, time, and energy functions to describe the element's new operating regime.

Summary

The representations employed in the transportation network model are adaptations of conventional transportation network analysis concepts. The study area is represented as a set of regions which serve as sources and sinks of commodity flows. The structure of the transportation system is defined by nodes, linehaul links, access links, and transfer links. Node and link operations are characterized by cost, transit time, and energy functions which represent underlying technological relationships. Commodity flows are represented as shipments, which may be constrained to follow specified paths or to partially observe specified modal split patterns. Network alterations may be represented by modifying the network structure and/or performance functions. This representational scheme is very general and flexible, and allows the model to be used for transportation network analyses at varying levels of detail.

PART II: LOGIC FLOW

The remainder of this chapter describes how the transportation network model assigns interregional commodity shipments to least-disutility paths through the transportation network. This discussion also explicitly defines some of the features of the model's structure and logic described earlier in general terms. An overview of the operational flow of the model is presented first, followed by more detailed descriptions of the model's principal algorithmic components.

Overview

The overall flow of operations within the model is displayed in Figure 3-10. The program begins by reading all of the input, with the exception of the shipments, and printing an echo-listing of the input cards if requested. Input data are stored into the various entities of the model, such as regions, nodes, and links. A series of optional playback reports are then printed, with full cross-referencing among all the input data, providing a hard-copy record of the conditions under which the run was made.

Values of cost, transit time, and energy use are then computed for each node and link, using the performance functions and initial estimates of traffic volumes. The shipment data are now read, and each shipment is allocated to the least-disutility path from origin to destination. Constraints which may be in effect for any or all shipments include route, mode, and capacity constraints, a path circuity constraint, and an inertia constraint. A record of the path selected for each shipment is generated, for use in subsequent operations. An optional equilibrium-seeking feedback loop, allowing for iteration of the shipment allocations based on refined node and link volume and disutility estimates, is also available.

After all shipments have been allocated to the network, the disutility incurred by each shipment is computed, using the node and link performance functions in conjunction with the total volume assigned to each node and link. A series of output reports and data files are then produced.

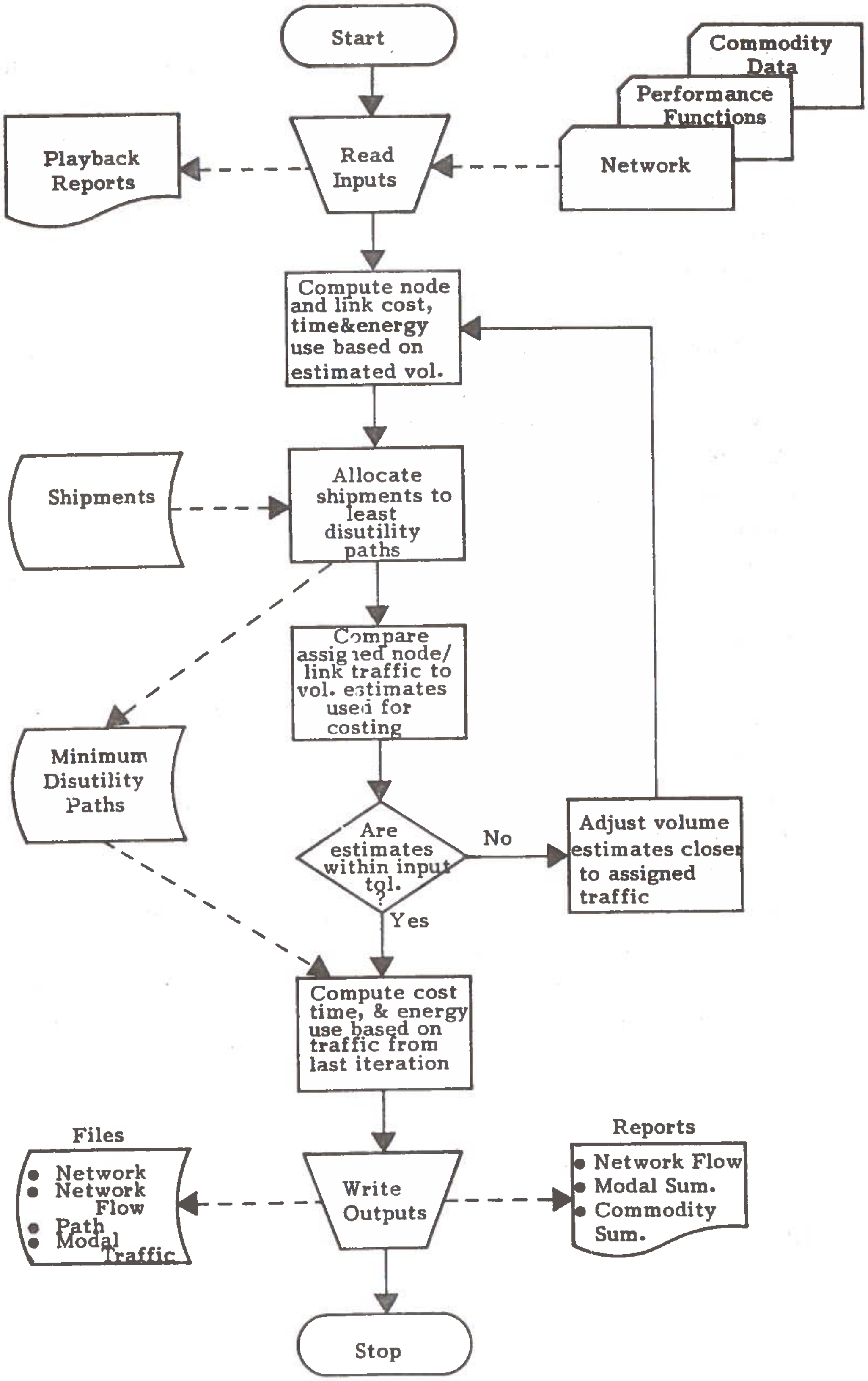


Figure 3-10. Transportation Network Model Logic Flow

In many respects, the transportation network model is similar to previous transportation network analysis models. The principal innovations in the model are its use of shipment-specific routing, the variety of useful path selection constraints employed, and the attention given to demand/supply dynamics and equilibrium. These features and innovations are described in the following sections.

Initial Impedance Estimates

The first logical operation of the model is computation of the commodity invariant portions of node and link disutilities, as follows:

$$c_j = f_m (\tilde{q}_j) \tag{2}$$

$$t_j = g_m (\tilde{q}_j) \tag{3}$$

$$e_j = h_m (\tilde{q}_j) \tag{4}$$

where

c_j = cost of traversing network element j ($/ton)

t_j = transit time through network element j (hr.)

e_j = energy used in traversing network element j (units/ton)

m = node or link class of network element j

$f_m(q)$ = cost function for class m

$g_m(q)$ = time function for class m

$h_m(q)$ = energy function for class m

$\tilde{q}_j$ = estimated volume of traffic through network element j (tons).

For linehaul links, the performance functions are specified on a per mile basis, and impedance may vary by direction. This directional variation is expressed in the form of three impedance directional factors, one each for cost, time, and energy use, which may be either multiplicative or additive. Hence the actual form of equation (2) for linehaul links is:

$$c_j = L_j C_m f_m (\tilde{q}_j) \qquad (2a)$$

where

L_j = length of link j (miles)

C_m = multiplicative directional factor for cost on link of class m.

or

$$c_j = L_j \left[C_m^+ + f_m (\tilde{q}_j) \right] \qquad (2b)$$

where

C_m^+ = additive directional factor for cost on link of class m.

Equation (2a) or (2b) is applied separately to each travel direction. Analogous forms are used for computing transit time and energy use, with directional factors T_m or T_m^+ for time and E_m or E_m^+ for energy.

The impedance directional factors are actually input on a class basis. The nodes which define a linehaul link are referred to as the A-node and the B-node, and travel direction is referred to as either A → B or B → A. The model's default mode of operation assumes the following adjustment factors for both travel directions:

$$C_m^+ = T_m^+ = E_m^+ = 0.$$

For any linehaul link class, the user may provide directional factors which are used to adjust link impedances for travel in the B→A direction on all links in the class, in the manner indicated by equations (2a) and (2b). This implies that all links in the class have their A-nodes and B-nodes assigned such that the A→B direction is the same (i.e., downstream, downgrade, etc.). The default polarity of the directional factors may be reversed for any link; that is, the user may indicate in the link input that the impedance directional factors are to be used for A→B travel, rather than B→A travel. Directional factors are not used for links which are coded to allow travel in only one direction.

Since cost, time, and energy use are all functions of traffic volume, estimates $\widetilde{q_j}$ of total expected volume must be provided for each node and link in the network. Initial volume estimates may be derived from several sources. Traffic volume is a basic operating statistic collected by virtually all transportation companies and government transportation agencies, so historical records may be consulted for existing facilities included in the network. In the absence of reliable data, estimated volume may simply be taken as that fraction (e.g., 50% to 80%) of capacity which will allow each network element to initially operate near the low points on its performance curves. For future time periods, the model itself may be used as a source of volume estimates. That is, volumes q_j output by the model for time period t may be used as estimates $\widetilde{q_j}$ input for time period t + 1. (Further discussion of this last concept is provided later.)

Whatever the source of the volume estimates, the possibility exists that the total traffic assigned to a facility by the model may not agree with the estimated volume used to compute the disutilities upon which the path selection decisions were based. From a conceptual view, this actually adds realism to the model, since impedances are not precisely known by shippers in advance; that is, shippers must make their mode and route choices on the basis of expected cost, time, and energy use. However, large differences between estimated and actual volumes can lead to erroneous or misleading model output. For this reason, an iterative shipment allocation feature is provided in the model, whereby volume estimates are adjusted and revised shipment assignments are made. This iteration or successive approximation logic is described further in a later section.

Path Selection Logic

- **Least-Disutility Path**

Commodity shipments are assigned to least-disutility paths through the multimodal transportation network. A path consists of a sequence of nodes and links followed from the origin region to the destination region. A given node or link may appear only once in the path. The disutility of a path is the sum of the impedances incurred on each element of the path.

Impedances for individual network elements are adjusted for commodity-specific effects during the path selection process, as follows:

$$c_{kj} = a_{km} c_j \tag{5a}$$

$$t_{kj} = b_{km} t_j \tag{6a}$$

$$e_{kj} = w_{km} e_j \tag{7a}$$

in which

m = class of network element j

c_{kj}, t_{kj}, e_{kj} = cost, time, and energy use, respectively, for commodity k to traverse network element j

c_j, t_j, e_j = cost, time, and energy use, respectively, for network element j, as defined previously

a_{km}, b_{km}, w_{km} = impedance commodity factors for cost, time, and energy use, respectively, for commodity k and node/link class m.

An additive form of the impedance commodity factors is also available, in which case the appropriate equations are:

$$c_{kj} = a^{+}_{km} + c_j \tag{5b}$$

$$t_{kj} = b^{+}_{km} + t_j \tag{6b}$$

$$e_{kj} = w^{+}_{km} + e_j \tag{7b}$$

where a^{+}_{km}, b^{+}_{km}, and w^{+}_{km} are additive impedance commodity factors. In the absence of user-provided factors, the model assumes values $a^{+}_{km} = b^{+}_{km} = w^{+}_{km} = 0$.

Path impedance is then computed as follows:

$$Z_{kIJ} = \sum_{j \epsilon P} A_k c_{kj} + B_k t_{kj} + W_k e_{kj} \tag{8}$$

where

Z_{kIJ}	=	disutility of shipping commodity k from region I to region J
P	=	the set of network elements (nodes, linehaul links, access links, transfer links) included in the path from I to J for commodity k
A_k, B_k, W_k	=	impedance weighting factors for cost, time, and energy use, respectively, for commodity k, as defined previously.

As noted earlier, the impedance weights input for commodity class k may be overridden by shipment-specific values. Equation (8) is the model's operational version of equation (1) appearing in part one of this chapter.

The model employs a shipper-optimizing rule for finding the least-disutility path. That is, P is selected so as to

$$\min Z_{kIJ} \quad \text{each } k, I, J, \tag{9}$$

In other words, decentralized, rather than globally optimal, decision-making on the part of shippers is assumed. Any path P satisfying equation (9) will subsequently be referred to as P_{min}. The computational technique used to find P_{min} is a variant of the Moore algorithm (8), and is described in detail in Appendix B.

- Path Selection Results

Upon determination of the least-disutility path P_{min}, the model adds the shipment volume to the total accumulated volume for each node and link included in P_{min}. The model also produces a record of P_{min} for later use, and optionally prints P_{min} for user inspection.

A brief discussion of the nature of a path and of the information needed to define a path is now in order. It will be recalled that network elements j are either nodes (N), linehaul links (L), access links (A), or transfer links (T); i.e., $j \in \{N\} \cup \{L\} \cup \{A\} \cup \{T\}$, where $\{X\}$ represents the set of all X and $\cup$ indicates union of sets. Given the data structure of the model, a path may be represented symbolically as the following generalized sequence:

$$P = (R, A, N, \ldots, L, N, \ldots, T, N, \ldots, A, R) \tag{10}$$

where $\{R\}$ is the set of all regions.

In this expression, consecutive symbols separated by commas must always appear in the order shown, the first and last such groupings are always required, and any number, or none, of the intermediate groups may appear, in any group sequence. Thus the path with the fewest possible elements, connecting two adjacent regions, would be (R, A, N, A, R). Some other permissible path sequences are (R, A, N, L, N,L, N, A, R), (R, A, N, L, N, L, N, T, N, L, N, L, N, A, R), and so on.

Upon study of expression (10) and the examples given above, it is clear that the first group of elements and all intermediate groups all have a node as their last element type. Further, the model's data structure requires that two nodes are directly connected by at most one link (or two one-way links). Hence it follows that a knowledge of the origin region, the destination region, and the sequence of nodes in the path completely specifies the path. Thus path records are stored and printed as node sequences. This property is also made use of in the path selection computations, as described below and in Appendix B.

Path Selection Constraints

The preceding section described the procedure used to find least-cost paths in the absence of constraints. Several types of path selection constraints included in the model are described in this section. In most cases, these constraints can be expressed in terms of subsets of nodes which are allowable candidates for inclusion in the least-cost path, all other nodes being excluded from consideration.

- Specified Route

The strongest path constraint available is direct specification of the entire route to be followed by a shipment from origin to destination. In this case, no cost minimization is attempted; the model merely records the specified path and augments the cumulative flow on each node and link in the path by the shipment quantity. The node sequence specified must be a "legal" path: if nodes N1 and N2 are specified in sequence, there must be a network link connecting N1 and N2 and allowing travel in the N1 → N2 direction. This requirement is checked by the model. It is the user's responsibility to insure that the transport modes represented by nodes N1 and N2 are "allowable modes" (discussed below) for the commodity involved.

This feature is included in the model to represent special shipment requirements (routing of explosives, oversize shipments, hazardous chemicals), to allow the user to "freeze" selected path assignments while experimenting with other flows, and as a model calibration aid. This feature is also useful for updating interregional transportation costs without disturbing the network flow pattern. This can be done by entering the paths generated in a previous model run as specified routes, in conjunction with revised cost, capacity, and energy functions.

- Mode Constraints

Each commodity class has as an attribute a set of allowable transport modes which may be selected for shipments of that class. For example, coal may be permitted to move by barge and rail, grain by barge, rail, and truck, crude petroleum by barge and crude pipeline. There must obviously be a path-selection constraint in the model to preserve the required commodity-mode incidences.

Because transport mode is a node attribute in the model, the constraints on allowable modes are implemented by simply requiring that any node considered for path inclusion be of a mode which is allowable for the commodity class of the shipment. Mathematically, this constraint is expressed as follows:

Let $\{M_k\}$ = the set of allowable modes for commodity k

$M(N)$ = the mode of Node N

$$\{N_k\} = \{N \mid M(N) \in M_k\}$$

Then only nodes $N \in \{N_k\}$ are considered for inclusion in P_{min} for shipments of commodity k.

- Capacity Constraints*

A third path selection constraint observed in the model is that no shipment may be assigned to a node or link if such assignment would cause the element's flow volume to exceed its capacity. Mathematically, this constraint requires that the following relation must always be true for network element j to be added to P_{min}:

$$q_j + Q_{kIJ} \leq Q_m \qquad (11)$$

where

q_j = cumulative flow on element j

Q_{kIJ} = quantity of commodity k shipped from region I to region J (currently being assigned to the network)

Q_m = capacity of elements in class m

m = node or link class of element j

Expression (11) is evaluated for both the node being considered and for the link leading into it, and must be true in both cases to add the node (and implicitly the link) to P_{min}.

---

* Transportation analysts often use the term "capacity constraint" (or "capacity restraint") to refer to the iterative traffic allocation technique mentioned earlier. That specific meaning is <u>not</u> intended here.

- **Circuity Constraint**

In order to reduce the amount of computer processing required to find P_{min}, a constraint is imposed on the amount which any path may deviate from a straight line between the origin and destination regions. Operationally, this circuity constraint takes the form of an ellipse of specified eccentricity e, $0 < e < 1$, with foci at the centers of the origin and destination regions. Given the coordinates of any node it is easy to determine whether or not the node lies within the ellipse (see Appendix B). Only nodes within the ellipse are considered for inclusion in P_{min}.

The need for this constraint actually arises from the computational sequence of the minimum path algorithm, so it is somewhat difficult to justify rigorously at this point in the text. However, consider the simple example shown in Figure 3-11. In this example, the network is a uniform rectangular grid of infinite extent and there is a network node at each intersection of a horizontal and vertical line. In the normal operation of the minimum path algorithm, nodes such as a and b in the figure will be considered for inclusion in the minimum path from I to J, even though they will probably be discarded eventually in favor of a more direct path. In fact, in the absence of some type of constraint, nodes which lie in a direction from the origin region diametrically opposite the required travel direction, i.e., those "behind" region I, will be considered. Restricting attention to only those nodes within the ellipse prohibits excessive backtracking and avoids all of this fruitless calculation. In the example given here, even disregarding that part of the network behind I not shown in the figure, computation time with the ellipse constraint is less than half of that without it.

Of course, computational efficiency comes at a price. In this case, imposition of the circuity constraint allows the possibility that the true least-disutility path will not be found; that is, the minimum path may pass through a node which lies outside the ellipse, such as nodes c or d in Figure 3-11. (In fact, if all nodes and links in the network of Figure 8-2 have equal impedances, there are numerous minimum paths of equal length from I to J, one of which passes through node c and another of which passes through node d.) If the eccentricity of the ellipse is not too large (the default value is e = 0.89), this is not likely to happen. Even if it does, the error will probably not

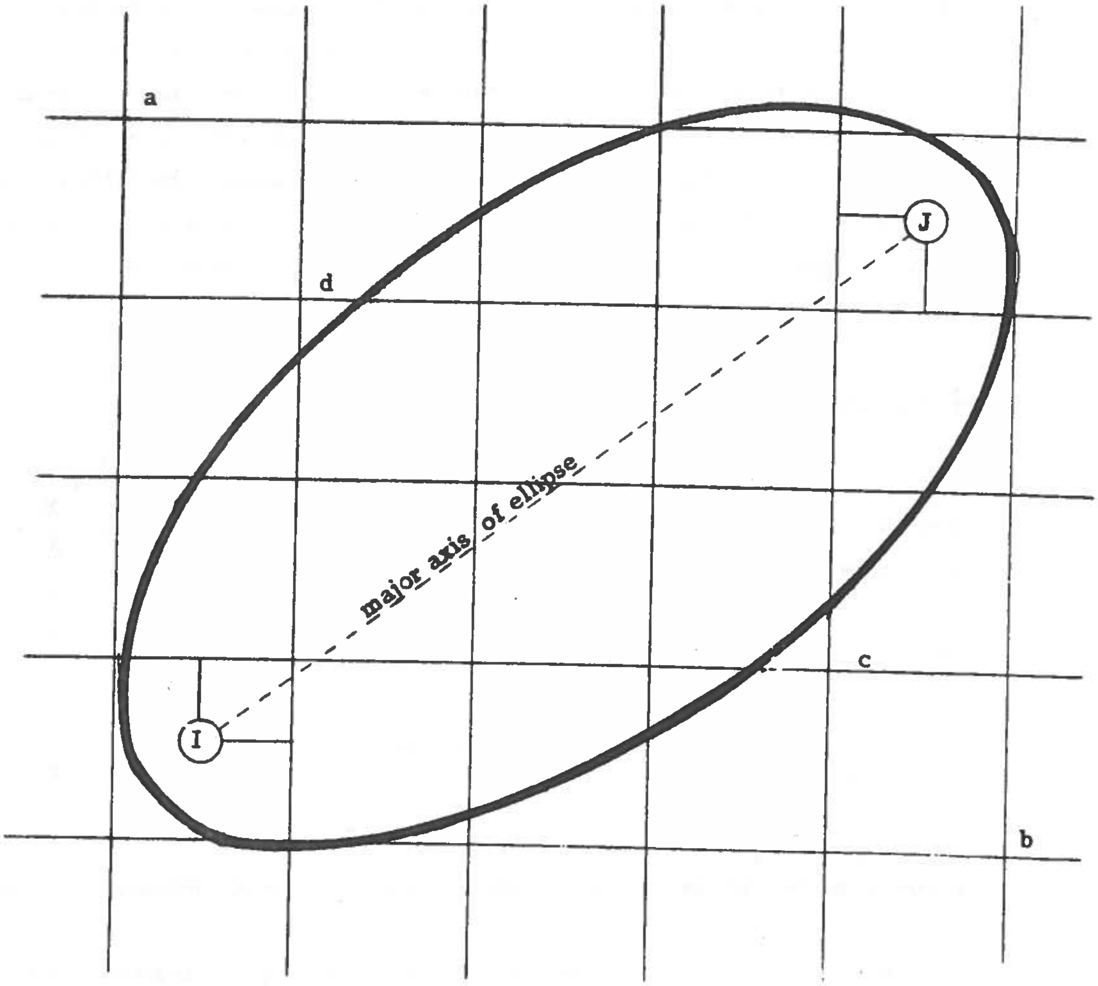


Figure 3-11. Example of Inclusion Ellipse

be serious, since the path chosen will usually have an impedance very close to the minimum. However, if the user suspects that numerous least-disutility paths are being missed, he can simply decrease the eccentricity of the inclusion ellipse.

In special situations characterized by unusual topography (large bodies of water, severe mountainous terrain) between two regions, it is possible that the inclusion ellipse will not contain a valid network path; the set of nodes within the ellipse may not be connected. If this happens, the model automatically relaxes the circuity constraint temporarily, by using a "backup" ellipse specified by the user for such situations, and initiates a new search for the minimum path. The model notifies the user each time the backup ellipse is invoked. If a valid path still cannot be found, a message to that effect is printed and the next shipment is read in.

Inertia Effect

The inertia effect is a feature included in the model by which some or all of a shipment may be directed to observe a modal split pattern input by the user. It is implemented as follows:

Let x = inertia factor, $0 \leq x \leq 1$

Y_i = modal split fraction for mode i, $i=1,\ldots,M$, $0 \leq Y_i \leq 1$,

$$\sum_{i=1}^{M} Y_i = 1.$$

where M is the number of modes. Then, letting Q_{kIJ} be the shipment quantity:

xY_iQ_{kIJ} = traffic allocated to least-disutility path consisting only of nodes of mode i, $i=1,\ldots,M$

$(1-x)Q_{kIJ}$ = traffic allocated to least-disutility path subject only to the usual mode constraints defined earlier.

Both the inertia factor, x, and the modal split fractions, Y_i, must be input for each shipment (the default is x = 0). The modal split fractions may be derived from historical data, or, for future time periods, from model results for the preceding period. The inertia factor represents the user's estimate of how rapidly shippers respond to changes in transportation costs and service levels, high values of x indicating slow response and low values indicating quick response. This interpretation of the inertia factor, of course, only has meaning within the context of successive network simulations for future time periods, which is exactly what the inertia effect is intended to cover.

Suppose, for example, that region I ships 10 million tons of coal per year by rail to region J. In year t, a new waterway is opened, making it cheaper to ship this coal by water. Assuming that the water cost remains below the rail cost, the following modal traffic shares result if x = 0.80:

Modal Traffic (million tons)

Year	Rail	Water
t	8.0	2.0
t + 1	6.4	3.6
t + 2	5.1	4.9
t + 3	4.1	5.9
t + 4	3.2	6.8

Due to the relatively high inertia factor, it takes the new waterway five years to capture two-thirds of the traffic. This might correspond to a long-term phasing out of existing contracts, a natural lag in shipper provision of compatible facilities, and so on. In other words, it takes a new facility a number of years to build a traffic base, and this adjustment period is accounted for by use of the inertia factor. With no factor, in this example all 10 million tons would shift to the waterway at time t. It is usually desirable to avoid such instantaneous severe dislocations in commodity flow patterns in the model, since they rarely occur, and since it would probably take the model several time periods to recover from the nonequilibrium distortions thereby produced.

It should be noted that intermodal shipments cannot have an inertia property. That is, it is not possible within the model's current structure to constrain a given portion of a shipment to observe some specified modal combination. For operational purposes, it is suggested that shipments assigned to intermodal paths by the model for time period t simply be added to the unconstrained tonnage for period t + 1, and the x and Y_i values adjusted accordingly. Upon reflection, it is clear that intermodal routings can only be selected by the model for the unconstrained tonnage anyway, and the cost advantages leading to such routings are likely to persist through several time periods. So the final result achieved is much the same as specifying an intermodal share. For special transition cases, where an intermodal path becomes non-optimal, the specified route option can be used to input the desired modal split pattern.

Iteration Procedure

As noted previously, the volume estimates used to calculate node and link impedances may not agree with the volumes actually assigned to the nodes and links. Hence the user may wish to iterate the path selection procedure several times to obtain a closer match between estimated and assigned traffic and thereby obtain an equilibrium flow pattern. This optional iteration process is controlled by several parameters input by the user, as follows:

n_{max} = maximum number of iterations

D_{max} = volume error tolerance

F_{min} = minimum fraction of network elements which must have a volume error not exceeding D_{max}

A = volume adjustment factor.

These parameters are used in the manner indicated below.

Upon completion of the nth iteration, $1 \leq n \leq n_{max}$, the model calculates the overall extent to which estimated and assigned volumes are in agreement, as follows:

$$D_j = \frac{|q_j^{an} - q_j^n|}{\min(q_j^{an}, q_j^n)} \tag{12}$$

$$F = \text{fraction of network elements with } D_j \leq D_{max}$$

where

D_j = relative volume error for network element j

q_j^{an} = volume assigned to element j during iteration n

q_j^n = volume estimate for element j on iteration n.

Then, if $F \geq F_{min}$, acceptable agreement has been achieved and no further iteration is required. If $F < F_{min}$ and $n < n_{max}$, at least one more iteration is needed. Volume estimates for the new iteration are computed as follows:

$$q_j^{(n+1)} = q_j^n + A\ (q_j^{an} - q_j^n) \tag{13}$$

For example, suppose $n_{max} = 4$, $D_{max} = 0.10$, $F_{min} = 0.95$, and $A = 0.75$. With these parameter settings, the user is stating that he will be satisfied if the assigned and estimated volumes are within 10% of each other, for at least 95% of the nodes and links in the network, but if this conformity cannot be achieved with 4 or less iterations further calculations should cease. For each new iteration, the estimated volume is to be incremented (or decremented) by 75% of the difference between the assigned volume and the previous estimate.

The iterative traffic assignment procedure described above constitutes a reasonable approach toward obtaining a network flow pattern sufficiently close to equilibrium for the user's needs. The parameter settings afford the user considerable flexibility in specifying the degree of precision deemed acceptable. If $n_{max} = 1$ no iterations will be performed. In this case, the model still reports the value of F attained, so some reasonable value for D_{max} must still be input; the other parameters are inoperative. The error tolerance, D_{max}, is a direct user specification of the maximum acceptable deviation between estimated and assigned volumes, or, equivalently, between expected and realized impedances. Note that if most nodes and links are operating on relatively flat portions of their performance functions, large volume errors produce relatively small impedance errors. Hence depending on the volume-to-capacity ratios expected, a typical range of D_{max} specifications is $0.05 \leq D_{max} \leq 0.50$. The acceptance criterion, F_{min}, controls the computer processing resources to be devoted to reducing volume estimation errors. If the majority of nodes and links have volume errors within the specified tolerance, it makes little sense to spend additional resources for marginal gains in precision. Thus typical settings for F_{min} are $0.75 \leq F_{min} \leq 0.95$. The maximum iterations parameter is a user override to prevent excessive iterating in the event that nonconvergent or slowly converging system behavior develops. Typical settings are $1 \leq n_{max} \leq 5$. The volume adjustment parameter. A, is a damping factor used to speed the convergence of the system toward equilibrium; typically, $0.25 \leq A \leq 1.00$ (low values are used for very sensitive systems, high values for systems which respond sluggishly).

In essence, parameters n_{max}, D_{max}, and F_{min} together constitute specification of the degree of precision desired. Hence mutually consistent values for these parameters should be selected. Some suggested combinations of relative parameter settings are given below:

	Desired Precision	
Parameter	Tight	Loose
n_{max}	high	low
D_{max}	low	high
F_{min}	high	low

The user may also generate equilibrium results via an "external" iteration procedure. In this case, for each run of the model the user specifies only a single iteration, i.e., $n_{max} = 1.$ and requests output of the network file. The user then inspects the results of a run. If another iteration is desired, the network file, which contains assigned traffic loadings in the fields normally used to input volume estimates, may be input directly to the model. Alternatively, a user supplied program may be used to generate new volume estimates from the prior network input and the network file. For very large networks, the external iteration procedure is preferred over the model's internal iteration mechanism, since it affords the user better control over allocation of computer resources.

Output Processing

After all iterations have been completed and all traffic has been assigned to the network, the model calculates final values of cost, transit time, and energy use, corresponding to the total assigned tonnage for each network element. In other words, at this point the model calculates realized or incurred impedances, rather than expected impedances. The model then retraces the path followed by each shipment and computes various types of disutilities for output purposes. Numerous types of averages and subtotals are also calculated, for inclusion in the model's output reports. The output reports themselves and other details relating to the model's output processing are presented in chapter five.

4. PROGRAM DESCRIPTION

The purpose of this chapter is to provide reference material for use by a programmer in operating, modifying, and enhancing the transportation network model. It provides descriptions of the operating environment, the organization of the model routines, and summary description of routines. The associated program source listing contains detailed descriptions of each routine at a program level of detail. Variable definitions are provided in chapter six.

Documentation

Instructions to assist an analyst in the use of the model are provided in chapter five. This should be considered a companion for the present chapter since it gives general descriptions of the organization and content of the model. Also, it provides examples of the input forms and output reports which should be referenced in following the descriptions of the input/output routines. A thorough study of chapter five is suggested as a prerequisite for reading this chapter.

An extensive effort has been made to document the model as much as possible within the program source code. This method serves two useful purposes. First, this chapter itself now becomes more of an introduction of the model to a programmer. Once the model is understood, the program itself becomes the programmer's reference, and constant referral to this chapter is no longer required. Second, when modifications to the model are made, the comments in the program will be changed as well, thereby reducing the potential obsolescence of this report.

The efficient programmer, therefore, will familiarize himself with the model by means of this report (and the accompanying program listings) but study the programs only with the most up-to-date listing. Equally important is that the programmer who changes the source code (for correctness or addition) also change the comments where necessary. Failure to do this, naturally, defeats this documentation effort.

Operating Environment

The transportation network model is written in SIMSCRIPT II.5, Version 3.0-00 for the CDC CYBER 175 computer. The program is operational at CDC's Eastern Cybernet Center (ECZ) in Rockville, Md., and is accessible through CYBERNET's batch processing, remote batch, and (indirectly) time-sharing facilities. The compilation and execution of the program are controlled by the SCOPE 3.4 operating system.*

The CYBER 175 provides 131,000 words (377,670 octal) of core memory. Each word is comprised of 60 bits, providing storage of 10 characters and 14 digits of single-precision accuracy. Model runs with full national networks (on the order of 171 regions, 2,000 nodes, and 4,000 links) require virtually all of this memory. Approximately 70,000 octal words are needed to compile the program.

Numerous files are referenced by the program for various purposes. By SIMSCRIPT logical unit number, these files are as follows:

Unit 3 - Title and Options Input
Unit 5 - Network File Input
Unit 6 - Printed Output
Unit 7 - Shipment File Input
Unit 9 - Internal Scratch File
Unit 13- Network File Output
Unit 15- Path File Output
Unit 17- Network Flow File Output
As Specified - Modal Traffic Output Files

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* The program should also operate successfully on any CYBER 175 under any operating system, at any facility equipped with a SIMSCRIPT II.5 compiler. Prospective users should contact TSC for the latest information on accessing the Freight Energy Model.

Unit numbers for the modal traffic files are specified by the user in the network input data, and must be selected from unused odd numbers in the range 1-99. The source of all input files and the disposition of all output files must be specified to the operating system via appropriate control cards. For details, the programmer should consult the SIMSCRIPT CDC User's Manual (9) and the SCOPE 3.4 Reference Manual.

Several types of program files and data files for transportation network model users have been established on the CYBERNET system. Since this information is subject to frequent change, it is available as a separate memorandum from TSC. This memorandum also provides sample job control run streams illustrating the use of the established files.

Routines

Fiqures 4-1 and 4-2 are flow diagrams which illustrate the calling sequence of the transportation network model. For simplicity and clarity, some small routines and all input/output routines have been omitted from the diagrams.

Following is a brief description of each of the routines which make up the executable part of the program. A good familiarity with SIMSCRIPT is assumed. Most of the features of the SIMSCRIPT II.5 language are used by the model, except the simulation features of level 5. The programmer will find it helpful to have references (9), (10), and (11) at hand when inspecting the program source code.

For a detailed description of each routine, refer to the latest program source listing. In the listings, a convention has been employed to alert the reader when implied subscripting has been utilized. An attribute name followed by two periods (such as MN.SHIP..) reminds the reader that the attribute subscript is not present and that the entity name(s) will be used (in this example, MN.SHIP (MODE, NCLASS) is the equivalent). As trailing periods in a name are ignored by SIMSCRIPT, the convention has no effect on the operation of the model.

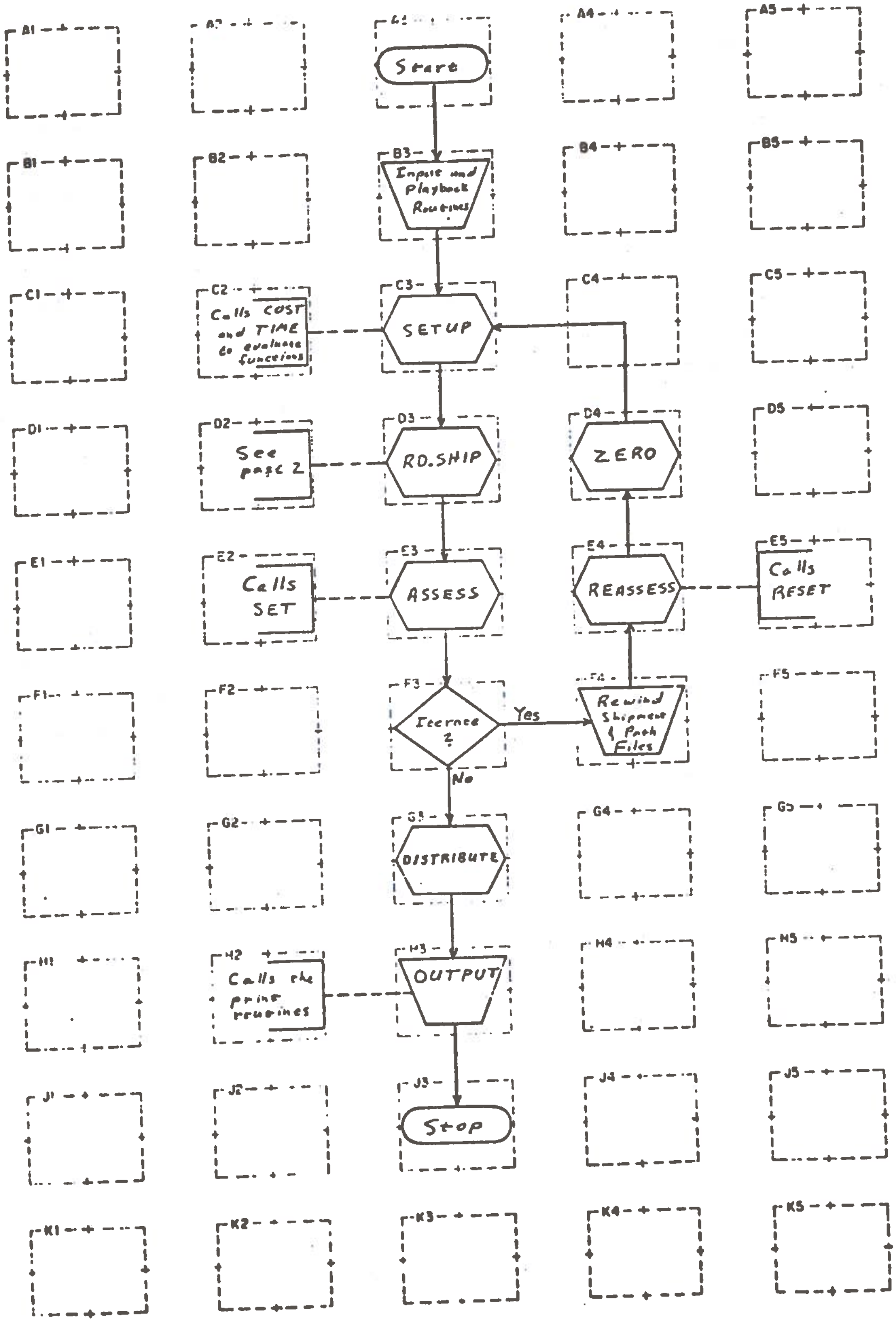


Figure 4-1 MAIN Flow Diagram

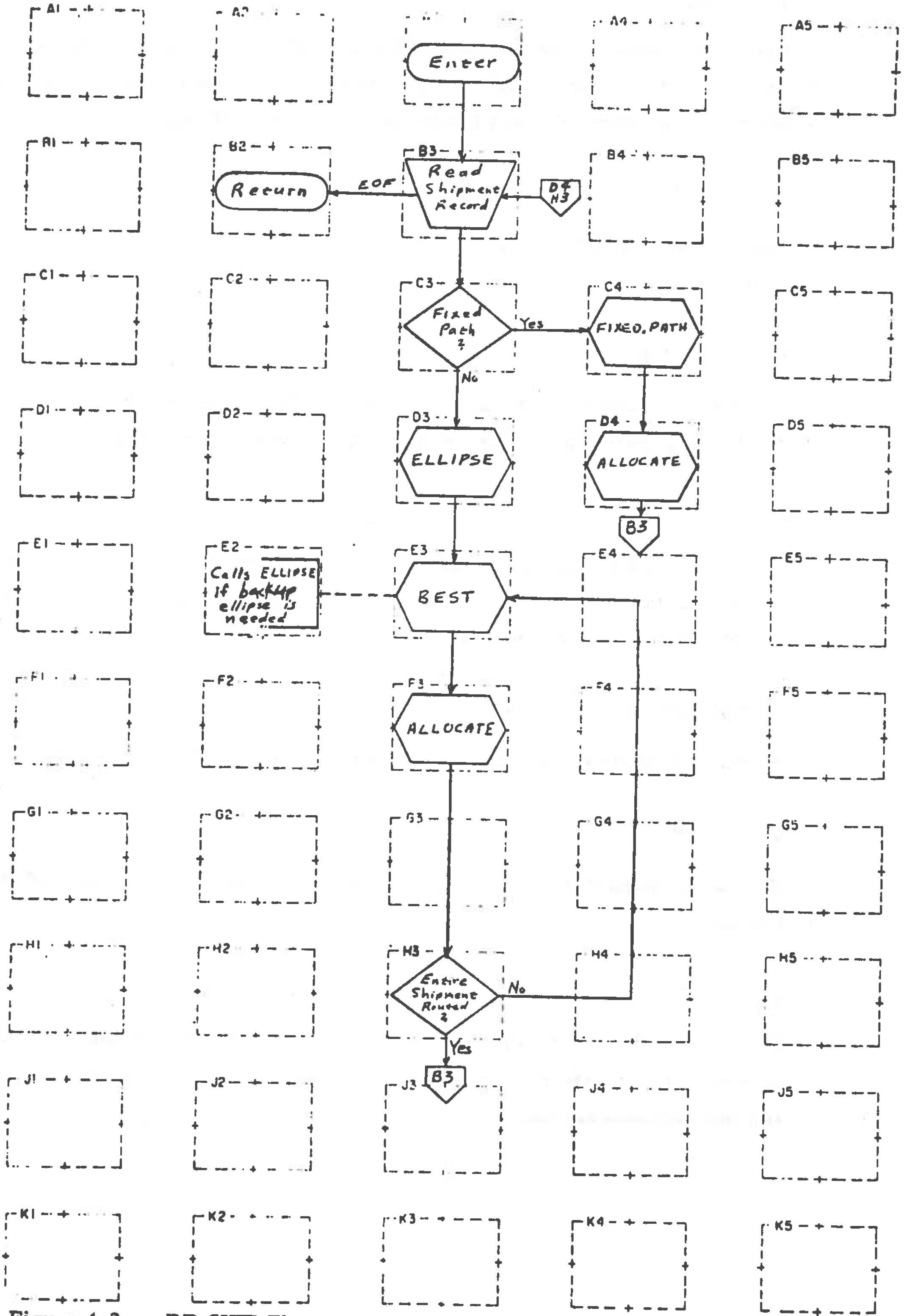


Figure 4-2. **RD.SHIP Flow Diagram**

- MAIN

The main routine of the transportation network model first calls the routines to read in the network and commodity data, then begins and iterates the allocation of shipments, and finally calls the OUTPUT routine.

- AC.OUT

This routine outputs the access link portion of the network flow report or flow data file.

- ADD.UP

This routine accumulates link and node volumes and impedances to the appropriate mode and class attributes for the modal summary report.

- ALLOCATE

Once the least disutility path for a shipment is found, this routine allocates the shipment volume to the links and nodes of that path. Also, the path traceback report is produced here.

- ANSWER

This utility routine converts zero/one flags to "yes" or "no" for printing.

- ASSESS

This routine performs the flow convergence test at the end of each iteration.

- BEST

This routine determines the least disutility path for a shipment or partial shipment, within the constraints of node/link capacities, allowable modes, and the inclusion ellipse.

- **CM.OUT**

This routine outputs the commodity summary report.

- **COST**

This function evaluates a cost function given node/link class and flow volume.

- **DISTRIBUTE**

This routine computes node and link disutilities based on final traffic allocations, accumulates values for the commodity summary report, and generates the modal traffic and path output files.

- **ECHO**

This routine calls print routines to play back the user's data in a restructured format.

- **ELLIPSE**

This routine sets up global variables to be used in routine "BEST" in determining when nodes are outside the inclusion ellipse.

- **ENERGY**

This routine evaluates an energy function given node/link class and flow volume.

- **FDBL.PARAB**

This function, which may be referenced by COST, TIME, or ENERGY, evaluates a disutility function composed of two parabolas.

- **FHYPERBOLA**

This function, which may be referenced by COST, TIME, or ENERGY, evaluates a hyperbolic disutility function.

- **FIXED.PATH**

This routine duplicates pointers which describe the path of a shipment input by the user in the same fashion as those computed in routine BEST, and verifies the path.

- **FPARABOLA**

This function, which may be referenced by COST, TIME, or ENERGY, evaluates a parabolic disutility function.

- **GET.CARD**

This routine reads and optionally prints the user's input cards.

- **LK.OUT**

This routine outputs the linehaul link portion of the network flow report or flow data file.

- **MA.OUT**

This routine outputs the access link portion of the modal summary report.

- **MD.OUT**

This routine produces the modal summary report.

- **ML.OUT**

This routine outputs the linehaul link portion of the modal summary report.

- **MN.OUT**

This routine outputs the node portion of the modal summary report.

- **MT.OUT**

This routine outputs the final portion of the modal summary report, for transfer link classes and network totals.

- ND.OUT

This routine outputs the mode portion of the network flow report or flow data file.

- NET.OUT

This routine outputs the network data file.

- OUTPUT

This routine calls the remaining output routines.

- PR.ACCESS

This routine prints the access playback report.

- PR.CLASS

This routine prints the class and function playback report.

- PR.COMM

This routine prints the commodity playback report.

- PR.HEAD

This routine prints a 2-line heading at the top of each page of printed output.

- PR.ICF

This routine prints the impedance commodity factor playback report.

- PR.LINKS

This routine prints the linehaul playback report.

- PR.NODES

This routine prints the node playback report.

- PR.PARAM

This routine prints the input parameters.

- PR.REGIONS

This routine prints the region playback report.

- PR.TRANSFER

This routine prints the transfer link playback report.

- RD.ACCESS

This routine reads the access link input data and structures the entity ACCESS.

- RD.CLASS

This routine reads the class data for nodes, linehaul links, access links, and transfer links.

- RD.COMM

This routine reads the commodity data.

- RD.FUNCT

This routine reads in the time, cost, and energy functions.

- RD.ICF

This routine reads in the impedance commodity factors.

- RD.LINK

This routine reads the linehaul link input data and structures the entity LINK.

- RD.MODE

This routine reads in the mode names and modal traffic file numbers.

- RD.NAME

This function reads an alpha name and returns it to the calling routine.

- RD.NODE

This routine reads the node input data and structures the entity NODE.

- RD.PARAM

This routine reads the input parameters and options.

- RD.REGION

This routine reads the region input data and structures the entity REGION.

- RD.SHIP

This routine reads the shipment data on each iteration, finds the best path for the shipment, and allocates it to the network links and nodes.

- RD.SIZES

This routine reads the first input network file record which describes the size of each entity for the run of the model.

- RD.TRANSFER

This routine reads the transfer link input data and structures the entity TRANSFER.

- REASSESS

This routine adjusts the volume estimates for all the links and nodes to a value closer to the amount of traffic assigned to the link or node during the preceding iteration.

- RESET

This routine is called by REASSESS to perform the actual mathematics of the volume estimate adjustment based on the input parameter PC.CHANGE.

- SET

This routine is called by ASSESS to compare assigned and estimated volumes for a node or link and to tally elements satisfying the user specified error tolerance.

- SETUP

This routine computes cost, time, and energy use for each node and link, using appropriate functions referenced by node/link class, linehaul link directional factors, and current volume estimates.

- SNAP.R

This routine displays the current values of various model variables upon the occurrence of an execution error which is detected by the SIMSCRIPT system.

- TIME

This function evaluates a transit time function given node/link class and flow volume.

- TITLE

This routine produces the cover pages.

- TR.OUT

This routine outputs the transfer link portion of the network flow report or flow data file.

- WRT.NAME

This routine outputs an alpha variable.

- ZERO

This routine prepares volume accumulating arrays for succeeding iterations by setting same to zero.

- **SIMSCRIPT Library Routines**

The following routines in the SIMSCRIPT II.5 Library are also referenced:

DATE.R
ARCTAN.F
COS.F
DIM.F
INT.F
MAX.F
MOD.F
REAL.F
SIN.F
SQRT.F

5. PROGRAM USE

This chapter sets forth the procedures required to set up and run the transportation network model computer program. Part one describes input procedures and formats, and part two covers program outputs.

PART I: INPUT

Input Files

The transportation network model (TNM) is designed to accept data from three separate input files, rather than from a single integrated input deck, as illustrated in Figure 5-1. By SIMSCRIPT logical unit number these files are:

Unit 3 -	Title and Options
Unit 5 -	Network File
Unit 7 -	Shipment File

As indicated in the figure, the TNM was written with the intention of receiving a network file prepared by the TNM preprocessor, which is used to update and edit the large data files normally required for this model. For this reason, all input data are assumed by the TNM to be free from error, and no diagnostic capability is provided. Also, the cross-referencing between data types is sequential according to the order in which the data elements are read in, rather than according to user-supplied names or numbers. The TNM preprocessor provides complete network data diagnostics and also performs the sequential cross-referencing task, thus removing a considerable burden from the model user. Appendix D documents the TNM preprocessor program.

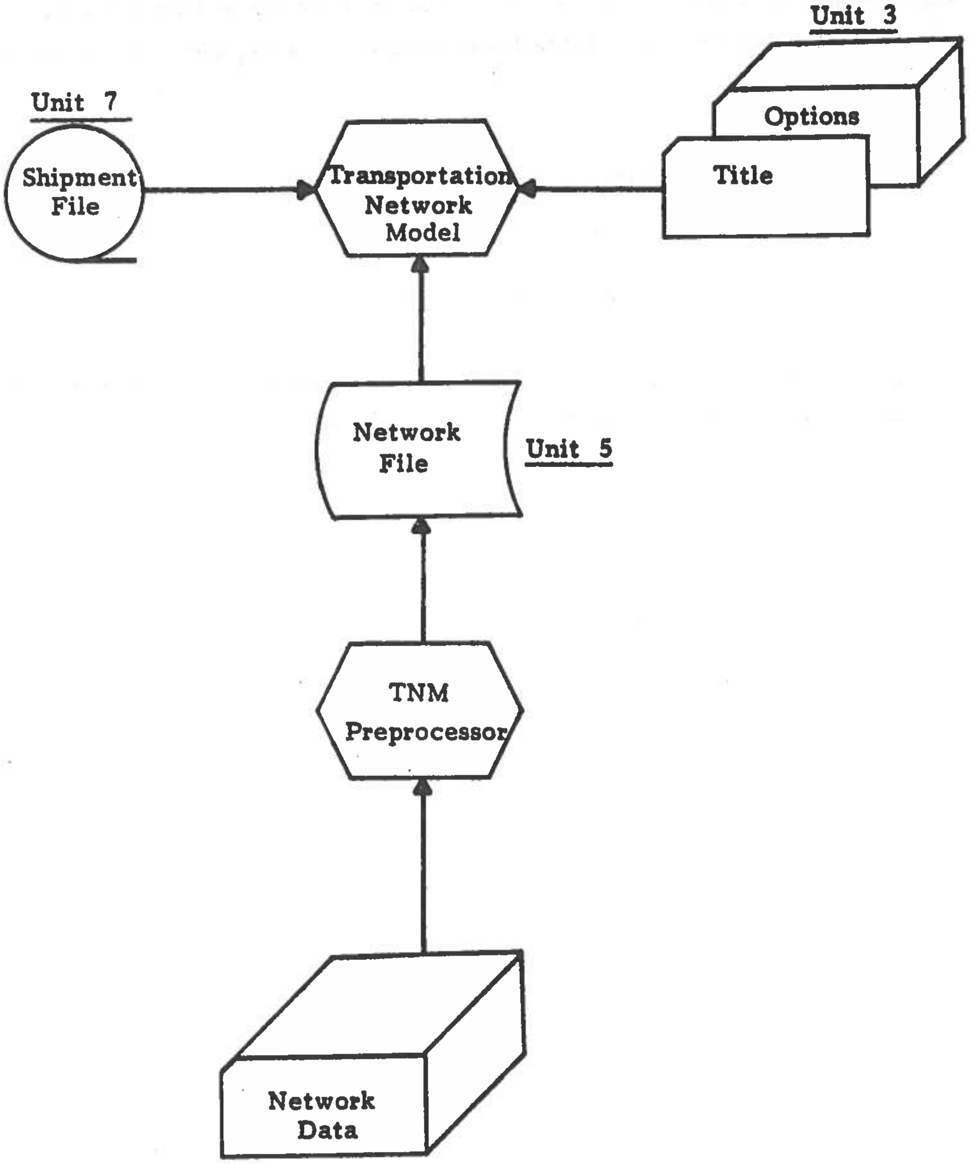


Figure 5-1. Transportation Network Model Input Files

Descriptions of the input card types and data follow. For each card type, an input form which illustrates the record layout is provided. Symbols adjacent to the data fields shown on these forms indicate the required data mode, as follows:

I - integer (fixed point)

F - real (floating point)

A - character (alphanumeric)

All numeric data without a decimal point must be right justified in the field. Names should be left justified.

Title and Options

This file allows free format input of a run title and commonly changed run parameters. The first card is required and contains an 80 character title which will be displayed on each page of the run output. Subsequent cards are optional and are used to change the value of specified run parameters. Each such card contains a code in column 1 designating the parameter to be altered, followed by the desired value in free format. The parameters which can be so altered are as follows:

Code	Description
I	Number of iterations - the maximum number of times the allocation of shipments to network routes is to occur if the convergence criterion is not exceeded. Default value = 1. (Referred to as "n_{max}" in chapter 3.)
C	Convergence criterion - the minimum percentage of all links and nodes which must have assigned volume within the error tolerance of estimated volume in order for the iteration process to be terminated. Default value = 90%. ("F_{min}" in chapter 3.)
T	Error tolerance - the maximum acceptable percentage difference between assigned volume and estimated volume for any link or node. Default value = 10%. ("D_{max}" in chapter 3.)
A	Volume estimate adjustment percentage - between iterations, link and node volume estimates are adjusted as follows: $\text{new estimate} = \text{old estimate} + \frac{A}{100}\left(\text{assigned volume} - \text{old estimate}\right)$ Default value: 75%.
E	Ellipse eccentricity - defines the shape of the inclusion ellipse with origin and destination region centers as the foci. Default value : 0.89. This produces an ellipse whose "width" midway between the foci is about half the distance between the foci, and with a distance along the major axis "beyond" a focus which is about 5% of the distance between the foci.

B	Backup eccentricity - defines the shape of the backup ellipse which is used if the regular ellipse fails to allow even one legitimate path. Default value : 0.5. This produces a nearly circular ellipse with "radius" about equal to the distance between the foci. Both eccentricities must be between zero and one exclusive.
U	Energy units - columns 3 through 7 contain up to a five character name designating the units in which energy use is measured. This name will appear in output reports, and must be consistent with the units used to define the energy functions. The default value is "BTU," indicating that energy use is measured in British thermal units. Other likely choices might include KBTU (thousands of BTU's), BBL (equivalent barrels of petroleum), KWH (kilowatt-hours), JOULE (joules), etc.
O	Output suppression switches - Columns 2 through 16 on this card may be used to suppress certain model outputs. A "1" is entered in the column corresponding to each output to be suppressed. If the card is omitted, all outputs are produced. The outputs which may be suppressed are, by column number: 2 - Input data card images 3 - Region data playback 4 - Node data playback 5 - Linehaul link data playback 6 - Access link data playback 7 - Transfer link data playback 8 - Commodity and impedance commodity factor data playback 9 - Class and function data playback 10- Shipment data playback 11- Node volume estimate adjustments 12- Link volume estimate adjustments 13- Network Flow report 14- Network file 15- Network Flow file 16- Path file

It is not good practice to suppress both the network flow report and the network flow file.

P Playback option - directs the model to read the input data and generate the playback reports, and then terminate. Enter a "1" to select this option.

Network Data

The TNM user will find it very difficult to prepare network inputs following the exacting data specifications for the network file. Accordingly, network file specifications are not given here; instead, network data descriptions are provided according to TNM preprocessor input formats. To remind the user of this, network data forms are annotated with the word "Preprocessor" in the upper right hand corner. The interested user and the programmer will find network file specifications in Appendix D.

Figure 5-2 illustrates the network data file structure. Card types are identified by a letter code appearing in column 1. For input to the preprocessor, the network data must be input in the order shown in the figure. Within a card type, there is no required ordering of records (except for functions; see "F" input format description below).

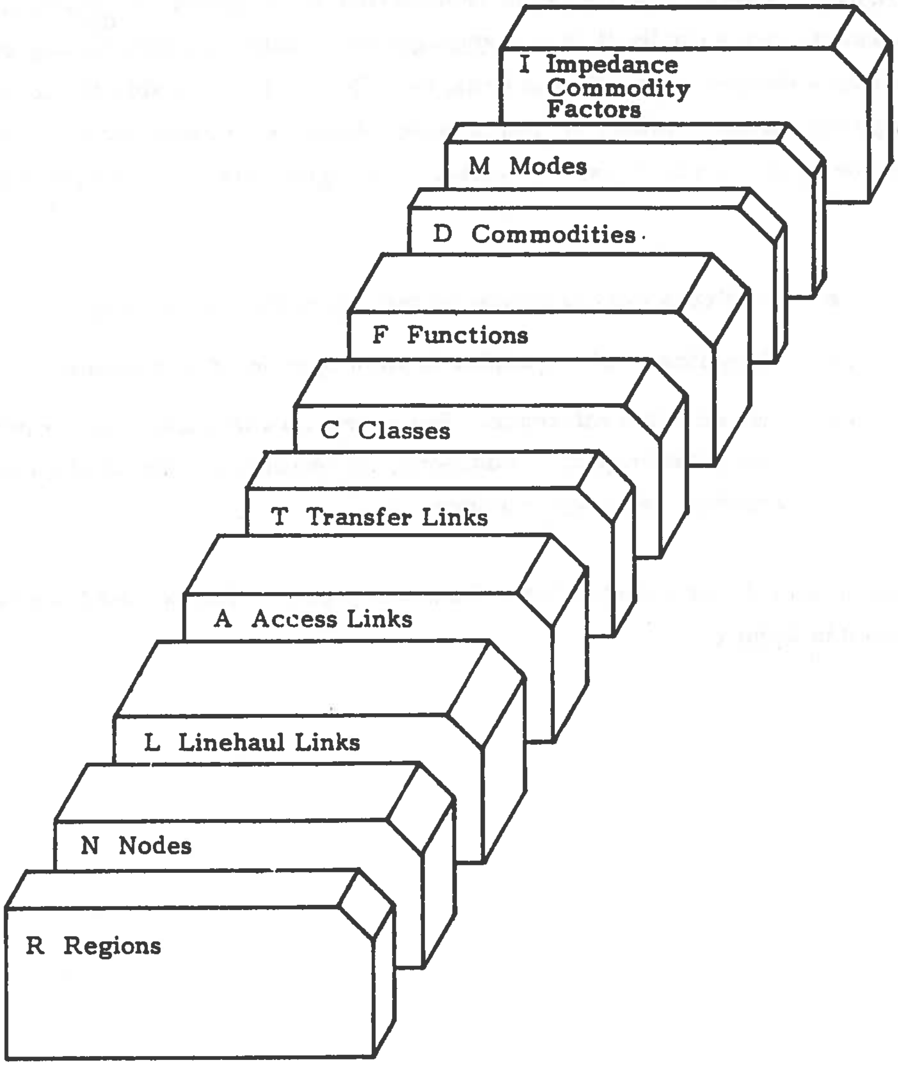


Figure 5-2. Network Data Deck Setup

- "R" Input Format - Regions

All origins and destinations for shipments allocated to the network occur at regions. Though the region is represented by a geographic point on the network, conceptually it is the aggregation of shipment terminating points within a defined area. Access links, described in later, enable the model to replicate transportation of commodities from the source location in the region to the network, or vice versa. The regions are defined to the model by:

- Latitude - of the center of the region (or Y-coordinate)
- Longitude - of the center of the region (or X-coordinate)
- Name - for reference. Ten characters will normally be printed on output reports. Additional spaces may be used on the form to further describe the region.

There must be one Region card for each region. The required format is shown in Figure 5-3.

REGION DATA

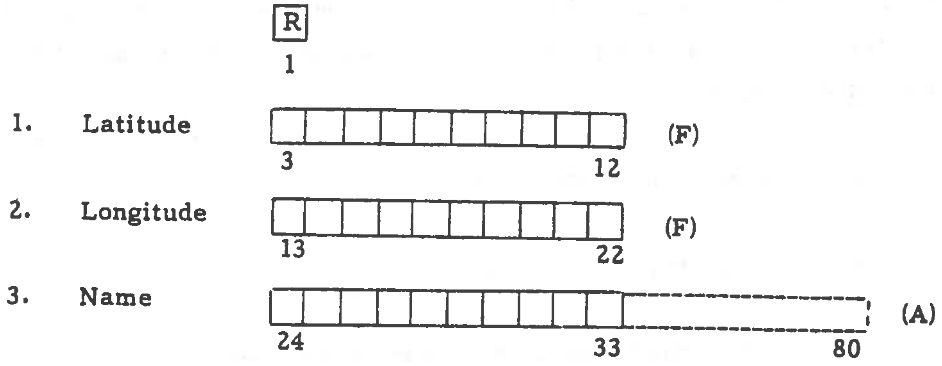


Figure 5-3. Region Input Form

- "N" Input Format - Nodes

Nodes are link end points, and represent locations where links cross and traffic is permitted to switch from one link to another, places where link characteristics change, terminals, and other types of transportation facilities such as waterway locks. Nodes are defined to the model by the following attributes:

- Latitude or Y-coordinate
- Longitude or X-coordinate
- Mode - the transportation mode (water, rail, truck, pipeline) of the facility represented by the node. Enter the first three characters of the mode name (see "M" input format).
- Node class - the class of facility represented by the node. Each class has associated with it three performance functions defining the operating characteristics of all nodes in the class. Enter the class name.
- Initial volume estimate - an estimate of the total traffic, in kilotons, passing through the node; used in conjunction with the node's performance functions, as described in chapter three.
- Name - for reference. Ten characters will normally be printed on output reports. Additional spaces may be used on the form to further describe the node.

There must be one node card for each node in the network. The required format is shown in Figure 5-4.

NODE DATA

		N	1	
1.	Latitude	3	12	(F)
2.	Longitude	13	22	(F)
3.	Mode Name	24	26	(A)
4.	Node Class	28	37	(A)
5.	Initial Volume Estimate	40	48	(F)
6.	Name	50	59 80	(A)

Figure 5-4 Node Input Form

- "L" Input Format - Linehaul Links

Transportation links between two nodes of the same mode are defined as follow:

- A-Node - the node name at one end of the linehaul link
- B-Node - the node name at the other end of the linehaul link
- Length, in miles
- Linehaul link class - the class of linehaul transportation facility represented by the link. Each class has associated with it three performance functions defining the operating characteristics of all links in the class. Enter the class name.
- Initial volume estimate in kilotons - used in conjunction with the link's performance functions, as described in chapter three. Enter the total estimated traffic in both directions.
- Direction Code

Entry	Meaning
Blank	Travel permitted in both directions
AB	Travel permitted A → B only
BA	Travel permitted B → A only
XX	Flag indicating that the "impendance directional factors" (see "C" input format) should be applied to A → B traffic for this link, rather than to B → A traffic.

There must be one linehaul link card for each linehaul link in the network. The required format is shown in Figure 5-5.

LINEHAUL LINK DATA

		L 1	
1.	A-Node Name	3 12	(A)
2.	B-Node Name	13 22	(A)
3.	Length	24 28	(I)
4.	Linehaul Link Class	30 39	(A)
5.	Initial Volume Estimate	41 49	(F)
6.	Directional Code	51 52	(A)

Blank = Two-way link
AB = A → B only
BA = B → A only
XX = Use directional factors for A → B

Figure 5-5. Linehaul Link Input Form

- "A" Input Format - Access Links

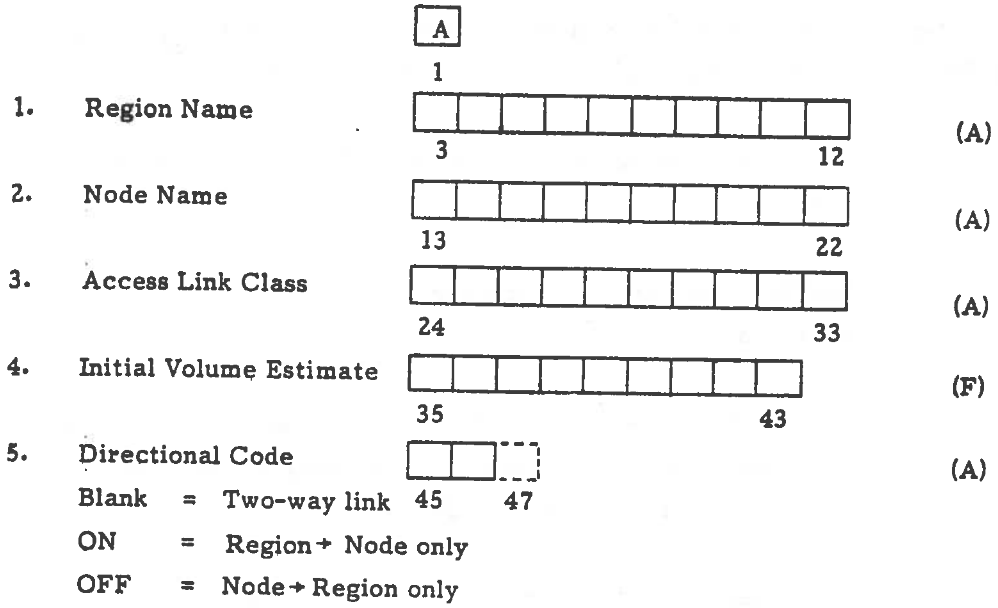
Access links connect regions to network nodes, and enable the model to represent the transportation of commodities from their source location within the region to the network, and from the network to their destination within the region. The input data required to define access links are as follow:

- Region - the name of the region served by the access link
- Node - the name of the network node connected to the region by the access link
- Access link class - the class of access facilities represented by the link. Each class has associated with it three performance functions defining the operating characteristics of all links in the class. Enter the class name.
- Initial volume estimate in kilotons - used in conjunction with the link's performance functions, as described in chapter three. Enter the total traffic expected in both directions.
- Directional code (first two characters significant)

Entry	Meaning
Blank	Travel permitted in both directions
ON	Travel permitted Region → Node only
OFF	Travel permitted Node → Region only

There must be one access link card for each access link in the network. The required format is shown in Figure 5-6.

ACCESS LINK DATA



		A 1	
1.	Region Name	3 – 12	(A)
2.	Node Name	13 – 22	(A)
3.	Access Link Class	24 – 33	(A)
4.	Initial Volume Estimate	35 – 43	(F)
5.	Directional Code	45 – 47	(A)

Blank = Two-way link

ON = Region → Node only

OFF = Node → Region only

Figure 5-6. Access Link Input Form

- "T" Input Format - Transfer Links

Transfer links connect nodes of different modes, and allow for intermodal transfers of commodity shipments. They are defined as follows:

  - From-node - the name of the node on the inbound side of the transfer facility
  - To-node - the name of the node on the outbound side of the transfer facility
  - Transfer link class - each class has associated with it three performance functions, defining the operating characteristics of all links in the class. Enter the class name.
  - Initial volume estimate in kilotons - used in conjunction with the link's performance functions, as described in chapter three.

There must be one transfer link card for each transfer link in the network. The required format is shown is Figure 5-7. Note that transfer links always represent single direction links. Linehaul links and access links can be either bidirectional (the normal case) or, by entering the appropriate directional code, single direction links.

TRANSFER LINK DATA

		T		
		1		
1.	From-node	3	12	(A)
2.	To-node	13	22	(A)
3.	Transfer Link Class	24	33	(A)
4.	Initial Volume Estimate	35	43	(F)

Figure 5-7. Transfer Link Input Form

- "C" Input Format - Classes

All links and nodes belong to a class. Nodes belong to node classes and each link belongs either to a linehaul link class, an access link class, or a transfer link class depending on the type of link. Each class points to a trio of cost, capacity, and energy functions and provides other operational data, as follows:

- Class type code - enter one of the following codes

  N for node classes
  L for linehaul link classes
  A for access link classes
  T for transfer links classes

- Class name - only the first five characters will appear on some output reports

- Cost function - enter the name of the cost function to be used for network elements in this class

- Time function - enter the name of the transit time function to be used for network elements in this class

- Energy function - enter the name of the energy function to be used for network elements in this class

- Capacity, in kilotons - the maximum flow to be permitted for any network element in this class. For linehaul and access links, the total two-way capacity must be specified.

- Impedance directional factors - applies to <u>linehaul links only</u> (type code "L" above). Entries for any other class type will be ignored. Function values (cost, transit time, and energy use) will be adjusted with these factors for traffic traveling in the B→A direction on the linehaul link. Note that the polarity of the adjustment may be reversed for any link by entering "XX" for that links' directional code (see "L" input format). Also, these impedance directional factors are not used for one-way links. Three separate factors may be input, and each factor occupies two data fields, as follows:

Code	Factor for
M or A	cost function
M or A	capacity function
M or A	energy function

  If code "M" is entered, the function value is multiplied by the factor. If code "A" is entered, the factor is added to the function value. If the code field is left blank, no directional adjustment is applied to the function value.

There need not be a unique mapping between classes and functions; any class may reference any function.

There must be four groups of class data, one group for each type of network element. Class names must be unique within groups. Class records with different class type codes may be freely intermingled in the input stream. The required class data format is shown in Figure 5-8.

CLASS DATA

		C	1		
1.	Class Type Code (N, L, A, T)	☐	2		(A)
2.	Class Name	☐☐☐☐☐☐☐☐☐☐	4	13	(A)
3.	Cost Function	☐☐☐☐☐☐☐☐☐☐	14	23	(A)
4.	Time Function	☐☐☐☐☐☐☐☐☐☐	24	33	(A)
5.	Energy Function	☐☐☐☐☐☐☐☐☐☐	34	43	(A)
6.	Capacity, kilotons	☐☐☐☐☐☐☐☐☐	44	52	(F)

7. Impedance Directional Factors (linehaul links only)

	Code (M,A)			Factor for B → A Traffic			
Cost	☐	53	(A)	☐☐☐☐☐☐☐☐	54	61	(F)
Time	☐	62	(A)	☐☐☐☐☐☐☐☐	63	70	(F)
Energy	☐	71	(A)	☐☐☐☐☐☐☐☐	72	79	(F)

Figure 5-8. Class Input Form

- **"F" Input Format - Functions**

Cost, time and energy functions model the relationship between node and link performance and traffic volume. The units assumed for these functions are as follows:

Function Type	Volume (abscissa)	Function Value (ordinate)
Cost	Kilotons	$/Kiloton
Time	Kilotons	hours
Energy	Kilotons	BTU/ton

In addition, for linehaul links, the function values must be specified on a per-mile basis. In this regard, note that $/Kton-mile = mills/ton-mile, hours/mile is the inverse of speed, and BTU/ton-mile is a commonly reported measure of energy use. Further, energy use may be specified in units other than BTU's, if desired. For linehaul and access links, the functions are entered (on the abscissa) with the total two-way link traffic volume.

Two forms of function input, tabular (piecewise linear) and mathematical, are available. In either case the first three data fields for a function are:

- Function type
    - C Cost function
    - T Time function
    - E Energy function
- Function name - must be unique within function type
- Function form
    - T Tabular
    - M Mathematical

Tabular functions are entered as sets of coordinate pairs. Coordinates are input in the following order:

- Volume, in kilotons
- Function value - cost, transit time, or energy use

A separate input form is required for each coordinate pair. These forms must be ordered by increasing volume; i.e., the volume entry on form n must be greater than (or equal to) the volume entry on form n-1. The function name may be omitted on all forms for a single function after the first. Linear interpolation and extrapolation (from the last two points) are used to compute function values for traffic volumes not directly represented by coordinate pairs.

Mathematical functions may have up to five parameters, and are input as follows:

- Code - indicates which of the available mathematical functions is to be used

- Parameter 1 value
- Parameter 2 value
- Parameter 3 value
- Parameter 4 value
- Parameter 5 value

Unused parameter fields are simply left blank. Appendix C catalogs the mathematical functions presently available and provides parameter specifications for each.

There must be at least one function card for each function. The required format is shown in Figure 5-9.

FUNCTION DATA

		F 1	
1.	Function Type (C,T,E)	2	(A)
2.	Function Name	4 13	(A)
3.	Function Form (T,M)	15	(A)

<u>Tabular Function (form "T")</u>

4.	Volume(abscissa) ,Kilotons	21 30	(F)
5.	Function Value (Ordinate) (per mile for linehaul links)	31 40	(F)

<u>Mathematical Function (form "M")</u>

4.	Code	17	(A)
5.	Parameter 1	21 30	(F)
6.	Parameter 2	31 40	(F)
7.	Parameter 3	41 50	(F)
8.	Parameter 4	51 60	(F)
9.	Parameter 5	61 70	(F)

Figure 5-9. Function Input Form

- **"D" Input Format - Commodities**

The general characteristics of commodities to be shipped are defined in terms of a commodity classification scheme. Input data for commodity classes are as follows:

- Code - two-digit identification code. Codes must be assigned sequentially in order of input.
- Impedance weighting factors - values of cost, transit time, and energy use are multiplied by these factors and summed to compute the disutility of routing shipments of this commodity through a particular node or link. Enter these factors with the following units:

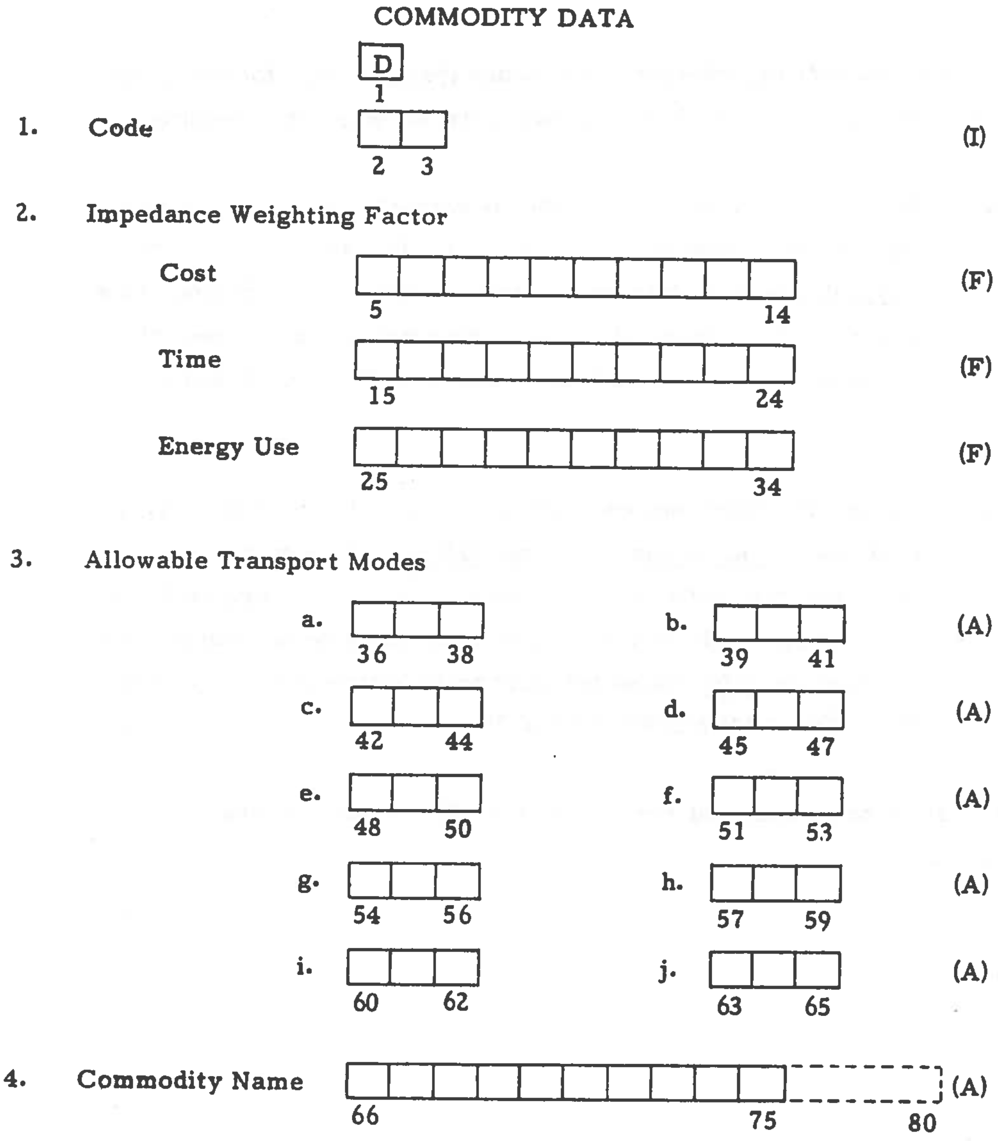
  Cost - impedance units per dollar
  Time - impedance units per Kton-day
  Energy - impedance units per <u>thousand</u> energy units

  These factors may be overridden by values input with a specific shipment, as described later.

- Allowable modes - routes containing nodes of other modes will not be selected for shipments of this commodity. Enter in consecutive fields the first three characters of the name (see "M" input format) of each allowable mode.

- Name - ten characters will be printed on output reports. Additional spaces on the form may be used to further describe the commodity.

There must be one commodity card for each commodity class. The required format is shown in Figure 5-10.



COMMODITY DATA

D
1

1. Code 2 3 (I)

2. Impedance Weighting Factor

Cost 5 14 (F)

Time 15 24 (F)

Energy Use 25 34 (F)

3. Allowable Transport Modes

a. 36 38 b. 39 41 (A)

c. 42 44 d. 45 47 (A)

e. 48 50 f. 51 53 (A)

g. 54 56 h. 57 59 (A)

i. 60 62 j. 63 65 (A)

4. Commodity Name 66 75 80 (A)

Figure 5-10. Commodity Input Form

"M" Input Format - Modes

Most of the data defining transportation modes are input with the node, link, class, and function data. The following additional information is required:

- Modal traffic file - if a number is entered here it is used as the logical unit number of an output file which will contain origin/destination data for all traffic shipped by this mode (see part two of this chapter). Enter any unused odd-numbered unit in the range 1-99, (the model uses units 3, 5, 7, 9,13, 15, and 17).

- Name - 75 characters are available to describe the mode, but *the first three characters must be unique*, as they are used to reference the mode on other input forms. It is suggested that the first three characters of the mode name be an abbreviation and that the *fifth* character start an elaborate name, e.g., "HWY U.S. HIGHWAY NETWORK (1972)".

There must be one mode card for each mode. The required format is shown in Figure 5-11.

MODE DATA

		M 1	
1.	Modal Traffic File	☐☐ 3 4	(I)
2.	Name	☐☐☐ 6 8 80	(A)

Figure 5-11. Mode Input Form

- **"I" Input Format - Impedance Commodity Factors**

Impedance commodity factors, which are optional, are used to adjust the cost, time, and energy functions for a node or link class upward or downward to account for specific commodity related operating differences. The first three data fields identify the commodity and facility class for which adjustments are desired, as follows:

- Commodity code
- Class type code (see "C" input format)
  N - node class
  L - linehaul link class
  A - access link class
  T - transfer link class
- Class name

The adjustment factors are input next. Each factor occupies two data fields, as follows:

Code	Factor for
M or A	cost function
M or A	time function
M or A	energy function

If code "M" is entered, the function values are multiplied by the factor. If code "A" is entered, the factor is added to the function values. If the code field is left blank, no commodity adjustment is applied to the corresponding function.

There must be one impedance commodity factor card for each commodity-facility class combination for which adjustments are desired. The required format is shown in Figure 5-12.

IMPEDANCE COMMODITY FACTOR DATA

I
1

1.	Commodity Code	☐☐ 3 4	(I)
2.	Class Type Code (N,L,A,T)	☐ 6	(A)
3.	Class Name	☐☐☐☐☐☐☐☐☐☐ 8 17	(A)
4.	Impedance Commodity Factors		

	Code (M,A)		Factor	
Cost	☐ 19	(A)	☐☐☐☐☐☐☐☐☐☐ 21 30	(F)
Time	☐ 32	(A)	☐☐☐☐☐☐☐☐☐☐ 34 43	(F)
Energy	☐ 45	(A)	☐☐☐☐☐☐☐☐☐☐ 47 56	(F)

Figure 5-12. Impedance Commodity Factor Input Form

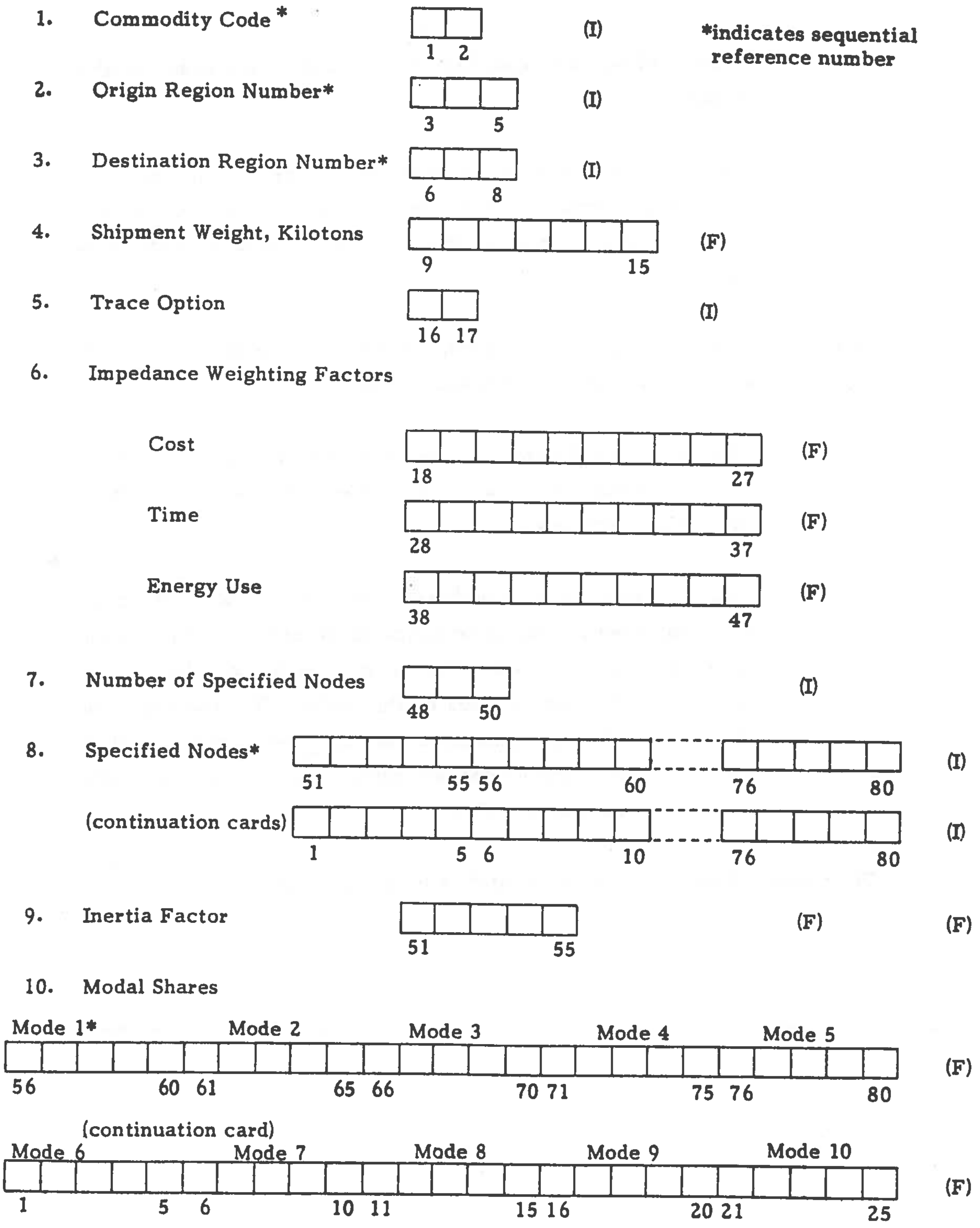
Shipment Data

Interregional commodity flows are input to the TNM on logical unit 7 (see Figure 5-1) as a list of shipments. Since the shipments are not processed by the TNM preprocessor, any references in the shipment records to data elements in the network file must be sequentially oriented, according to the order in which the network elements are read in. These sequential network element reference numbers may be obtained from the TNM preprocessor output reports or from the TNM playback reports.

The contents of each shipment record are as follows:

- Commodity code
- Origin region number -1 = first region defined above,
  2 = second, etc.
- Destination region number -1 = first region defined above
  2 = second, etc.
- Weight of the shipment in kilotons.
- Trace Option - to print the path selected for this shipment. Enter iteration number when traceback is to begin, e.g., "1" begins traceback on the first iteration.
- Impedance weighting factors - enter weighting factors for cost, transit time, and/or energy use to override those specified for the commodity class (see "D" input format). Leave any or all fields blank to accept the weights specified for the commodity class.

SHIPMENT DATA



*indicates sequential reference number

1. Commodity Code* 1 2 (I)
2. Origin Region Number* 3 5 (I)
3. Destination Region Number* 6 8 (I)
4. Shipment Weight, Kilotons 9 15 (F)
5. Trace Option 16 17 (I)
6. Impedance Weighting Factors
   - Cost 18 27 (F)
   - Time 28 37 (F)
   - Energy Use 38 47 (F)
7. Number of Specified Nodes 48 50 (I)
8. Specified Nodes* 51 55 56 60 76 80 (I)

   (continuation cards) 1 5 6 10 76 80 (I)
9. Inertia Factor 51 55 (F) (F)
10. Modal Shares

Mode 1* 56 60 Mode 2 61 65 Mode 3 66 70 Mode 4 71 75 Mode 5 76 80 (F)

(continuation card)

Mode 6 1 5 Mode 7 6 10 Mode 8 11 15 Mode 9 16 20 Mode 10 21 25 (F)

Figure 5-13. Shipment Input Form

If the specified route option is used, the following data elements are required:

- Number of nodes in specified route. Leave blank to inhibit this option.

- Specified nodes - enter in consecutive five-column fields the sequential reference numbers of the nodes which make up the route specified for this shipment. As many cards as needed may be used.

If the specified route option is not used, the inertia option maybe selected, in which case the following data elements are input:

- Inertia factor - fraction (between zero and one, inclusive) of the total shipment which is to be subject to the modal share allocations given below.

- Modal shares - fractions (between zero and one, inclusive) of the above shipment portion to be allocated to specific modes. Enter these shares in consecutive five-column fields, according to the sequential reference numbers of the modes. If there are more than five modes, a continuation card must be provided (even if the shares for these modes are zero). The sum of the modal share fractions must be = 1.0.

The required format for the shipment data is shown in Figure 5-13.

PART II: OUTPUT

The transportation network model simulates interregional freight transportation in sufficient detail to provide a wide range of statistical output data. A series of output reports designed to display the statistics most likely to be of interest to a transportation analyst are described below. Reports which display the model's input data in convenient, readable format are taken up first, followed by a description of the model's standard output reports. The output data files produced by the model are also described.

The output files used by the program are, by SIMSCRIPT logical unit number:

Unit 6 - Standard printed output
Unit 13 - Network file
Unit 15 - Path file
Unit 17 - Network Flow file
Unit 9 - Internal scratch file
As Specified - Modal Traffic files. One such file may be produced for each mode. The unit numbers are specified in the mode data input.

Playbacks of Input Data

- Input Card Echo

The first output of the model is an "echo listing" of the input data cards, excluding the shipment records. An example is given in Figure 5-14.

- Inclusion Ellipse

To get an idea of how much area is being included by the inclusion ellipse, the standard ellipse used during the shipment allocation and the backup ellipse are displayed on the model output cover pages. Asterisks are printed at the foci representing the origin and destination of a shipment. The user can envision these foci as a sample O/D pair and approximate the area of the network which would be included in the shipment allocation. A sample cover page is shown in Figure 5-15.

```
LIBRARY INPUT
=============
   1.        4     3      6    20    16    11     3     9     8     3     3     1
   2.     172.0000    56.0000TITUSVILLE
   3.     165.0000   118.0000PLAINS
   4.     102.0000    78.0000IRONTON
   5.      14.0000    78.0000PORT YORK
   6.      19.0000    78.0000 1    2      40000PE 1
   7.      43.0000    77.0000 1    3      40000SOUTH LD
   8.      58.0000    80.0000 1    1      40000PE 2
   9.      86.0000    92.0000 1    1      40000PE 3
  10.      99.0000    82.0000 1    4      40000BIG J LD
  11.     104.0000    82.0000 1    2     140000PE 4
  12.     146.0000    71.0000 1    1     100000PE 5
  13.     158.0000    68.0000 1    9     100000NORTH LD
  14.     184.0000    65.0000 1    2     100000PE 6
  15.     119.0000    94.0000 1    1      15000PE 7
  16.     142.0000   106.1000 1    1      15000PE 8
  17.     152.0000   115.0000 1    5      15000EAST LD
  18.     166.0000   135.0000 1    2      15000PE 9
  19.      17.0000    80.0000 2    6      10000R PORT YRK
  20.     103.0000    85.0000 2    7      40000R JUNC CTY
  21.     196.0000    70.0000 2    6      65000R TITUSVLE
  22.     162.0000   140.0000 2    6      65000R PLAINSVL
  23.      17.0000    73.0000 3    6      25000P-PORT YRK
  24.     105.0000    72.0000 3    8      70000P-IRONTON
  25.     177.0000    33.0000 3    6      70000P-TITUSVLE
  26.        36     1     2  1     400000
  27.        19     2     3  1     400000
  28.        40     3     4  1     400000
  29.        21     4     5  1     400000
  30.         7     6     5  1     400003
  31.        61     6     7  2    1000000
  32.        19     7     8  2    1000000
  33.        37     8     9  2    1000000
  34.        24     6    10  3     150000
  35.        42    10    11  3     150000
  36.        18    11    12  3     150000
  37.        34    12    13  3     150000
  38.       108    14    15  4     100000
  39.       119    15    16  5     120000
  40.       104    15    17  5     180000
  41.       105    16    17  6     500000
  42.        20    18    19  8     180002
```

Figure 5-14. Input Card Echo

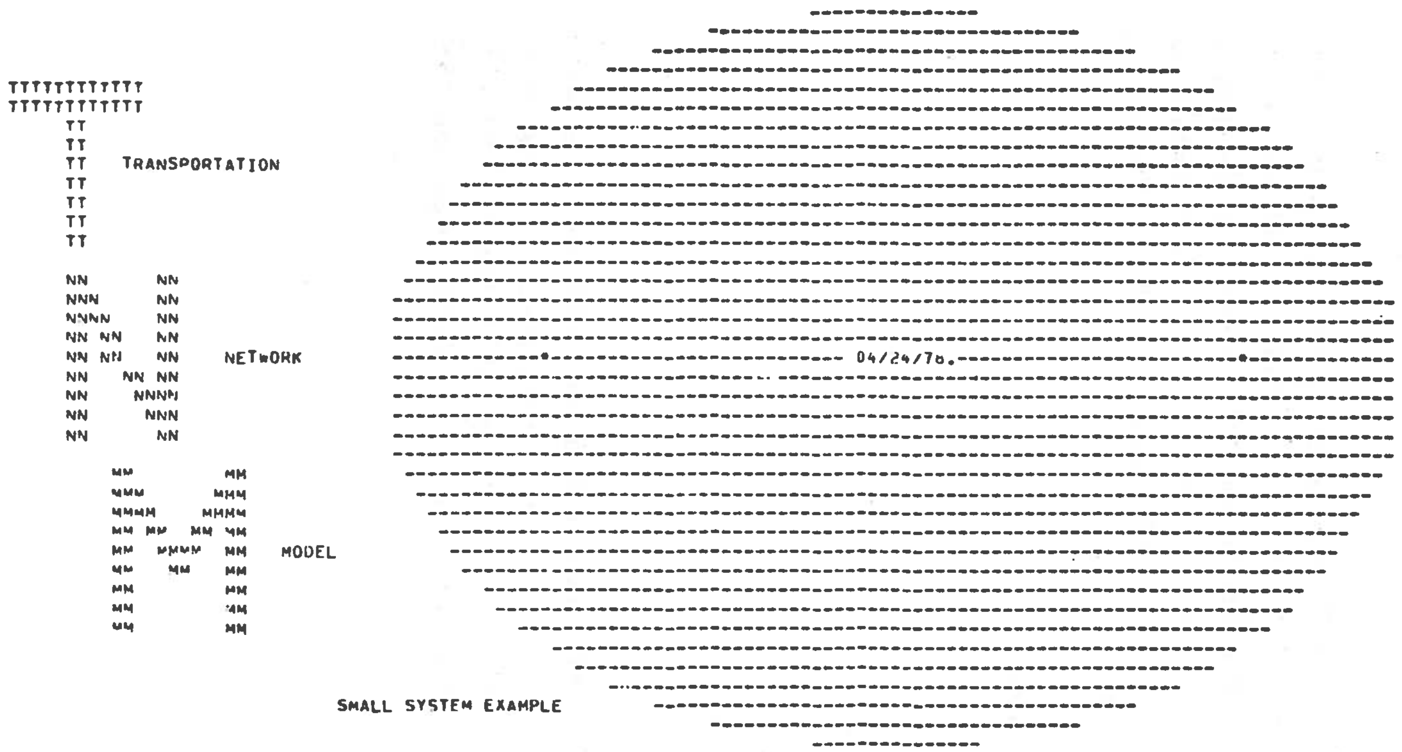


Figure 5-15. Cover Page Showing Inclusion Ellipse

- **Playback Reports**

As the next output function of the model the input data are "played back" in convenient format as a series of reports. These playback reports show exactly how the data supplied by the user were interpreted by the program, which is very useful for detecting data errors; they also provide a hard copy record of the conditions represented in a run of the model. The following nine reports are included:

- System Parameters
- Regions
- Nodes
- Linehaul Links
- Access Links
- Transfer Links
- Commodities
- Classes and Functions
- Shipments

The information contained in these reports has already been described in detail in part one of this chapter, hence these reports are not considered further here. Examples of these reports are given in Figures 5-16 through 5-25. Playback type data displays are also available from the TNM Preprocessor (see Appendix D).

```
                                                    TRANSPORTATION NETWORK MODEL
                                                       SMALL SYSTEM EXAMPLE

S-Y-S-T-E-M  P-A-R-A-M-E-T-E-R-S
================================

 MAXIMUM        LINK, NODE VOLUME                                INCLUSION      BACKUP        VOLUME
 NUMBER OF     CONVERGENCE CRITERION   VOLUME VS. ESTIMATION      ELLIPSE       ELLIPSE       ESTIMATE ENERGY
ITERATIONS      TO STOP ITERATION       ERROR TOLERANCE        ECCENTRICITY  ECCENTRICITY    CHANGE   UNITS
----------     ---------------------   ---------------------   ------------  ------------   -------- ------
     1                80.0                     15.0                .70000        .40000        75.0    BTU



OUTPUTS SELECTED
------- --------

INPUT ECHO                      YES
PLAYBACK REPORTS
  REGIONS                       YES
  NODES                         YES
  LINEHAUL LINKS                YES
  ACCESS LINKS                  YES
  TRANSFER LINKS                YES
  COMMODITIES                   YES
  CLASSES/FUNCTIONS             YES
  SHIPMENTS                     YES
CONTINUE AFTER PLAYBACK ?       YES
NODE VOLUME ESTIMATE CHANGES    YES
LINK VOLUME ESTIMATE CHANGES    YES
NETWORK FLOW REPORT             YES
NETWORK FILE                    YES
NETWORK FLOW FILE               YES
PATH FILE                       YES
```

Figure 5-16. System Parameters Playback

```
                                                    TRANSPORTATION NETWORK MODEL
                                                       SMALL SYSTEM EXAMPLE
  R-E-G-I-O-N-S
  =============

                                                                   CONNECTED
  NAME                      LATITUDE  LONGITUDE  ACCESS LINKS  TO NODES
  ----                      --------  ---------  ------------  --------

1 TITUSVILLE                172.000     56.000          3      P-TITUSVLE
                                                        2      R TITUSVLE
                                                        1      PE 6
2 PLAINS                    165.000    118.000          5      R PLAINSVL
                                                        4      PE 9
3 IRONTON                   102.000     78.000          7      R JUNC CTY
                                                        6      PE 4
4 PORT YORK                  14.000     78.000         10      R PORT YRK
                                                        9      PE 1
```

Figure 5-17.   Region Playback

```
                                                      TRANSPORTATION NETWORK MODEL.
                                                         SMALL SYSTEM EXAMPLE
   N-O-D-E-S
   =========

   NAME          LATITUDE  LONGITUDE MODE CLASS CAPACITY  EST.VOL OUT LINKS  TO NODES
   ----          --------  --------- ---- ----- -------- -------- ---------- --------

 1 PE 1            19.000     78.000 WTR  FLEET 200000.0  40000.0      1     SOUTH LD
 2 SOUTH LD        43.000     77.000 WTR  OPEN  200000.0  40000.0      2     PE 2
                                                                       1     PE 1
 3 PE 2            58.000     80.000 WTR  ZERO  200000.0  40000.0      3     PE 3
                                                                       2     SOUTH LD
 4 PE 3            86.000     82.000 WTR  ZERO  200000.0  40000.0      4     BIG J LD
                                                                       3     PE 2
 5 BIG J LD        99.000     82.000 WTR  LOCK   50000.0  40000.0      5     PE 4
                                                                       4     PE 3
 6 PE 4           104.000     82.000 WTR  FLEET 200000.0 140000.0      1     R JUNC CTY
                                                                       9     PE 7
                                                                       6     PE 5
                                                                       5     BIG J LD
 7 PE 5           146.000     71.000 WTR  ZERO  200000.0 100000.0      7     NORTH LD
                                                                       6     PE 4
 8 NORTH LD       158.000     68.000 WTR  LOCK  150000.0 100000.0      8     PE 6
                                                                       7     PE 5
 9 PE 6           184.000     65.000 WTR  FLEET 200000.0 100000.0      8     NORTH LD
10 PE 7           119.000     94.000 WTR  ZERO  200000.0  15000.0     10     PE 8
                                                                       9     PE 4
11 PE 8           142.000    108.000 WTR  ZERO  200000.0  15000.0     11     EAST LD
                                                                      10     PE 7
12 EAST LD        152.000    115.000 WTR  LOCK   50000.0  15000.0     12     PE 9
                                                                      11     PE 8
13 PE 9           166.000    135.000 WTR  FLEET 200000.0  15000.0     12     EAST LD
14 R PORT YRK      17.000     60.000 RR   RTERM 200000.0  10000.0     13     R JUNC CTY
15 R JUNC CTY    103.000     85.000 RR   CLASS 200000.0  40000.0      2     PE 4
                                                                      15     R PLAINSVL
                                                                      14     R TITUSVLE
                                                                      13     R PORT YRK
16 R TITUSVLE     196.000     70.000 RR   RTERM 200000.0  65000.0     16     R PLAINSVL
                                                                      14     R JUNC CTY
17 R PLAINSVL     162.000    146.000 RR   RTERM 200000.0  65000.0     16     R TITUSVLE
                                                                      15     R JUNC CTY
18 P-PORT YRK      17.000     73.000 P    PIPE  100000.0  20000.0
19 P-IRONTON      105.000     72.000 P    PIPE  100000.0  70000.0      3     PE 4
                                                                      17     P-PORT YRK
20 P-TITUSVLE     177.000     33.000 P    PIPE  100000.0  70000.0     18     P-IRONTON
```

Figure 5-18. Node Playback

```
                                                TRANSPORTATION NETWORK MODEL
                                                   SMALL SYSTEM EXAMPLE

   L-I-N-E  H-A-U-L  L-I-N-K-S
   ===========================

   A-NODE      B-NODE      LENGTH CLASS       CAPACITY DIR  EST.VOL
   ------      ------      ------ -----       -------- ---  -------

 1 PE 1        SOUTH LD        36 *LARGE       200000. TWO  40000.0
 2 SOUTH LD    PE 2            19 *LARGE       200000. TWO  40000.0
 3 PE 2        PE 3            40 *LARGE       200000. TWO  40000.0
 4 PE 3        BIG J LD        21 *LARGE       200000. TWO  40000.0
 5 PE 4        BIG J LD         7 *LARGE       200000. XX   40000.0
 6 PE 4        PE 5            61 *MEDIUM      200000. TWO 100000.0
 7 PE 5        NORTH LD        19 *MEDIUM      200000. TWO 100000.0
 8 NORTH LD    PE 6            37 *MEDIUM      200000. TWO 100000.0
 9 PE 4        PE 7            24 *SMALL       200000. TWO  15000.0
10 PE 7        PE 8            42 *SMALL       200000. TWO  15000.0
11 PE 8        EAST LD         18 *SMALL       200000. TWO  15000.0
12 EAST LD     PE 9            34 *SMALL       200000. TWO  15000.0
13 R PORT YRK  R JUNC CTY     108 DOUBLE TRK   100000. TWO  10000.0
14 R JUNC CTY  R TITUSVLE     119 SINGLE TRK    60000. TWO  12000.0
15 R JUNC CTY  R PLAINSVL     104 SINGLE TRK    60000. TWO  18000.0
16 R TITUSVLE  R PLAINSVL     105 BRANCH        60000. TWO  50000.0
17 P-PORT YRK  P-IRONTON       20 MPIPE         25000. B-A  18000.0
18 P-IRONTON   P-TITUSVLE      32 LPIPE        100000. B-A  70000.0
```

Figure 5-19.   Linkhaul Link Playback

```
                                                    TRANSPORTATION NETWORK MODEL
                                                       SMALL SYSTEM EXAMPLE

     A-C-C-E-S-S  L-I-N-K-S
     ======================

                                                   ACCESS   ACCESS CAPACITY              EST.VOL
           REGION              NODE       MODE     CLASS        (KTONS)          DIR     (KTONS)
       --------------       ----------    ----   --------- ---------------       ---     -------

  1      1 TITUSVILLE       PE 6          WTR    LOCAL TRUK     200000.0         TWO    100000.0
  2      1 TITUSVILLE       R TITUSVLE    RR     IND SWITCH     200000.0         TWO     61000.0
  3      1 TITUSVILLE       P-TITUSVLE    P      GATHER         200000.0         ON      70000.0
  4      2 PLAINS           PE 9          WTR    LOCAL TRUK     200000.0         TWO     15000.0
  5      2 PLAINS           R PLAINSVL    RR     IND SWITCH     200000.0         TWO     66000.0
  6      3 IRONTON          PE 4          WTR    LOCAL TRUK     200000.0         TWO    115000.0
  7      3 IRONTON          R JUNC CTY    RR     IND SWITCH     200000.0         TWO     45000.0
  8      3 IRONTON          P-IRONTON     P      GATHER         200000.0         OFF     55000.0
  9      4 PORT YORK        PE 1          WTR    LOCAL TRUK     200000.0         TWO     40000.0
 10      4 PORT YORK        R PORT YRK    RR     IND SWITCH     200000.0         TWO     10000.0
 11      4 PORT YORK        P-PORT YRK    P      GATHER         200000.0         OFF     18000.0
```

Figure 5-20.   Access Link Playback

```
                                          TRANSPORTATION NETWORK MODEL
                                             SMALL SYSTEM EXAMPLE
  T-R-A-N-S-F-E-R  L-I-N-K-S
  ==========================

            FROM NODE  MODE     TO NODE    MODE  CLASS     CAPACITY   EST.VOL
            ---------  ----     ---------  ----  -----    ---------  --------

1           PE 4       WTR      R JUNC CTY RR    WATER-RAI 100000.0        0.
2           R JUNC CTY RR       PE 4       WTR   RAIL-WATE 100000.0        0.
3           P-IRONTON  P        PE 4       WTR   PIPE-WATE 100000.0    1000.0
```

Figure 5-21.   Transfer Link Playback

```
                                                              TRANSPORTATION NETWORK MODEL
                                                                 SMALL SYSTEM EXAMPLE
C-O-M-M-O-D-I-T-I-E-S
=====================

                        IMPEDANCE WEIGHTING FACTORS              PERMISSIBLE
       NAME              COST        TIME        ENERGY             MODES
    ----------       ----------  ----------   ----------        -----------

 1 STEEL                1.000      532.800        0.            WTR RR
 2 GRAIN                1.000      540.000        0.            WTR RR
 3 COAL                 1.000        6.158        0.            WTR RR
 4 FERTILIZER           1.000      109.440        0.            WTR RR
 5 PETROLEUM            1.000       90.288        0.            WTR RR   P
 6 IRON ORE             1.000       12.312        0.            WTR RR
```

Figure 5-22. Commodity Playback

```
                                                  TRANSPORTATION NETWORK MODEL
                                                      SMALL SYSTEM EXAMPLE

IMPEDANCF COMMODITY FACTORS
===========================

              CLASS                       FACTORS
COMMODITY   TYPE  NAME        CUST          TIME         ENERGY
---------   ----  ----    -----------  -----------  -----------

IRON ORE    ACCS  LOCAL   *       .500  *       .500 *-25000.000
```

Figure 5-23.   Impedance Commodity Factor Playback

```
                                                     TRANSPORTATION NETWORK MODEL
                                                        SMALL SYSTEM EXAMPLE
  C-L-A-S-S  F-U-N-C-T-I-O-N-S
  ============================

   NODE          TIME     COST     ENERGY   CAPACITY   LINK         TIME    ADJUSTMT   COST    ADJUSTMT  ENERGY   ADJUSTMT   CAPACITY
   CLASS       FUNCTION FUNCTION FUNCTION  KILOTONS    CLASS      FUNCTION   FACTOR  FUNCTION   FACTOR  FUNCTION   FACTOR    KILOTONS
   ----------  -------- -------- --------  --------    ---------- --------  -------- --------  -------- --------  --------   --------
 1 ZERO            1        1        1     200000.0    WLARGE         8       0. *       8       0. *      5         .8*     200000.0
 2 FLEET AREA      2        2        2     200000.0    WMEDIUM        9       0. *       9       0. *      5         .8*     200000.(
 3 OPEN PASS       3        3        1     200000.0    WSMALL         9       0. *       9       0. *      5         .8*     200000.0
 4 LOCK 1          4        4        3      50000.0    DOUBLE TRK    10       0. *      10       0. *      6        0. *     100000.0
 5 LOCK 2          5        5        3      50000.0    SINGLE TRK    11       0. *      11       0. *      6        0. *      60000.0
 6 RTERMINAL       6        6        4     200000.0    BRANCH        12       0. *      12       0. *      6        0. *      60000.0
 7 CLASS YD        2        7        4     200000.0    LPIPE         13       0. *      13       0. *      7        0. *     100000.0
 8 PIPE TERML      7        2        1     100000.0    MPIPE         14       0. *      14       0. *      7        0. *      25000.0
 9 LOCK 3         17       19        3     150000.0


   ACCESS        TIME     COST     ENERGY   CAPACITY   XFER          TIME     COST     ENERGY   CAPACITY
   CLASS       FUNCTION FUNCTION FUNCTION  KILOTONS    CLASS       FUNCTION FUNCTION FUNCTION  KILOTONS
   ----------  -------- -------- --------  --------    ----------  -------- -------- --------  --------
 1 LOCAL TRUK      2       15        8     200000.0    PIPE-WATER     15        2        1     100000.0
 2 IND SWITCH      2       16        4     200000.0    RAIL-WATER     16       18        1     100000.0
 3 GATHER          7       17        9     200000.0    WATER-RAIL     16       18        1     100000.0


 FUNCTION  -------TIME-----------   -------COST-----------   ------ENERGY------------
  NUMBER   TYPE KTONS/PARA  TIME    TYPE KTONS/PARA $/KTON   TYPE KTONS/PARA BTU  /TON
 --------  ---- ---------- -----    ---- ---------- ------   ---- ---------- ---------

    1       C          0.   0.       C          0.     0.     C          0.   0.

    2       C        24.0   0.       C      1000.0     0.     C       750.0   0.

    3       C          .3   0.       C         3.0     0.     C      1500.0   0.

    4       H         1.0   0.       H        50.0     0.     C      7500.0   0.
                      5.5   0.               100.0     0.
                  50000.0   0.             50000.0     0.

    5       H         1.0   0.       H        10.0     0.     C       300.0   0.
                      1.5   0.                33.0     0.
                  50000.0   0.             50000.0     0.

    6       C        12.0   0.       C      1200.0     0.     C       500.0   0.

    7       C         8.0   0.       C      2500.0     0.     C       150.0   0.
```

Figure 5-24. Class and Function Playback

```
                                                TRANSPORTATION NETWORK MODEL
                                                   SMALL SYSTEM EXAMPLE

S-H-I-P-M-E-N-T-S
=================

                                                                 ----------FACTORS---------------
COMMODITY CODE    ORIGIN     DESTINATION   KTONS  TRACE    COST       TIME     ENERGY    INERTIA  MODAL SPLITS OR SPECIFIED NODES
--------- ----    ------     -----------   -----  ----- ---------- --------- --------- --------  ------------------------------

STEEL       1     3 IRONTON    1 TITUSVIL  13184.0  YES       0.          0.         0.       0.
--- PATH TRACEBACK FOR STEEL       FROM IRONTON    TO TITUSVILLE  ( 13184.0 KTONS)
    PE 6        NORTH LD    PE 5        PE 4
    COST = $  15.190 PER TON     TIME =137.0 HOURS     ENERGY =1820710.40 MBTU
    LINEHAUL DISTANCE =  117 MILES                     DISUTILITY =   18230.53 PER KTON

STEEL       1     3 IRONTON    4 PORT YOR  10000.0  YES       0.          0.         0.       0.
--- PATH TRACEBACK FOR STEEL       FROM IRONTON    TO PORT YORK   ( 10000.0 KTONS)
    R PORT YR   R JUNC CTY
    COST = $  15.996 PER TON     TIME = 86.7 HOURS     ENERGY = 640000.00 MBTU
    LINEHAUL DISTANCE =  108 MILES                     DISUTILITY =   17920.74 PER KTON

GRAIN       2     2 PLAINS     1 TITUSVIL  48500.0  YES       0.          0.         0.       0.
--- LARGE ELLIPSE USED FOR GRAIN      FROM PLAINS     TO TITUSVILLE  ( 48500.0 KTONS)

--- PATH TRACEBACK FOR GRAIN       FROM PLAINS     TO TITUSVILLE  ( 48500.0 KTONS)
    R TITUSVLE  R PLAINSVL
    COST = $  15.391 PER TON     TIME = 78.6 HOURS     ENERGY =4001250.00 MBTU
    LINEHAUL DISTANCE =  105 MILES                     DISUTILITY =   17158.32 PER KTON

GRAIN       2     2 PLAINS     3 IRONTON   18000.0  YES       0.          0.         0.       0.
--- PATH TRACEBACK FOR GRAIN       FROM PLAINS     TO IRONTON     ( 18000.0 KTONS)
    PE 4        PE 7        PE 8        EAST LD     PE 9
    COST = $  15.200 PER TON     TIME =136.5 HOURS     ENERGY =2363760.00 MBTU
    LINEHAUL DISTANCE =  118 MILES                     DISUTILITY =   18271.29 PER KTON

GRAIN       2     4 PORT YOR   1 TITUSVIL       .0  YES       0.          0.         0.       0.
--- PATH TRACEBACK FOR GRAIN       FROM PORT YORK  TO TITUSVILLE  (      .0 KTONS)
    R TITUSVLE  R JUNC CTY  R PORT YRK
    COST = $  18.624 PER TON     TIME =102.6 HOURS     ENERGY =       1.51 MBTU
    LINEHAUL DISTANCE =  227 MILES                     DISUTILITY =   20933.11 PER KTON

GRAIN       2     4 PORT YOR   3 IRONTON        .0  YES       0.          0.         0.       0.
--- PATH TRACEBACK FOR GRAIN       FROM PORT YORK  TO IRONTON     (      .0 KTONS)
    R JUNC CTY  R PORT YRK
    COST = $  15.996 PER TON     TIME = 86.7 HOURS     ENERGY -        .84 MBTU
    LINEHAUL DISTANCE =  108 MILES                     DISUTILITY =   17946.75 PER KTON

COAL        3     1 TITUSVIL   2 PLAINS      795.0  YES       0.          0.         0.       0.
--- LARGE ELLIPSE USED FOR COAL       FROM TITUSVILLE TO PLAINS      (   795.0 KTONS)

--- PATH TRACEBACK FOR COAL        FROM TITUSVILLE TO PLAINS      (   795.0 KTONS)
    R PLAINSVL  R TITUSVLE
    COST = $  15.391 PER TON     TIME = 78.6 HOURS     ENERGY =  65587.50 MBTU
    LINEHAUL DISTANCE =  105 MILES                     DISUTILITY =   15410.81 PER KTON
```

Figure 5-25   Shipment Playback

Standard Output Reports

The statistics which will most likely be of interest to a transportation analyst are presented in four standard output reports, as follows:

- Path Traceback
- Network Flow Report
- Modal Summary Report
- Commodity Summary Report

The output statistics contained in each report are described in the following sections.

- Path Traceback

For shipments with the "TRACE" option set, node names from destination back to origin are listed (for each iteration) when each such shipment is allocated to a path through the network. The commodity name, origin region number, destination region number, and shipment weight are also listed.

Based upon the volume and impedance estimates which were in effect when this path was selected, the following statistics are printed immediately below the path listing:

- Transportation Cost, $/ton
- Transit Time, hours
- Energy Use, millions of energy units
- Total Linehaul Distance, miles
- Total Disutility - weighted sum of cost, time, and energy use.

After the last iteration, and after all node and link impedance estimates have been updated to reflect final traffic flows, the path tracebacks are printed again, so that the final values of the above statistics may be displayed. Figure 5-26 shows a sample path traceback. On the first iteration, traceback reports are interspersed with the shipment playback data.

```
                                                  TRANSPORTATION NETWORK MODEL
                                                     SMALL SYSTEM EXAMPLE

ITERATION #  1   PERCENT CONVERGENCE =  31.25

--- PATH TRACEBACK FOR STEEL       FROM IRONTON    TO TITUSVILLE   ( 13184.0 KTONS)
    PE 6          NORTH LD    PE 5          PE 4
    COST = $  15.198 PER TON     TIME =137.7 HOURS      ENERGY =1820710.40 MBTU
    LINEHAUL DISTANCE =  117 MILES                      DISUTILITY =   18255.76 PER KTON

--- PATH TRACEBACK FOR STEEL       FROM IRONTON    TO PORT YORK    ( 10000.0 KTONS)
    R PORT YRK  R JUNC CTY
    COST = $  15.996 PER TON     TIME = 86.7 HOURS      ENERGY = 840000.00 MBTU
    LINEHAUL DISTANCE =  108 MILES                      DISUTILITY =   17920.74 PER KTON

--- PATH TRACEBACK FOR GRAIN       FROM PLAINS     TO TITUSVILLE   ( 48500.0 KTONS)
    R TITUSVLE  R PLAINSVL
    COST = $  15.254 PER TON     TIME = 78.5 HOURS      ENERGY =4001250.00 MBTU
    LINEHAUL DISTANCE =  105 MILES                      DISUTILITY =   17019.51 PER KTON

--- PATH TRACEBACK FOR GRAIN       FROM PLAINS     TO IRONTON      ( 18000.0 KTONS)
    PE 4          PE 7          PE 8          EAST LD     PE 9
    COST = $  15.240 PER TON     TIME =137.4 HOURS      ENERGY =2363760.00 MBTU
    LINEHAUL DISTANCE =  118 MILES                      DISUTILITY =   18330.71 PER KTON

--- PATH TRACEBACK FOR GRAIN       FROM PORT YORK  TO TITUSVILLE   (       .0 KTONS)
    R TITUSVLE  R JUNC CTY  R PORT YRK
    COST = $  28.596 PER TON     TIME =118.0 HOURS      ENERGY =         1.51 MBTU
    LINEHAUL DISTANCE =  227 MILES                      DISUTILITY =   31250.74 PER KTON

--- PATH TRACEBACK FOR GRAIN       FROM PORT YORK  TO IRONTON      (       .0 KTONS)
    R JUNC CTY  R PORT YRK
    COST = $  15.996 PER TON     TIME = 86.7 HOURS      ENERGY =          .84 MBTU
    LINEHAUL DISTANCE =  108 MILES                      DISUTILITY =   17946.75 PER KTON

--- PATH TRACEBACK FOR COAL        FROM TITUSVILLE TO PLAINS       (   795.0 KTONS)
    R PLAINSVL  R TITUSVLE
    COST = $  15.254 PER TON     TIME = 78.5 HOURS      ENERGY =  65587.50 MBTU
    LINEHAUL DISTANCE =  105 MILES                      DISUTILITY =   15274.31 PER KTON

--- PATH TRACEBACK FOR COAL        FROM TITUSVILLE TO IRONTON      ( 28506.0 KTONS)
    PE 4          PE 5          NORTH LD    PE 6
    COST = $  15.198 PER TON     TIME =137.7 HOURS      ENERGY =3736566.48 MBTU
    LINEHAUL DISTANCE =  117 MILES                      DISUTILITY =   15233.17 PER KTON

--- PATH TRACEBACK FOR COAL        FROM TITUSVILLE TO PORT YORK   ( 18757.0 KTONS)
    PE 1          SOUTH LD    PE 2          PE 3          BIG J LD    PE 4          PE 5          NORTH LD    PE 6
    COST = $  17.068 PER TON     TIME =205.8 HOURS      ENERGY =3054577.45 MBTU
    LINEHAUL DISTANCE =  240 MILES                      DISUTILITY =   17120.79 PER KTON

--- PATH TRACEBACK FOR FERTILIZER FROM IRONTON    TO PLAINS       ( 15001.0 KTONS)
    PE 9          EAST LD     PE 8          PE 7          PE 4
    COST = $  15.240 PER TON     TIME =137.4 HOURS      ENERGY =2076138.40 MBTU
    LINEHAUL DISTANCE =  118 MILES                      DISUTILITY =   15866.19 PER KTON
```

Figure 5-26. Path Traceback Report

- Network Flow Report

Final flow volumes and the disutility values corresponding to these traffic levels are displayed in this report for every node and link in the network with nonzero flow. Since many commodities may use a given node or link, the impedances printed here represent tonnage-weighted averages.

Figure 5-27 is a sample network flow report. The statistics appearing in each section of the report are defined below.

- Nodes. Descriptive data printed for each node include node number, name, mode, and node class (first five characters of the class name). Numerical data are as follows:

  - Capacity, kilotons - as input for the node class.
  - Flow, kilotons - total traffic assigned to the node.
  - Average Disutility Per Kiloton - includes the effects of any commodity adjustment factors.

$$\text{Cost} = \frac{\text{Total transportation cost, \$}}{\text{Flow}}$$

$$\text{Time} = \frac{\text{Total Kiloton-hours}}{\text{Flow}}$$

$$\text{Energy} = \frac{\text{Total energy use}}{\text{Flow}}$$

$$\text{Weighted Sum} = \frac{\text{Total disutility, all shipments}}{\text{Flow}}$$

- Linehaul Links. Descriptive data printed for each link include link number, A-node name, B-node name, mode, link length, and class name. Other outputs provided are as follows:

  - Capacity, Kilotons - as input for the linehaul link class.

  - Direction - identifies the travel direction to which the remaining statistics apply. An asterisk next to the "A B" field indicates that the impedance directional factors for the class were applied to the A→ B direction for this link.

```
                                   TRANSPORTATION NETWORK MODEL
                                      SMALL SYSTEM EXAMPLE

                                       NETWORK FLOW REPORT
                                       ===================

                                              NODES
                                              -----

                                       KILOTONS                 AVERAGE DISUTILITY PER KILOTON
                                                                                 ENERGY
 NO.     NAME       MODE   CLASS     CAPACITY      FLOW       COST($)   TIME(HR)  (KBTU  )    WTD-SUM
 ----  ----------   ----   -----     --------      ----       -------   --------   -------    -------

   1   PE 1         WTR    FLEET     200000.0     40086.0     1000.00     24.00     750.00    1061.11
   2   SOUTH LD     WTR    OPEN      200000.0     40086.0        3.00       .25       0.         3.64
   3   PE 2         WTR    ZERO      200000.0     40086.0        0.        0.         0.         0.
   4   PE 3         WTR    ZERO      200000.0     40086.0        0.        0.         0.         0.
   5   BIG J LD     WTR    LOCK       50000.0     40086.0      252.17     19.20    1500.00     301.05
   6   PE 4         WTR    FLEET     200000.0    172678.0     1000.00     24.00     750.00    1151.95
   7   PE 5         WTR    ZERO      200000.0    117155.0        0.        0.         0.         0.
   8   NORTH LD     WTR    LOCK      150000.0    117155.0       27.83      2.78    1500.00      40.14
   9   PE 6         WTR    FLEET     200000.0    117155.0     1000.00     24.00     750.00    1106.15
  10   PE 7         WTR    ZERO      200000.0     34194.0        0.        0.         0.         0.
  11   PE 8         WTR    ZERO      200000.0     34194.0        0.        0.         0.         0.
  12   EAST LD      WTR    LOCK       50000.0     34194.0       59.76      2.00    1500.00      88.85
  13   PE 9         WTR    FLEET     200000.0     34194.0     1000.00     24.00     750.00    1335.42
  14   R PORT YRK   RR     WTERM     200000.0     10000.0     1200.00     12.00    7500.00    1466.43
  15   R JUNC CTY   RR     CLASS     200000.0     64129.0     2500.00     24.00    7500.00    2593.47
  16   R TITUSVLE   RR     WTERM     200000.0    103424.0     1200.00     12.00    7500.00    1329.86
  17   R PLAINSVL   RR     WTERM     200000.0     49295.0     1200.00     12.00    7500.00    1465.70
  18   P-PORT YRK   P      PIPE      100000.0     13136.0     1000.00      8.00       0.      1030.10
  19   P-IRONTON    P      PIPE      100000.0     14329.0     1000.00      8.00       0.      1030.10
  20   P-TITUSVLE   P      PIPE      100000.0     14329.0     1000.00      8.00       0.      1030.10

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                                             SMALL SYSTEM EXAMPLE

                                              NETWORK FLOW REPORT
                                              ===================

                                               LINE HAUL LINKS
                                               ---------------

                                                                                  AVERAGE DISUTILITY PER TON-MILE
                                       LENGTH            CAPACITY               FLOW    SPEED   COST     TIME      ENERGY   WTD-SUM
 NO.    A NODE       B NODE     MODE   MILES    CLASS    KILOTONS   DIR      KILOTONS   (MPH)  (MILLS)  (MIN.)    (BTU  )   (.001)
 ----  ----------   ----------  ----   ------   -----    --------   ---     ---------   -----  -------  ------   --------   -------

   1   PE 1         SOUTH LD    WTR      36     WLARG    200000.0   B A       40086.0    5.0     5.00   12.000     240.00      5.51
   2   SOUTH LD     PE 2        WTR      19     WLARG    200000.0   B A       40086.0    5.0     5.00   12.000     240.00      5.51
   3   PE 2         PE 3        WTR      40     WLARG    200000.0   B A       40086.0    5.0     5.00   12.000     240.00      5.51
   4   PE 3         BIG J LD    WTR      21     WLARG    200000.0   B A       40086.0    5.0     5.00   12.000     240.00      5.51
   5   PE 4         BIG J LD    WTR       7     WLARG    200000.0   A B       40086.0    5.0     5.00   12.000     240.00      5.51
   6   PE 4         PE 5        WTR      61     WMEDI    200000.0   A B       13164.0    3.0    10.00   19.980     300.00     17.39
                                                                    B A      103471.0    3.0    10.00   19.980     240.00     10.72
   7   PE 5         NORTH LD    WTR      19     WMEDI    200000.0   A B       13164.0    3.0    10.00   19.980     300.00     17.39
                                                                    B A      103471.0    3.0    10.00   19.980     240.00     10.72
   8   NORTH LD     PE 6        WTR      37     WMEDI    200000.0   A B       13164.0    3.0    10.00   19.980     300.00     17.39
                                                                    B A      103471.0    3.0    10.00   19.980     240.00     10.72
   9   PE 6         PE 7        WTR      24     WSMAL    200000.0   A B       16194.0    3.0    10.00   19.980     300.00     11.50
                                                                    B A       16000.0    3.0    10.00   19.980     240.00     17.49
  10   PE 7         PE 8        WTR      42     WSMAL    200000.0   A B       16194.0    3.0    10.00   19.980     300.00     11.50
                                                                    B A       18000.0    3.0    10.00   19.960     240.00     17.49
  11   PE 8         EAST LD     WTR      18     WSMAL    200000.0   A B       16194.0    3.0    10.00   19.980     300.00     11.50
                                                                    B A       18000.0    3.0    10.00   19.980     240.00     17.49
  12   EAST LD      PE 9        WTR      36     WSMAL    200000.0   A B       16194.0    3.0    10.00   19.980     300.00     11.50
                                                                    B A       18000.0    3.0    10.00   19.980     240.00     17.49
  13   R PORT YRK   R JUNC CTY  RR      108     DOUBL    100000.0   B A       10000.0   40.0    12.00    1.500     500.00     12.55
  14   R JUNC CTY   R TITUSVLE  RR      119     SINGL     60000.0   B A       54124.0    6.2    95.80    9.715     500.00     95.89
  15   R TITUSVLE   R PLAINSVL  RR      105     BRANC     60000.0   A B         795.0   16.3    17.66    3.691     500.00     17.67
                                                                    B A       48500.0   16.3    17.66    3.691     500.00     19.04
  17   P-PORT YRK   P-IRONTON   P        20     MPIPE     25000.0   B A       13136.0    1.9     4.80   30.811     150.00      6.80
  18   P-IRONTON    P-TITUSVLE  P        32     LPIPE    100000.0   B A       14329.0     .5    11.69   -1.+02     150.00     19.37

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                                             SMALL SYSTEM EXAMPLE

                                              NETWORK FLOW REPORT
                                              ===================

                                                    ACCESS
                                                    ------

                                                                                  AVERAGE DISUTILITY PER KILOTON
                                            CAPACITY                                                 ENERGY
 NO.  REGION     NODE       MODE   CLASS    KILOTONS    DIR    KILOTONS     COST($)   TIME(HR)    (KBTU  )    WTD.SUM
 ----  ------  ----------   ----   -----    --------    ---    --------     -------   --------     -------    -------

   1     1     PE 6         WTR    LOCAL    200000.0    OUT    103471.0     6000.00     24.00     50000.00    6052.04
                                            200000.0    IN      13164.0     6000.00     24.00     50000.00    6532.80
   2     1     R TITUSVLE   RR     INDUS    200000.0    OUT     54924.0     5500.00     24.00      7500.00    5512.22
                                            200000.0    IN      48500.0     5500.00     24.00      7500.00    6040.00
   3     1     P-TITUSVLE   P      GATHE    200000.0    OUT     14329.0     2000.00      8.00      3750.00    2030.10
   4     2     PE 9         WTR    LOCAL    200000.0    OUT     18000.0     6000.00     24.00     50000.00    6540.00
                                            200000.0    IN      16194.0     6000.00     24.00     50000.00    6108.03
   5     2     R PLAINSVL   RR     INDUS    200000.0    OUT     48500.0     5500.00     24.00      7500.00    6040.00
                                            200000.0    IN        795.0     5500.00     24.00      7500.00    5506.16
   6     3     PE 4         WTR    LOCAL    200000.0    OUT     49514.0     6000.00     24.00     50000.00    6222.17
                                            200000.0    IN     103214.0     6000.00     24.00     50000.00    6145.48
   7     3     R JUNC CTY   RR     INDUS    200000.0    OUT     10000.0     5500.00     24.00      7500.00    6032.80
                                            200000.0    IN      54124.0     5500.00     24.00      7500.00    5512.31
   9     4     PE 1         WTR    LOCAL    200000.0    IN      40086.0     6000.00     24.00     50000.00    6061.11
  10     4     R PORT YRK   RR     INDUS    200000.0    IN      10000.0     5500.00     24.00      7500.00    6032.80
  11     4     P-PORT YRK   P      GATHE    200000.0    IN      13130.0     2000.00      8.00      3750.00    2030.10

DOT/TRANSPORTATION SYSTEMS CENTER         TRANSPORTATION NETWORK MODEL                           PAGE  19
                                             SMALL SYSTEM EXAMPLE

                                              NETWORK FLOW REPORT
                                              ===================

                                                TRANSFER LINKS
                                                --------------

                                                                                   AVERAGE DISUTILITY PER KILOTON
                 FROM NODE             TO NODE                        KILOTONS                                ENERGY
 NO.          NAME       MODE        NAME      MODE   CLASS    CAPACITY      FLOW      COST($)   TIME(HR)   (KBTU  )   WTD.SUM
 ----     ----------     ----     ----------   ----   -----    --------   --------     -------   --------    -------   -------

   3      P-IRONTON      P        PE 4          WTR   PIPE-    100000.0     1193.0     1000.00     16.00        0.      1060.19
```

Figure 5-27.   Network Flow Report

  - Flow, Kilotons - total traffic allocated to the link in this direction.

  - Speed, mph - weighted (by tonnage) average travel speed on the link in this direction. Computed as the inverse of the average transit time.

  - Average Disutility Per Ton-Mile - includes the effects of any directional and commodity adjustment factors.

$$\text{Cost} = \frac{\text{Total transportation cost, \$}}{\text{Flow x Length}}$$

$$\text{Time} = \frac{\text{Total kiloton-hours x 60}}{\text{Flow x Length}}$$

$$\text{Energy} = \frac{\text{Total energy use}}{\text{Flow x Length}}$$

$$\text{Weighted Sum} = \frac{\text{Total disutility, all shipments}}{\text{Flow x Length}}$$

- <u>Access Links</u>. Access links are identified by link number, region number, node name, mode, and access link class. The remaining data are exactly the same as that provided for nodes, with the exception that flow and disutility values are reported by flow direction. "OUT" indicates flow out of the region onto the network, while "IN" indicates the reverse flow.

- <u>Transfer Links</u>. Identification data include link number, "From Node" name and mode, "To Node" name and mode, and transfer link class. The remaining items are exactly the same as those defined for nodes.

- Modal Summary Report

This output report summarizes the data contained in the previous report. Summary statistics are provided for each mode of transportation, broken down by type of network element and by facility class. A separate table presents summary data for transfer links. Totals for the entire network appear in the last line of the report.

A sample modal summary report is shown in Figure 5-28. The statistics contained in each section of the report are described below.

- Nodes. For each node class, the following data are printed:
    - Node Class - the number and name of the class.
    - Total Nodes - the total number of nodes in the class.
    - Percent Used - the percent of nodes in the class with nonzero flow.
    - Capacity, Kilotons - as input for the class.
    - Average Flow, Kilotons - total traffic allocated to nodes of this class divided by number of used nodes. Note that this statistic excludes nodes with zero flow.
    - Average Disutility Per Kiloton - total disutility values, as defined below, divided by total flow for all nodes in the class.
    - Total Disutility - summations over all nodes in the class of:
        - Cost, $ thousands
        - Transit time, Kiloton-days
        - Energy use, Billions of energy units
        - Weighted sum, computed using individual commodity or shipment impedance weighting factors, and reported in thousands of impedance units.

```
                                        TRANSPORTATION NETWORK MODEL
                                           SMALL SYSTEM EXAMPLE

                                        MODAL SUMMARY REPORT - WTR
                                        ==========================

                                                  NODES
                                                  -----

                                                                AVG DISUTILITY PER KTON            TOTAL     DISUTILITY
   CLASS            TOTAL                    KILOTONS                                 ENERGY                  KTON      ENERGY      WEIGHTED
 NO.      NAME      NODES      USED     CAPACITY    AVG. FLOW    COST($)   TIME(HR)  (KBTU  )    COST ($K)    DAYS      BBTU        SUM(000)
 ---   ----------   -----     ------    --------    ---------    -------   --------  -------     ---------   -------    ------      --------

   1   ZERO             5      100.0    200000.0      53143.0         0.         0.         0.           0.         0.       0.            0.
   2   FLEET AREA       4      100.0    200000.0      91028.2    1000.00      24.00     750.00     364113.0 364112.9     273.1       416706.
   3   OPEN PASS        1      100.0    200000.0      40086.0       3.00        .25         0.        120.3    417.6       0.           145.
   4   LOCK 1           1      100.0     50000.0      40086.0     252.17      19.20    1500.00      10108.4  32060.7      60.1        12067.
   5   LOCK 2           1      100.0     50000.0      34194.0      59.76       2.08    1500.00       2043.3   2965.9      51.3         3038.
   9   LOCK 3           1      100.0    150000.0     117155.0      27.83       2.78    1500.00       3261.0  13587.3     175.7         4703.

 SUBTOTALS             13      100.0    173076.9      66257.6     440.76      11.51     650.42     379646.0 413144.4     560.2       436661.

                                               LINEHAUL LINKS
                                               --------------

                                                              AVG     AVG PER TON/MILE              TOTAL     DISUTILITY
  CLASS           TOTAL    TOTAL     USED        KILOTONS         MTON- SPEED    COST  TIME ENERGY                 KTON      ENERGY      WEIGHTED
NO.     NAME      LINKS    MILES     MILES   CAPACITY AVG FLOW    MILES (MPH)   MILLS (MIN.) BTU      COST ($K)    DAYS      BBTU        SUM(000)
--- ----------    -----   ------    ------   -------- --------    ----- ------  ------ ------ ----    ---------   -------   -------    ----------

  1 WLARGE           5      123     100.0    200000.  40086.0      4931   5.0    5.00 12.000  240.     24652.9    41088.     1183.        27164.
  2 WMEDIUM          3      117     100.0    200000. 117155.0     13707   3.0   10.00 19.980  247.    137071.3   190186.     3382.       157259.
  3 WSMALL           4      118     100.0    200000.  34194.0      4035   3.0   10.00 19.980  268.     40348.9    55984.     1083.        59127.

SUBTOTALS           12      358     100.0    200000.  63331.3     22673   3.3    8.91 18.245  249.    202073.2   287259.     5649.       243550.

                                                 ACCESS LINKS
                                                 ------------

                                                                AVG DISUTILITY PER KTON            TOTAL          DISUTILITY
   CLASS            TOTAL                    KILOTONS                                 ENERGY                  KTON      ENERGY      WEIGHTED
 NO.      NAME      LINKS      USED     CAPACITY     AVG FLOW    COST($)   TIME(HR)  (KBTU  )    COST ($K)    DAYS      BBTU        SUM(000)
 ---   ---------    -----     ------    --------    ---------    -------   --------  -------     ---------    ----      ------      --------

   1   LOCAL TRUK       4      100.0     200000.       86041.    6000.00      24.00 50000.00    2064978.0  344163.     17208.      2117349.

 SUBTOTALS              4      100.0     200000.       86041.    6000.00      24.00 50000.00    2064978.0  344163.     17208.      2117349.

MODE TOTALS         (TOTAL KTONS =   172678.)                                                  2646697.1 1044566.     23417.      2797560.
```

Figure 5-28. Modal Summary Report

- Linehaul Links. for each linehaul link class, the following summary statistics are provided:

  - Link Class - the number and name of the class.
  - Total Links - the total number of links in the class.
  - Total Miles - the total mileage of linehaul transportation facilities represented by links of this class. For two-way links, the mileage is counted only once, i.e., the mileage figure printed here is nondirectional. Any facility represented as two one-way links, however, will have its length included twice in the class mileage.
  - Percent Used Miles - the percentage of total link miles in the class which carry nonzero flow.
  - Capacity, Kilotons - as input for the class.
  - Average Flow Kilotons - the weighted average traffic allocated to links of this class, excluding links with zero flow. Link flows are weighted by link length in computing this statistic, to better reflect the spatial characterstics of average link traffic density.
  - Megaton-miles - product of link flow and link length, summed over all links in the class. (Note: the preceding statistic, average kilotons, is computed in the program by dividing kiloton-miles by total used miles.)
  - Average Speed - inverse of average travel time per mile, defined below.
  - Average Disutility Per Ton-Mile - total cost, transit time, and energy use for the class divided by total ton-miles for the class.
  - Total Disutility - as defined above for nodes.

- Access Links. The statistics printed for each class of access links are exactly the same as those printed for node classes, and are defined in the same manner. It will be recalled that access links do not have a length attribute, since they do not necessarily represent single physical facilities. Hence they are treated similarly to nodes for output purposes.

- Mode Totals. Total flow and disutility statistics for the mode are printed at the bottom of each modal summary report. The total kilotons shown are accumulated during the shipment allocation processing; this total is incremented by the amount of a particular shipment the first time that shipment accesses the mode. Hence intermodal shipments appear in the total flow statistics for each mode used.

- Intermodal Transfers. A separate report giving flow and disutility data for transfer links is printed as the last section of the modal summary report. An example is shown in Figure 5-28. The entries in this report are defined in the same manner as those for nodes and access links.

- Network Totals. The last line of the modal summary report provides flow and disutility totals for the entire network, as shown in Figure 5-29. The total kilotons figure given here does not include any double counting.

```
                              TRANSPORTATION NETWORK MODEL
                                 SMALL SYSTEM EXAMPLE

                         MODAL SUMMARY REPORT - INTERMODAL TRANSFERS
                         ===========================================

                                                       AVG DISUTILITY PER KTON              TOTAL           DISUTILITY
 CLASS             TOTAL                 KILOTONS                                ENERGY                  KTON     ENERGY    WEIGHTED
NO.     NAME       LINKS     USED    CAPACITY    AVG FLOW    COST($)   TIME(HR)  (KBTU  )   COST ($K)    DAYS     BBTU      SUM(000)
---  ----------    -----   ------   ----------   --------    -------   --------  -------   ----------    ----     ------    --------

 1   PIPE-WATER        1    100.0     100000.       1193.    1000.00      16.00      .00       1193.0    795.          .        1265

SUBTOTALS              3     33.3     100000.       1193.    1000.00      16.00      .00       1193.0    795.          .        1265


NETWORK TOTALS      (TOTAL KTONS =   249238.)                                              5075960.7 1543265.   33380.    5340759
```

Figure 5-29.   Summary Report for Transfer Links

- **Commodity Summary Report**

A second type of summary report included in the standard model output is shown in Figure 5-30. This report is organized on a commodity basis, and shows how traffic flows and disutilities were split among the various modes. For each commodity, and for the total over all commodities, the following data are provided:

- Commodity - name and two-digit commodity code.
- Mode - name of the mode for which traffic statistics are given in this line. A separate line, labeled "XFER," is provided to summarize intermodal shipments, if any. Hence the totals shown for any single mode do not include that mode's share of intermodal traffic.
- Kilotons - the total quantity of the commodity allocated to this mode. The percentage of tonnage of this commodity which this flow represents follows immediately.
- Megaton-miles - traffic flow (amount and percentage) allocated to this mode as measured on a ton-mileage basis.
- Cost - total cost, $ thousands, accrued by shipments of this commodity using this mode, and the percentage this is of total cost over all modes.
- Kiloton-days - the amount and percentage of travel time and delay incurred by shipments of the commodity allocated to this mode.
- Energy Use - the amount and percentage of energy used by shipments of the commodity allocated to this mode, reported in billions of energy units.
- Total Disutility - weighted sum of cost, transit time, and energy use for this commodity and mode, in thousands of impedance units.

```
                                              TRANSPORTATION NETWORK MODEL
                                                  SMALL SYSTEM EXAMPLE

                                                COMMODITY SUMMARY REPORT
                                                ========================

 COMMODITY                     PER-   MTON-   PER-             PER-     KTON   PER-   ENERGY   PER-     TOTAL     PER-
NO.    NAME    MODE    KTONS   CENT   MILES   CENT  COST($K)   CENT     DAYS   CENT   BBTU     CENT  DISUTILITY   CENT
--- ---------- -------------  -----  ------  -----  --------  -----  -------  -----  -------  -----  ----------  -----

  1 STEEL        WTR   13184   56.9    1543   58.8    200368   55.6    75668   67.7     1821   68.4      240684   57.3
                  RR   10000   43.1    1080   41.2    159960   44.4    36125   32.3      840   31.6      179207   42.7
               TOTAL   23184  100.0    2623  100.0    360328  100.0   111793  100.0     2661  100.0      419891  100.0

  2 GRAIN        WTR   18000   27.1    2124   29.4    274316   27.0   103032   39.4     2364   37.1      329953   28.6
                  RR   48500   72.9    5093   70.6    739828   73.0   158552   60.6     4001   62.9      825447   71.4
               TOTAL   66500  100.0    7217  100.0   1014144  100.0   261584  100.0     6365  100.0     1155399  100.0

  3 COAL         WTR   47263   98.3    7837   98.9    753374   98.4   324439   99.2     6791   99.0      755371   98.4
                  RR     795    1.7      83    1.1     12127    1.6     2599     .8       66    1.0       12143    1.6
               TOTAL   48058  100.0    7920  100.0    765501  100.0   327038  100.0     6857  100.0      767514  100.0

  4 FERTILIZER   WTR   36330  100.0    4394  100.0    545777  100.0   210325  100.0     4903  100.0      568795  100.0
               TOTAL   36330  100.0    4394  100.0    545777  100.0   210325  100.0     4903  100.0      568795  100.0

  5 PETROLEUM    WTR   56708   79.8    6635   88.5    861839   88.2   325467   81.4     7433   95.9      891225   87.9
                   P   13136   18.5     683    9.1     98144   10.0    63280   15.8      201    2.6      103858   10.2
                 XFR    1193    1.7     179    2.4     17434    1.8    10872    2.7      116    1.5       18416    1.8
               TOTAL   71037  100.0    7497  100.0    977417  100.0   399620  100.0     7750  100.0     1013498  100.0

  6 IRON ORE      RR   54129  100.0    6441  100.0   1412793  100.0   232907  100.0     4845  100.0     1415660  100.0
               TOTAL   54129  100.0    6441  100.0   1412793  100.0   232907  100.0     4845  100.0     1415660  100.0

TOTAL, ALL COMMODITIES-
                 WTR  171485   57.3   22532   62.4   2635674   51.9  1038931   67.3    23312   69.8     2786028   52.2
                  RR  113424   37.9   12697   35.2   2324708   45.8   430183   27.9     9751   29.2     2432457   45.5
                   P   13136    4.4     683    1.9     98144    1.9    63280    4.1      201     .6      103858    1.9
                 XFR    1193     .4     179     .5     17434     .3    10872     .7      116     .3       18416     .3

TOTAL, ALL MODES=     299238  100.0   36091  100.0   5075961  100.0  1543265  100.0    33380  100.0     5340759  100.0
```

Figure 5-30. Commodity Summary Report

Output Data Files

In addition to the printed outputs described above, the model also produces four types of output data files. These files, intended for use as input to postprocessors or to other models, are described below.

- Network File

This file is an exact duplicate of the input file, with the exception that all initial volume estimates are replaced by the flows assigned to nodes and links on the last iteration. The main purpose of this file is to provide a convenient means of externally iterating the model, and for time-series simulations. It may also be used in conjuction with the path file to produce special reports. This file is output to SIMSCRIPT logical unit number 13.

- Network Flow File

This file contains the same information as the network flow report, but in machine processable form. The main uses of this file are:

- to permit remote or overnight printing of the network flow report, thus freeing the remote batch terminal for other jobs
- to provide another means of creating new volume estimates for cases where the network file was not created or saved
- to provide a permanent record of the model's detailed network reports
- to provide a source for generating additional hard copies of the network flow report.

The network flow file is output to SIMSCRIPT logical unit number 17. File contents and formats are given in Table 5-1.

Table 5-1. Network Flow File Formats

Variable	Format
Nodes	
Number ("0000" indicates end of node data)	I4
Name	A10
Mode	A3
Class	A5
Capacity	I8
Flow	D(8,1)
Cost	D(7,2)
Time	D(7,2)
Energy	D(7,2)
Weighted Sum	D(7,2)
Linehaul Links	
Number ("0000" indicates end of linehaul link data)	I4
A-node	A10
B-node	A10
Mode	A3
Length	I5
Class	A5
Capacity	I8
Direction	A3
Directional Factor Reversal Flag	A1
Flow	D(8,1)
Speed	D(4,1)
Cost	D(6,2)
Time	D(6,3)
Energy	D(8,2)
Weighted Sum	D(7,2)

Table 5-1. (continued)

Variable	Format
Access Links	
Number ("0000" indicates end of access link data)	I4
Region	I4
Node	A10
Mode	A3
Class	A5
Capacity	I8
Direction	A3
Flow	D(8,1)
Cost	D(7,2)
Time	D(7,2)
Energy	D(7,2)
Weighted Sum	D(7,2)
Transfer Links	
Number ("0000" indicates end of transfer link data)	I4
From node	A10
Mode	A3
To node	A10
Mode	A3
Class	A5
Capacity	I8
Flow	D(8,1)
Cost	D(7,2)
Time	D(7,2)
Energy	D(7,2)
Weighted Sum	D(7,2)

- **Path File**

This file contains detailed path and impedance data for each shipment, based on results for the last iteration, as follows:

- Commodity code
- Origin region number
- Destination region number
- Modes used - ten characters; for ith character, "x" = ith mode used, blank = ith mode not used.
- Weight (kilotons)
- Transportation cost ($ per ton)
- Transit time (hours)
- Energy use (user-specified units)
- Distance (miles)
- Impedance weighting factors
    cost
    time
    energy
- Path traceback - node numbers, in reverse order from destination back to origin.

The file may be used to:

- create special purpose reports
- generate a file of O/D transportation costs
- generate a file for input to minimum path plotting program.

The path file is output to SIMSCRIPT logical unit number 15. Data formats are given in Table 5-2, and a sample file listing appears in Figure 5-31.

- Modal Traffic Files

The transportation network model outputs data which may be used as partial input to a modal simulation model such as the DOT/TSC waterway cost model. The data elements of each record are:

```
 1    3    1X        13184.00   15.20 138    138100 117 1.000E+00 2.220E+01 0.000E+00  4   9   8   7   6
 1    3    4  X      10000.00   16.00  67     84000 108 1.000E+00 2.220E+01 0.000E+00  2  14  15
 2    2    1  X      48500.00   15.25  78     82500 105 1.000E+00 2.250E+01 0.000E+00  2  16  17
 2    2    3X        18000.00   15.24 137    131320 118 1.000E+00 2.250E+01 0.000E+00  5   6  10  11  12  13
 2    4    1  X           .01   28.60 118    151000 227 1.000E+00 2.250E+01 0.000E+00  3  16  15  14
 2    4    3  X           .01   16.00  87     84000 108 1.000E+00 2.250E+01 0.000E+00  2  15  14
 3    1    2  X        795.00   15.25  78     82500 105 1.000E+00 2.565E-01 0.000E+00  2  17  16
 3    1    3X        28506.00   15.20 138    131080 117 1.000E+00 2.565E-01 0.000E+00  4   6   7   8   9
 3    1    4X        18757.00   17.07 206    162850 240 1.000E+00 2.565E-01 0.000E+00  9   1   2   3   4   5   6   7   8   9
 4    3    2X        15001.00   15.24 137    138400 118 1.000E+00 4.560E+00 0.000E+00  5  13  12  11  10   6
 4    3    4X        21329.00   14.87 140    132520 123 1.000E+00 4.560E+00 0.000E+00  6   1   2   3   4   5   6
 5    1    2X  X      1193.00   14.61 219     96950 150 1.000E+00 3.762E+00 0.000E+00  7  13  12  11  10   6  19  20
 5    1    3X        56708.00   15.20 138    131080 117 1.000E+00 3.762E+00 0.000E+00  4   6   7   8   9
 5    1    4   X     13136.00    7.47 116     15300  52 1.000E+00 3.762E+00 0.000E+00  3  18  19  20
 6    1    3  X      54129.00   26.10 103     89500 119 1.000E+00 5.130E-01 0.000E+00  2  15  16
```

Figure 5-31   Sample Path File Listing

Table 5-2. Path File Formats

Variable	Format
Commodity code	I2
Origin region	I4
Destination region	I4
Modes used	A10
Weight	D(8,2)
Transportation cost	D(7,2)
Transit time	I4
Energy use	I10
Distance	I4
Impedance weighting factors	3E(10,3)
Path traceback	
number of nodes in path ("n")	I3
node numbers	nI4

Note: Maximum record length is 132 characters. If there are more than 11 nodes in the path a "+" is written in column 132 and the path is continued starting in column 3 of th next record. As many records as needed to contain the entire path will be output, all but the last containing a "+" in column 132.

- Commodity code - two-digit code.
- Weight in kilotons of the shipment allocated to this mode.
- Beginning node name - first entry point of the shipment on this mode.
- Ending node name - last node of this mode for this route or route segment.

Formats are given in Table 5-3, and a sample output is shown in Figure 5-32.

There may be one traffic file for each mode if desired. These files are output to SIMSCRIPT logical units specified in the "Mode" input data. The beginning and ending node name of each file record mark the boundaries of a route or route segment which is entirely composed of nodes of the specified mode. This file in essence is a mechanism for "tapping off" traffic data for input to a detailed modal simulator, such as port-to-port commodity flows for input to the waterway cost model.

Table 5-3. Modal Traffic File Formats

Variable	Format
Commodity code	I2
Weight	D(8,2)
Beginning node	A10
Ending node	A10

Messages

Four messsages* generated by the TNM may appear in the printed output. These messages are defined below.

- LARGE ELLIPSE USED commodity FROM region TO region (MODE-mode, weight KTONS)

This informational message indicates that the backup inclusion ellipse was invoked for the identified shipment. If the shipment has a nonzero inertia factor, the parenthetical portion of the message, which identifies the shipment fraction for which the message was generated, is also produced. If numerous messages of this type appear, the user should reduce the circuity of the standard inclusion ellipse.

- NO PATHS FOUND FOR commodity FROM region TO region (MODE: mode, weight KTONS)

This error message, which may be found interspersed with the shipment playback data, indicates that no legitimate path could be found for the identified shipment. If the shipment has a nonzero inertia factor, the parenthetical portion of the message, which identifies the shipment fraction for which the message was generated, is also produced. The shipment (or fraction) is then discarded and the next shipment (or fraction) is selected for processing. No statistics for this shipment will be included in the model outputs.

The usual reason for the occurrence of this message is that the inclusion ellipses are too confining. Reducing the ellipse eccentricities should correct the problem. An alternative solution is to increase the density or coverage of network elements (assuming some network detail has been omitted). A second possible cause is that one or more important links have been inadvertantly omitted from the network. Miscoding of node coordinates can also produce this error. Errors of these types can be discovered by inspecting network plots and comparing them with independent network maps.

---

* As noted on the first page of this chapter, the TNM expects to receive error-free data. Hence there are only two bonafide error messages in the program. TNM preprocessor diagnostic messages are given in Appendix D.

```
113184.00PE 4      PE 6
218000.00PE 9      PE 4
328506.00PE 6      PE 4
318757.00PE 6      PE 1
415001.00PE 4      PE 9
421329.00PE 4      PE 1
5 1193.00PE 4      PE 9
556708.00PE 6      PE 4
```

Figure 5-32.   Sample Modal Traffic File

- ROUTE NODE # i IS INVALID FOR commodity FROM region TO region

This error message appears when the specified route option is selected for a shipment and the ith node in the route is not directly connected to the preceding node. The program discards the identified shipment and selects the next shipment for processing. To correct the error, the user must replace the ith node in the specified route with the correct node number, or else add the missing link to the network file.

- ITERATION # n PERCENT CONVERGENCE = xx.xx

This message is produced at the end of each iteration of the shipment routing process. The percentage of links and nodes with assigned volumes adequately close to estimated volumes (i.e., within the error tolerance) is printed. For example, in a network of 3000 nodes and links if 2000 assigned vs. estimated volumes were within the error tolerance on iteration n, a percent convergence of 66.67 would be displayed.

6. SYMBOLS

The Preamble in a SIMSCRIPT program defines all the program entities, their attributes, and the sets which they own and in which they belong. Also defined are functions, releasable routines, and other global variables and arrays. Hence a current listing of the transportation network model program should be consulted for a complete and up to date symbol table.

Following is a description of the key elements of the Preamble.

Permanent Entities

REGION	The highest network division, and the origin/destination points of all shipments. Each region owns a set of VECTOR's called "ENTRY" comprising the access links by which shipments enter or leave the network.
LCLASS	Linehaul Link Class. For each linehaul link, there is a class attribute which points to this entity which in turn points to a cost function, a capacity function, and an energy function.
ACLASS	Similar to LCLASS except pointed to by access links.
NCLASS	Similar to LCLASS except pointed to by nodes.
TCLASS	Similar to LCLASS except pointed to by transfer links.
MODE	Transportation Mode. Basically an attribute of the nodes.

●	TRANSFER	Transfer Link. A one-way link which connects nodes of different modes.
●	ACCESS	Access link. A two-way link which connects nodes to regions.
●	NODE	Link connecting point. Every node defines a geographic point as well as structurally connecting a set of VECTORS called "FLOW".
●	LINK	Linehaul link. A two-way link which permits travel between two nodes of the same mode.
●	COMMODITY	Item to be shipped.

Temporary Entities

●	VECTOR	A one-way linkage between nodes or between node and region. A VECTOR is the storage location for the flow on a transportation link. A LINK, ACCESS, or TRANSFER describes the costing and naming considerations. TRANSFERS may have only one VECTOR, since they are unidirectional by definition.

Sets

●	ENTRY	The set of VECTORS (owned by a REGION) which emanate from the REGION. VECTORS which are directed toward the REGION are filed in "FLOW" sets of NODEs from which they emanate.

•	FLOW	The set of VECTORs (owned by a NODE) which emanate from the NODE. VECTORs which are directed toward the NODE are filed in"FLOW" sets of the NODEs from which they emanate or "ENTRY" sets of the REGIONs from which they emanate. As an example, suppose a NODE has three LINKs connecting it to the network. As LINKs are composed of two VECTORs, the FLOW set for this NODE would be comprised of one VECTOR from each of the LINKs, namely, that VECTOR whose "From Node" is this NODE. The remaining three VECTORs would be filed in FLOW sets of other NODEs or ENTRY sets of other REGIONs, wherever they emanate.
•	SEQ	Sequence table for minimum disutility path algorithm. This corresponds to set "S" in the description of the algorithm in Appendix B. The members of SEQ are NODES, filed in ascending order of disutility to reach the node. The only region appearing in the set, the destination, is represented by a dummy node pointed to by global variable DEST.NODE. Because operations on this set account for a significant portion of the total running time, all set operations are coded in-line rather than using the normal SIMSCRIPT provided subroutines. The efficiency of set operations is further improved by filing 2 dummy nodes as the permanent first and last members, thereby eliminating the need for special handling for operations involving the first and last elements.

System Variables

The following SIMSCRIPT system-defined variables are referenced in the program:

- EOF.V
- LINES.V
- LINE.V
- RCOLUMN.V
- RRECORD.V
- WCOLUMN.V

APPENDIX A. REFERENCES

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APPENDIX B. MINIMUM PATH ALGORITHM

This Appendix defines the mathematical structure and computational procedure of the algorithm used to find least-disutility paths through a multimodal tranportation network.

Problem Definition

Given the network structure defined in the main body of this report, assume that the following quantities are known:

Q_{IJ}^{k} = quantity of commodity k to be shipped from region I to region J in a single shipment

c_i = disutility for traversing node i

c_{ij} = disutility for traversing the link connecting nodes i and j in the i to j direction

For notational convenience, regions I and J may be represented as nodes, with $c_I = c_J = 0$.

Define path P to be an ordered set of nodes, P = (I,a,b,...,i,j,...,x,J), in which each node appears only once, and in which each consecutive pair of nodes i,j are connected by a network link permitting travel in the i to j direction. The disutility of traversing path P may then be defined as:

$$C_P = \sum_{\substack{j \epsilon P \\ j \neq I}} (c_{ij} + c_j)$$

The minimum path problem may then be stated as follows: find path P which minimizes C_P.

Solution Technique

The procedure used in the transportation network model to solve the minimum path problem is a variant of the Moore algorithm (8). The basic principle embodied in the Moore algorithm may be stated as follows: for given origin node I and any node j, the minimum path has cost* C_{Ij}, which may be found from the unique solution of the equations

$$C_{Ij} = \min_{i \varepsilon A_j} \left\{ C_{Ii} + c_{ij} + c_j \right\}$$

$$C_{II} = 0$$

where A_j = set of nodes connected to node j by directed links (i,j)

That is, the cost of the minimum path from node I to node j is calculated as the minimum of the costs of the minimum paths from node I to node i, plus the costs of link (i,j) and node j.

A step-by-step description of the algorithmic expression of this principle follows.

1. Set C_{II} equal to zero. Set all other C_{Ij} equal to some large finite number greater than any possible C_P, say Y. Define set S to be initially empty. Set i = I.

2. Calculate Z_{Ij} for all nodes j connected directly to node i as

$$Z_{Ij} = C_{Ii} + c_{ij} + c_j$$

---

*For convenience, the term "cost" is used interchangeably with "disutility." The actual form of the disutility variable, which includes cost, transit time, and energy-use components, is given in chapter three.

3. If $Z_{Ij} < C_{Ij}$, set C_{Ij} equal to Z_{Ij}, note i as the next node back toward I through which the minimum path from I to j passes, and insert j into S.

4. Select from S the node h having the minimum C_{Ih}. If h = J, stop. Otherwise, set i equal to h, and remove all values h from set S.

5. Go back to step 2.

This algorithm produces for each node j a triplet (j, i, C_{Ij}), where i is the node connected to j through which the minimum path from I to j passes, and C_{Ij} is the cost of this path.

Node Constraints

All nodes j considered for inclusion in any path P must meet the constraints listed below. These requirements are checked at step 2 of the algorithm.

1. Allowable Mode Constraint

$$j \in \{N_k\}$$

where

$\{N_k\}$ = $\{N \mid M(N) \in M_k\}$

$M(N)$ = mode of node N

$\{M_k\}$ = modes by which commodity k may be transported

2. Capacity Constraint

$$q_{ij} + Q_{IJ}^{k} \leq Q_{ij}$$

$$q_j + Q_{IJ}^{k} \leq Q_j$$

where

q_{ij} = volume level currently assigned to link (i,j)

Q_{ij} = physical capacity of link (i,j)

q_j = volume level currently assigned to node j

Q_j = physical capacity of node j

3. Circuity Constraint

$$j \in \{E\}$$

where

$\{E\}$ = set of nodes contained inside the "inclusion ellipse," defined below

Inclusion Ellipse

Assume the centers of the origin and destination regions of a shipment to be the foci of an ellipse of given eccentricity, e. Constraint 3 above states that all nodes considered for inclusion in P must be located inside the geographical space bounded by this ellipse. The following ellipse property is used to evaluate this constraint. The ratio d_f/d_d of the distance from any point n to a focus of the ellipse, d_f, to the distance from point n to the corresponding directrix of the ellipse, d_d, will be : (1) equal to the eccentricity of the ellipse, e, if the point is on the ellipse; (2) greater than e if the point is outside the ellipse; or (3) less than e if the point is within the ellipse. The calculations made to check this condition proceed as follows (see Figure B-1).

The origin (x_1, y_1) and destination (x_2, y_2) of the shipment are the foci of an ellipse with eccentricity e. Arbitrarily selecting the origin focus, the equation of the corresponding directrix line is found. The focal length of the ellipse, f, is the distance from the "center" of the ellipse (x_0, y_0), to one focus, or half of the distance between the foci.

$$f = \frac{1}{2} \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

The semi-major axis is then

$$a = f/e$$

The distance from the center to the directrix is given by

$$d = a/e$$

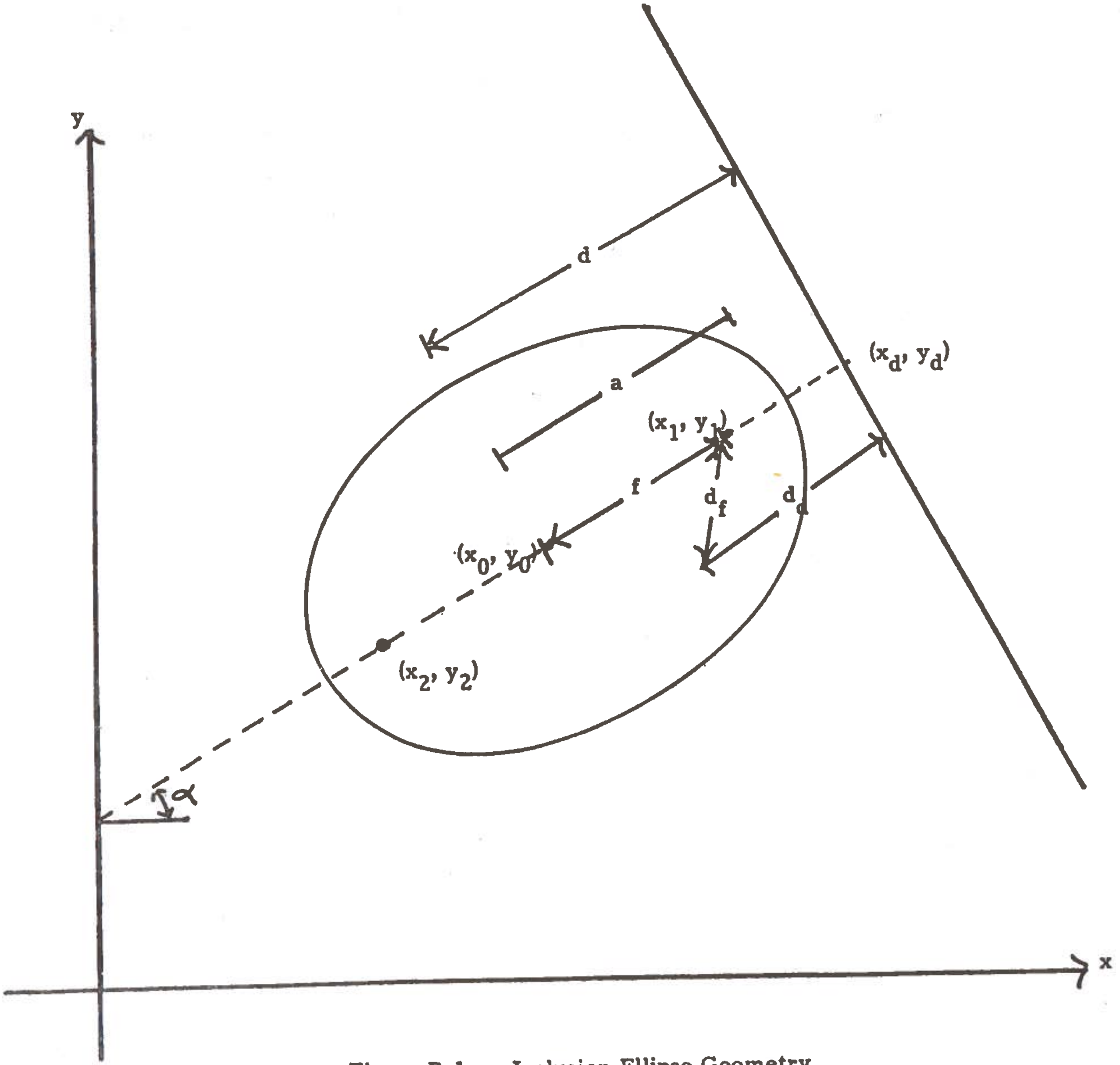


Figure B-1. Inclusion Ellipse Geometry

The location of the center is

$$x_0 = (x_1 + x_2)/2$$

$$y_0 = (y_1 + y_2)/2 .$$

Knowing the location of the center and the distance from that point to the directrix, the point of intersection of the directrix and the semi-major axis (extended) is found. The angle that the ellipse makes with the x-axis is:

$$a = \tan^{-1}\left(\frac{y_2 - y_1}{x_2 - x_1}\right) .$$

The point of intersection, (x_d, y_d) then becomes

$$x_d = x_0 + d \cos a$$

$$y_d = y_0 + d \sin a .$$

The equation of the directrix line is given by

$$y = mx + c$$

or

$$mx - y + c = 0 ,$$

where m is the slope of the line.

Since the slope of the major axis is

$$\frac{y_2 - y_1}{x_2 - x_1} ,$$

the slope of the directrix (normal to the major axis) is the negative inverse, or

$$m = -\frac{x_2 - x_1}{y_2 - y_1} .$$

Thus the equation of the directrix is

$$\left(- \frac{x_2 - x_1}{y_2 - y_1} \right) x - y + c = 0$$

or

$$(x_2 - x_1)x + (y_2 - y_1)\, y + c = 0 .$$

The equation of the directrix is now in the form

$$Ax + By + C = 0 ,$$

where

$$A = x_2 - x_1$$

$$B = y_2 - y_1$$

and C can be found by using the point (x_d, y_d) known to be on the directrix

$$C = -Ax_d - By_d .$$

For every candidate node with coordinates (x_n, y_n), the distance from the node to the focus is found as

$$d_f = \sqrt{(x_n - x_1)^2 + (y_n - y_1)^2} \quad ,$$

and the distance from the node to the directrix as

$$d_d = \frac{Ax_n + By_n + C}{\sqrt{A^2 + B^2}} \quad .$$

Then, if

$d_f/d_d > e$ the node is outside the ellipse ,

$d_f/d_d \leq e$ the node is inside the ellipse .

The computation of square roots can be avoided by testing the equivalent condition

$$d_f^2/d_d^2 \leq e^2.$$

APPENDIX C. FUNCTION SPECIFICATIONS

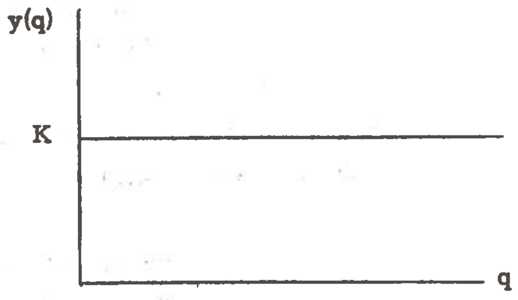
As noted in chapter five ("F" input format), cost, time, and energy functions may be input to the transportation network model in the form of mathematical functions. This appendix provides specifications for those functional forms presently available in the model. New functional forms may be added by supplying a source routine and providing appropriate function references in the COST, TIME, and ENERGY routines. The requisite function specifications will be added to this appendix as new routines become available.

The main restriction to be observed, both in selecting parameter values for input and in adding new functions, is that the function must be defined over the full domain of node/link flows $0 \leq q \leq Q$, where q is the flow and Q is the capacity input for a node or link class.

Specifications for the mathematical functions listed below appear in the following pages. In all cases, y(q) represents the function value at flow volume q. The units assumed for flows and disutilities are given in chapter five.

Type Code	Function Type	Number of Parameters
C	Constant	1
H	Hyperbola	3
P	Parabola	3
D	Double Parabola	5

Code "C" - Constant Function



- **Function Definition**

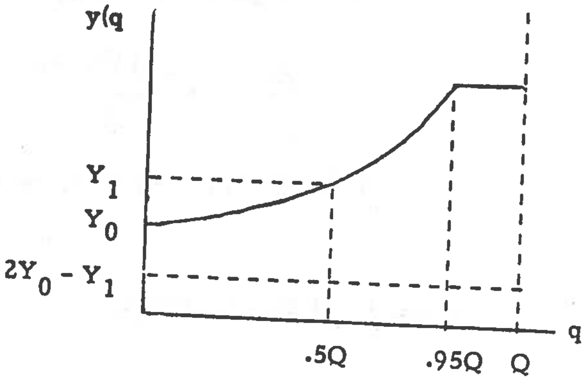
  y(q) = K

- **Input Parameters**

Parameter	Symbol	Definition	Units
1	K	Function value at all flow volumes	Disutility

Code "H" - Hyperbolic Function

- **Function Definition**



$$y(q) = 2Y_0 - Y_1 + \frac{Q\,(Y_1 - Y_0)}{Q - q}\quad,\ 0 \le q \le 0.95Q$$

$$= y(0.95Q) = Y_1 + 18(Y_1 - Y_0)\quad,\ 0.95Q < q \le Q$$

- **Input Parameters**

Parameter	Symbol	Definition	Units
1	Y_0	Function Value at q = 0	Disutility
2	Y_1	Function value at q = 0.5Q	Disutility
3	Q	Capacity; maximum flow volume	Flow

- **Notes**

1. The curved portion of this function is a rectangular hyperbola with asymptotes $q = Q$ and $y(q) = 2Y_0 - Y_1$. To provide protection against creating an overflow condition at high flow volumes, the function is arbitrarily defined to become horizontal for flows exceeding 95% of node/link capacity. The function value for such flows is equal to its value at $q = 0.95Q$.

2. Y_1, which might be thought of as a shape parameter, is restricted to the range $Y_0 \le Y_1 < \infty$. If $Y_1 = Y_0$, the function reduces to $y(q) = Y_0$.

3. The function may be expressed as

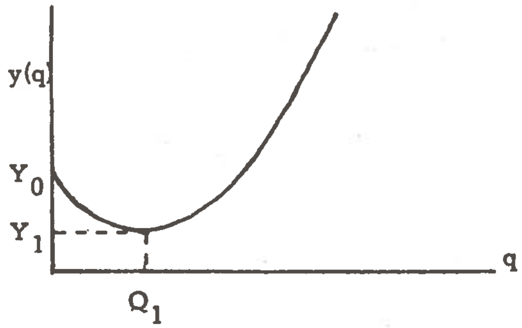
$$y(q) = Y_0 + \frac{q\,(Y_1 - Y_0)}{Q - q} ,$$

which is similar to the formula for delay in a simple queueing system.

Code "P" - Parabolic Function

- Function Definition

$$y(q) = Y_1 + (Y_0 - Y_1)\left(\frac{q - Q_1}{Q_1}\right)^2$$



- Input Parameters

Parameter	Symbol	Definition	Units
1	Y_0	Function value at $q = 0$	Disutility
2	Y_1	Function value at low point	Disutility
3	Q_1	Flow q at which $y(q) = Y_1$	Flow

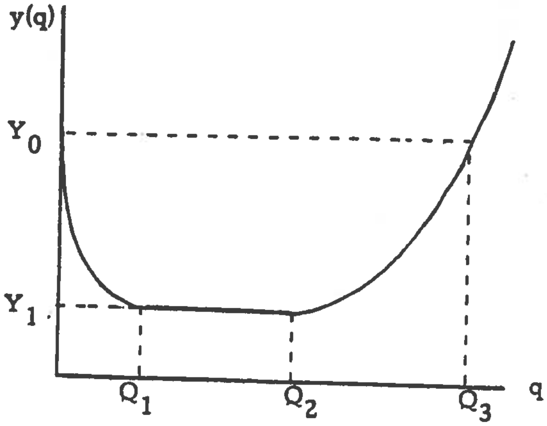
- Notes

1. This function is a vertical parabola with vertex at (Q_1, Y_1).

2. The user should check the function value at flow = capacity, to be sure that an overflow condition will not occur.

Code "D" - Double Parabola

- **Function Definition**



$$y(q) = Y_1 + (Y_0 - Y_1)\left(\frac{q - Q_1}{Q_1}\right)^2 , \quad 0 \leq q < Q_1$$

$$= Y_1 \qquad Q_1 \leq q \leq Q_2$$

$$= Y_1 + (Y_0 - Y_1)\left(\frac{q - Q_2}{Q_3 - Q_2}\right)^2 , \quad Q_2 < q$$

- **Input Parameters**

Parameter	Symbol	Definition	Units
1	Y_0	Function value at $q = 0$	Disutility
2	Y_1	Function value at low point	Disutility
3	Q_1	Minimum q at which $y(q) = Y_1$	Flow
4	Q_2	Maximum q at which $y(q) = Y_1$	Flow
5	Q_3	Flow q at which the second parabolic segment has $y(q) = Y_0$	Flow

- Notes

1. This function is composed of the left half of a vertical parabola with vertex (Q_1, Y_1), the right half of a vertical parabola with vertex (Q_2, Y_1), and an intervening horizontal segment over which $Y(q) = Y_1$. Selecting $Q_2 = Q_1$ deletes the horizontal segment.

2. If $Q_3 = Q_2 + Q_1$, the function will be symmetric.

3. The user should check the function value at flow = capacity, to be sure that an overflow condition will not occur.

APPENDIX D. TRANSPORTATION NETWORK MODEL PREPROCESSOR

The transportation network model preprocessor (TNMPP) is a FORTRAN computer program which updates and edits a library file of network data with formats convenient for the user, and then structures the network file required for input to the TNM. The update capability provides for deletion or modification of existing library records and insertion of new records. A common record format is used for each type of network data for all operations.

The main reason for the use of the TNMPP, as discussed in chapter five, is for conversion of the network file from user-convenient to machine-optimized formats and organization. The TNM uses sequential reference numbers for all system entities, while the user normally wishes to use element labels with some external significance or meaning. The TNMPP performs the tedious job of converting all entity labels and references to the sequential system, and also checks the data for validity. The TNM user may bypass the preprocessor and prepare the network file directly if he wishes, but this is not recommended.

Program Organization and Logic

Figure D-1 illustrates the processing sequence of the TNMPP. The program begins by reading in the preprocessor options and the current network library. Any deletions from, insertions to, or modifications of the library, specified by the user on separate input files, are then processed. Deletions and modifications are made by finding the record in the current library and either marking it for removal or altering it as directed. Insertions are made by simply appending the new record to the appropriate library array. If any delete or modify record cannot be found in the library, the user is notified of this and the next record is selected for processing. If any errors were detected during the library update, the program either terminates or proceeds to the next operation, depending upon the option selected by the user.

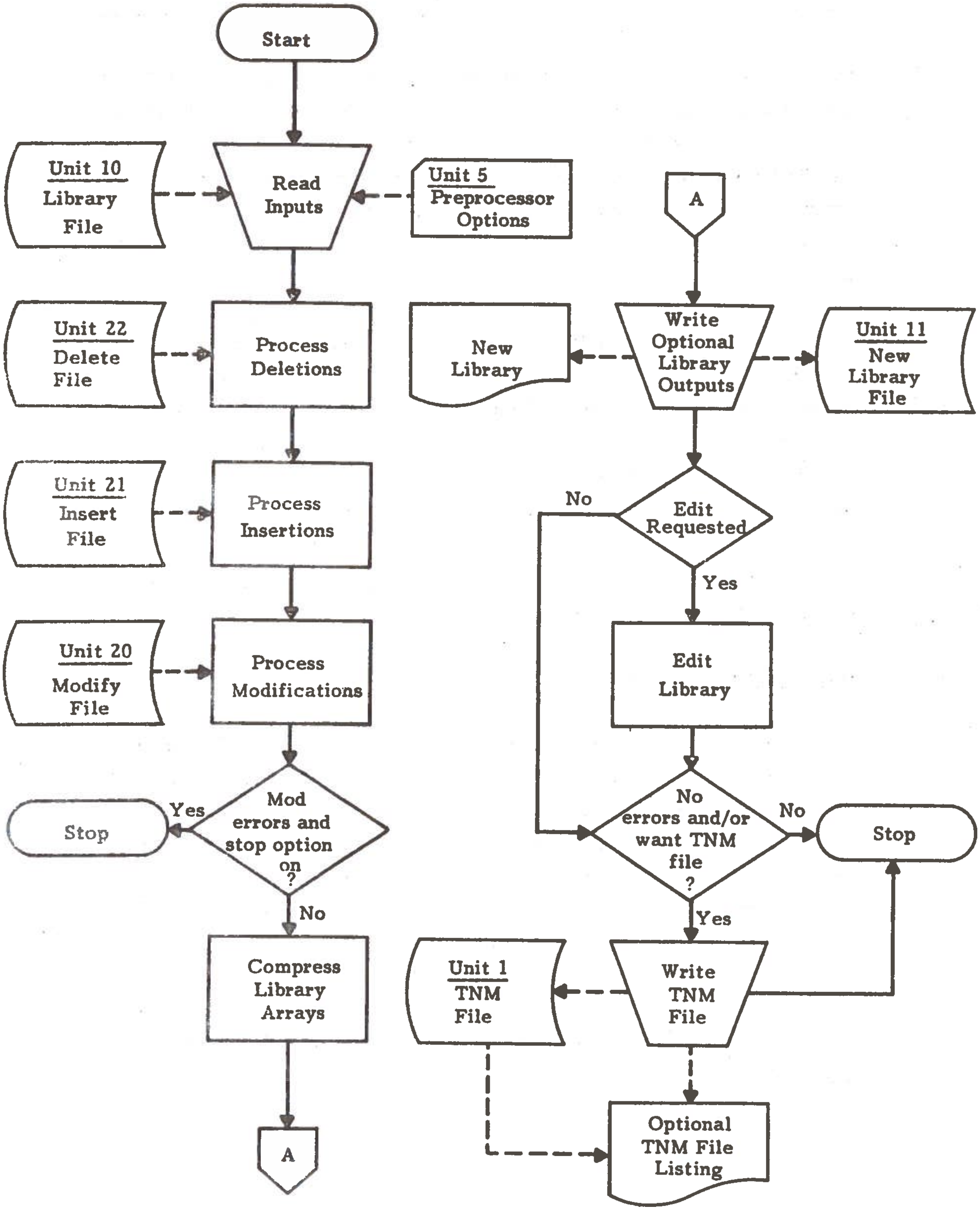


Figure D-1. TNMPP Operational Flow

The program next compresses the library arrays to physically remove from the library all records which were marked for deletion. This is done by writing the library on a scratch file, skipping over the deleted array elements, and then reading the library from the scratch file back into the library arrarys. If requested by the user, the new library is then written to an output file and optionally printed in a series of formatted reports.

If the edit option has been selected, the program next checks the network data elements for the existence of certain properties required for successful execution of the TNM. The edit checks performed are listed in Table D-1. Failure of any edit test causes the display of an appropriate error message and the edit scan continues. Upon completion of the edit, the program either terminates or outputs the TNM network file, depending on the options in effect.

In addition to the edit checks described above, the program checks all records for valid card type and parameter codes upon the initial input of any library, delete, insert, or modify record. Records with invalid codes are ignored during all subsequent operations (and hence will likely cause edit test failures).

Program Description

As with the TNM, the TNMPP is thoroughly documented in the source code listing, which should be consulted for up to data program information. Some general program characteristics are given below.

The TNMPP is written in FORTRAN Extended 4 (FTN4.5 + 410A) for the CDC CYBER 175 computer. Other details of the program operating environment are given in chapter four.

Table D-1. TNMPP Edit Checks

Data Type	Required Conditions
Region	Name must be unique Must have an access link
Node	Name must be unique Mode must be valid Node class must be valid Must have at least two links
Linehaul Link	Must have two valid nodes Node modes must be equal Linehaul link class must be valid
Access Link	Must have a valid region and node Access link class must be valid
Transfer Link	Must have two valid nodes Node modes must not be equal Transfer link class must be valid
Class	Name must be unique within class type Must have valid cost, time, and energy function names
Function	Name must be unique within function type Tabular function records must be sorted by increasing abscissa values
Commodity	Commodity code must be unique Allowable modes must be valid Must have at least one nonzero impedance weighting factor
Mode	No checks
Impendance Commodity Factor	Commodity must be valid Class must be valid

The program uses nine files for various purposes, as illustrated in Figure D-2 and listed below.

Unit	Description
1	Output file for use as input TNM network file
5	Option input
6	Printed output
10	Current library file
11	New library file (if one is to be created)
19	Internal scratch file
20	Modify records
21	Insert records
22	Delete records

Input

- Options

TNMPP options are selected in columns 1-8 of the only card input on unit 5. Leaving a column blank selects the default status for the corresponding option, and entering an "X" turns the option on. The options which may be set are as follows.

Option	Blank (Default)	"X" (select option)
1	No new library file	Create new library file
2	Create TNM network file	Stop after edit
3	Do not list TNM file	List TNM file (card images)
4	Do not list library updates	List library updates (card images)
5	Do not print library	Print library
6	Proceed if update errors occur	Stop if update errors occur
7	Do not create TNM file if edit errors occur	Create TNM file regardless of edit errors
8	Perform edit checks	Skip edit

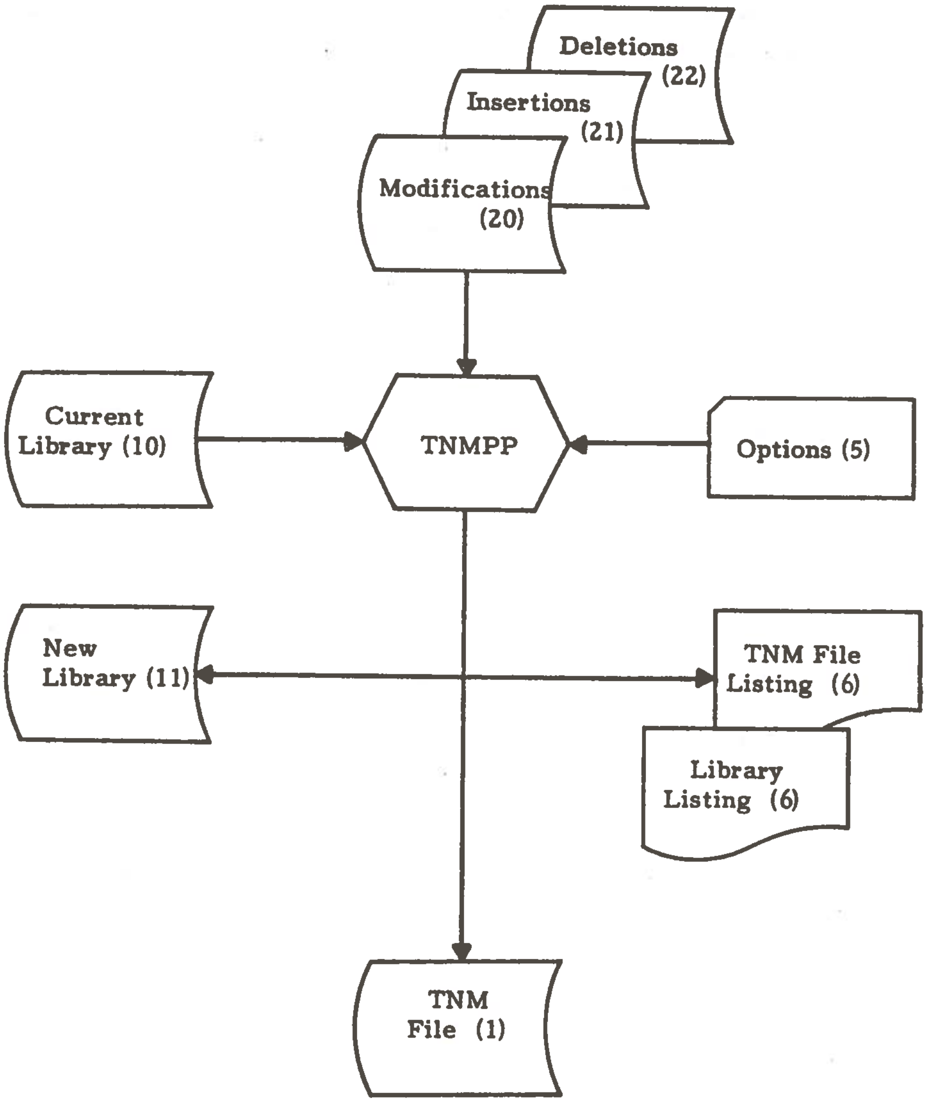


Figure D-2. TNMPP File Structure

It is usually advisable to select option 8 only when recreating a TNM network file from a library file which is already known to be valid. Note also that if options 1 and 5 are left off and option 2 is turned on, the TNMPP run will produce essentially no useful output.

- Library

The deck setup and input formats for the network data appear in chapter five of this report. The required order of the input records is repeated in Table D-2. Within a record type, the records may be input in any order. The only exception is for functions, where all the records for a single tabular function must appear consecutively, sorted by increasing abscissa value (i.e., the points must be input from "left to right" along the curve defining the function).

Table D-2 also shows the current maximum allowable array sizes for various library elements. Exceeding any of these limits will cause program termination.

- Modifications, Insertions, and Deletions

Modify, Insert, and Delete records, input on units 20, 21, and 22, respectively, have exactly the same format as library records. Unlike the library, however, record types may be freely intermingled in these files.

There is a certain minimum amount of information which must be contained in any library update record, as listed in Table D-3. Only the minimum is needed for deletions. Leaving some other key fields blank for insertions or modifications will likely produce edit errors, so complete records should be submitted whenever possible.

Table D-2. TNMPP Network Library Input Data

Input Sequence	Type Code	Description	Maximum Number
1	R	Regions	200
2	N	Nodes	2000
3	L	Linehaul Links	4000
4	A	Access Links	700
5	T	Transfer Links	100
6	C	Classes	200
7	F	Functions	900*
8	D	Commodities	30
9	M	Modes	10
10	I	Impedance Commodity Factors	1500**

---

*Maximum of 300 each of cost, capacity, amd energy function input records.

**Number of records.

Table D-3. TNMPP Library Minimum Record Contents

Code	Description	Minimum Input*
R	Regions	Name
N	Nodes	Name
L	Linehaul Links	A-node, B-node
A	Access Links	Region, Node
T	Transfer Links	From-node, To-node
C	Classes	Type code, Name
F	Functions	Type, Name, Form
D	Commodities	Code
M	Modes	Name (first three characters)
I	Impedance Commodity Factors	Commodity Code, Class type, Class name

---

*In addition to the card type code.

There are four additional restrictions which apply to function records, as follows:

- The required input order for tabular functions must be observed.
- When modifying a function, the function form (mathematical or tabular) cannot be changed. This type of change must be handled as a delete and an insert.
- When modifying a tabular function, the same number of records must be input as there already are in the current function description. For example, if a function has eight coordinate pairs, modification of any pair requires input of all the other pairs as well. The number of points used to define a function can only be altered by processing a delete and an insert.
- When deleting a function, only one card with the minimum function record contents may be input.

Output

- New Library

If a new library file is requested via selection of option 1, the updated library is written on unit 11 in exactly the same format as the input library. Hence this file is directly suitable for input to a subsequent run of the TNMPPP. Note: the new library will not contain any erroneous records* detected during the reading of the old library or the update files. Since this output occurs prior to the library edits, however, any errors detected there will be included in the new library.

---

*Error Messages identifying all such records appear in the printed output.

- **TNM Network File**

The main output of the preprocessor is a network file structured in conformance with the input requirements of the TNM program. This file is written on unit 1 and can be input directly to the TNM. Format specifications for this file appear in Table D-4. Detailed definitions of the various data elements are not provided here, since they are given in chapter five.

- Printed Output

The following optional printed outputs are available from the TNMPPP:

  - Modification, Insertion, and Deletion card images
  - New Library Listing, formatted and labeled
  - TNM Network File card images.

These outputs are self explanatory, so no examples are given here.

- Error Messages

Numerous self explanatory error messages may appear in the printed output. They are of three general types, as follows:

  - Messages identifying library or update records with invalid card type codes. A card image of the bad record is produced, and the record is ignored.
  - Messages indicating that there is no entry in the current library for a record read from the delete or modify file. The bad delete/modify record is identified and then ignored.
  - Edit messages, indicating nonconformance to a required condition listed in Table D-1. The error count is incremented and the data scan continues; a single error can generate several error messages.

Table D-4. Network File Formats

The network file consists of 14 sections which must appear in the order shown. The format for each section is described below. The reader will find it useful to consult the corresponding preprocessor input formats and explanations in chapter 5 in conjunction with this table. "SRN" denotes sequential reference number.

Columns	Description	Data Type
1. Array Sizes	(1 Record)	
1-5	Number of Regions	I
6-10	Number of Modes	I
11-15	Number of Commodities	I
16-20	Number of Nodes	I
21-25	Number of Linehaul Links	I
26-30	Number of Access Links	I
31-35	Number of Transfer Links	I
36-40	Number of Node Classes	I
41-45	Number of Linehaul Link Classes	I
46-50	Number of Access Link Classes	I
51-55	Number of Transfer Link Classes	I
56-60	Number of Impedence-Commodity Factors	I
2. Regions		
1-10	Latitude	F
11-20	Longitude	F
21-30	Name	A
3. Nodes		
1-10	Latitude	F
11-20	Longitude	F
21-22	Mode SRN	I
23-26	Node Class SRN	I
27-35	Initial Volume Estimate	F
36-45	Name	A
4. Linehaul Links		
1-6	Length	F
7-11	A-Node SRN	I
12-16	B-Node SRN	I
17-19	Linehaul Link Class SRN	I
20-28	Initial Volume Estimate	F
29	Direction Code (0=Blank, 1="AB", 2="BA", 3="xx")	I

Table D-4 (continued)

Columns	Description	Data Type
5. Access Links		
1-6	Unused	
7-11	Region SRN	I
12-16	Node SRN	I
17-19	Access Link Class SRN	I
20-28	Initial Volume Estimate	F
29	Direction Code (0=Blank, 1="ON", 2="OFF")	I
6. Transfer Links		
1-6	Unused	
7-11	A-Node SRN	I
12-16	B-Node SRN	I
17-19	Transfer Link Class SRN	I
20-28	Initial Volume Estimate	F
7. Node Classes		
1-4	Time Function SRN	I
5-8	Cost Function SRN	I
9-12	Energy Function SRN	I
13-21	Capacity	F
49-58	Name	A
8. Linehaul Link Classes		
1-4	Time Function SRN	I
5-8	Cost Function SRN	I
9-12	Energy Function SRN	I
13-21	Capacity	F
22	Time Impedance Directional Factor Type (1="A", 2="M")	I
23	Cost Factor Type	I
24	Energy Factor Type	I
25-32	Time Impedance Directional Factor	F
33-40	Cost Factor	F
41-48	Energy Factor	F
49-58	Name	A

9. Access Link Classes - Same format as Node Classes

10. Transfer Link Classes - Same format as Node Classes

Table D-4 (continued)

Columns	Description	Data Type
11. Functions		
(a) Function Header Record:		
1-3	Number of Time Functions	I
4-6	Number of Cost Functions	I
7-9	Number of Energy Functions	I
(b) Function Description Records:		
1-2	Function Type (1=Tabular, 2="C", 3="H", 4="P", 5="D")	I
3-5	Number of points (tabular) or parameters (mathematical)	I
11-17	First abscissa (tabular) or parameter (mathematical)	F
18-24	First ordinate (tabular) or unused, (mathmatical)	F
25-31	Second abscissa/parameter	F
32-38	Second ordinate	F
39-45	Third abscissa/parameter	F
46-52	Third ordinate	F
53-59	Fourth abscissa/parameter	F
60-66	Fourth ordinate	F
67-73	Fifth abscissa/parameter	F
74-80	Fifth ordinate	F
(Note: columns 11-80 are repeated for tabular functions with more than 5 specified points.)		
12. Commodities		
1-2	Commodity Code	I
3-12	Cost Impedance Weighting Factor	F
13-22	Time Impedance Weighting Factor	F
23-32	Energy Impedance Weighting Factor	F
33-42	Allowable Modes - "x" in column i indicates mode (i-32) is allowable, blank indicates not allowed.	A
43-52	Name	A
13. Modes		
1-2	Modal Traffic File Unit Number	I
3-5	Name	A
14. Impedance Commodity Factors		
1-2	Commodity SRN	I
3	Class Type (0="N", 1="L", 2="A", 3="T")	I
4-5	Class SRN	I
6	Cost Factor Code (1="A", 2="M")	I
7	Time Factor Code	I
8	Energy Factor Code	I
9-18	Cost Factor Value	F
19-28	Time Factor Value	F
29-38	Energy Factor Value	F

Two messages with meanings which may not be obvious are defined below.

THE LIMIT HAS BEEN EXCEEDED FOR TYPE code CARDS THE PREPROCESSOR IS NOW TERMINATING . . . ARRAY SIZE MUST BE INCREASED TO PROCEED

This message is generated during the reading of the current library file whenever the number of records of a particular type exceeds the maximum given in Table D-2. This is a fatal error. To correct it, either reduce the amount of detail in the network or alter the dimension specifications in the TNMPP source code.

INSERT RECORD CANNOT BE ADDED DUE TO OVERFLOW OF ARRAY SIZE . . . (Card Image of Insert Record)

This message has a meaning similar to that of the previous message. The insert record is ignored and processing continues. This message is generated before the compression of the network arrays occurs. Hence one possible corrective action is to use one run of the TNMPP to process all deletions, then process insertions in a subsequent run.

Symbols

All variables used in the TNMPP are adequately defined via comments in the source code, which should be consulted for up to date information.

APPENDIX E. MODAL SIMULATORS

The recommended way to generate the cost, time, and energy functions required for input to the transportation network model is to make use of modal simulators adopted for the TSC Freight Energy Model. These simulators model transport operations at a level of detail which is not possible within the context of a complete network analysis. By basing the network operations data on the results of detailed simulations of individual modal facilities, the modal simulators are implicitly nested within the transportation network model (TNM). This modeling strategy provides a degree of operational realism which has heretofore been unattainable with large network models.

Of course, the user is free to develop network performance functions in any way he chooses; that is, connections between the modal simulators and the network model are not "hard wired". However, it should be noted that the modal simulators were carefully chosen to maintain comparability across all modes. This is an extremely important concept. Differences in modal performance reported by the network model can be accepted as valid only if the underlying modal performance functions are developed under comparable assumptions as to included-and-excluded cost elements, average operating characteristics, vehicle load factors, treatment of empty vehicle redistribution, equipment availability limitations, cost allocation methods, time value of money, and so on.

Summary descriptions of the modal simulators are provided in this appendix. It is not possible within the confines of this report to provide complete documentation for each simulator. In lieu of this, references to the documentation are given (see Appendix A for citations).

Rail Capacity Model

Rail travel times may be derived with a rail capacity model developed by CACI for the Rail Services Planning Office (RSPO) of the Interstate Commerce Commission (ICC). Model documentation is provided in (12), and use of the model to generate rail capacity functions is described in (13). The model itself is available through CACI, RSPO, or TSC.

The rail capacity model estimates the performance and capacity of specific railway lines. For a specified set of variables, including track configuration, signal system, speed restrictions, train schedules, and train priority scheme, the model simulates train dispatching and the resultant interaction of trains along the line.

Model inputs include the following elements:

- track layout
- grades and curvature
- siding capacity
- yard capacity
- track deletions
- signals and signal spacing
- station locations
- train schedules
- train class priorities
- train speeds and/or running times

The train speeds input to the model are typical or desired values. The actual travel times attained, given the presence of other traffic, are output by the model. If initial speed estimates are not available, they may be obtained with the train performance calculator described below, or from standard railway engineering formulas.

Figure E-1 is a logic diagram of the rail capacity model. The major activity of the model is to simulate the sequence of interactions between dispatching and train movements as they would occur along a real rail line. In this model, the dispatcher becomes aware of trains a reasonable length of time before they enter the system, makes dispatching decisions based upon track configuration and train characteristics, and then revises these decisions and makes new decisions as required by the subsequent movement of trains. The simulator receives data from the dispatcher on the reserved path for each train. By combining each train's reservations together with the physical data describing line configuration,

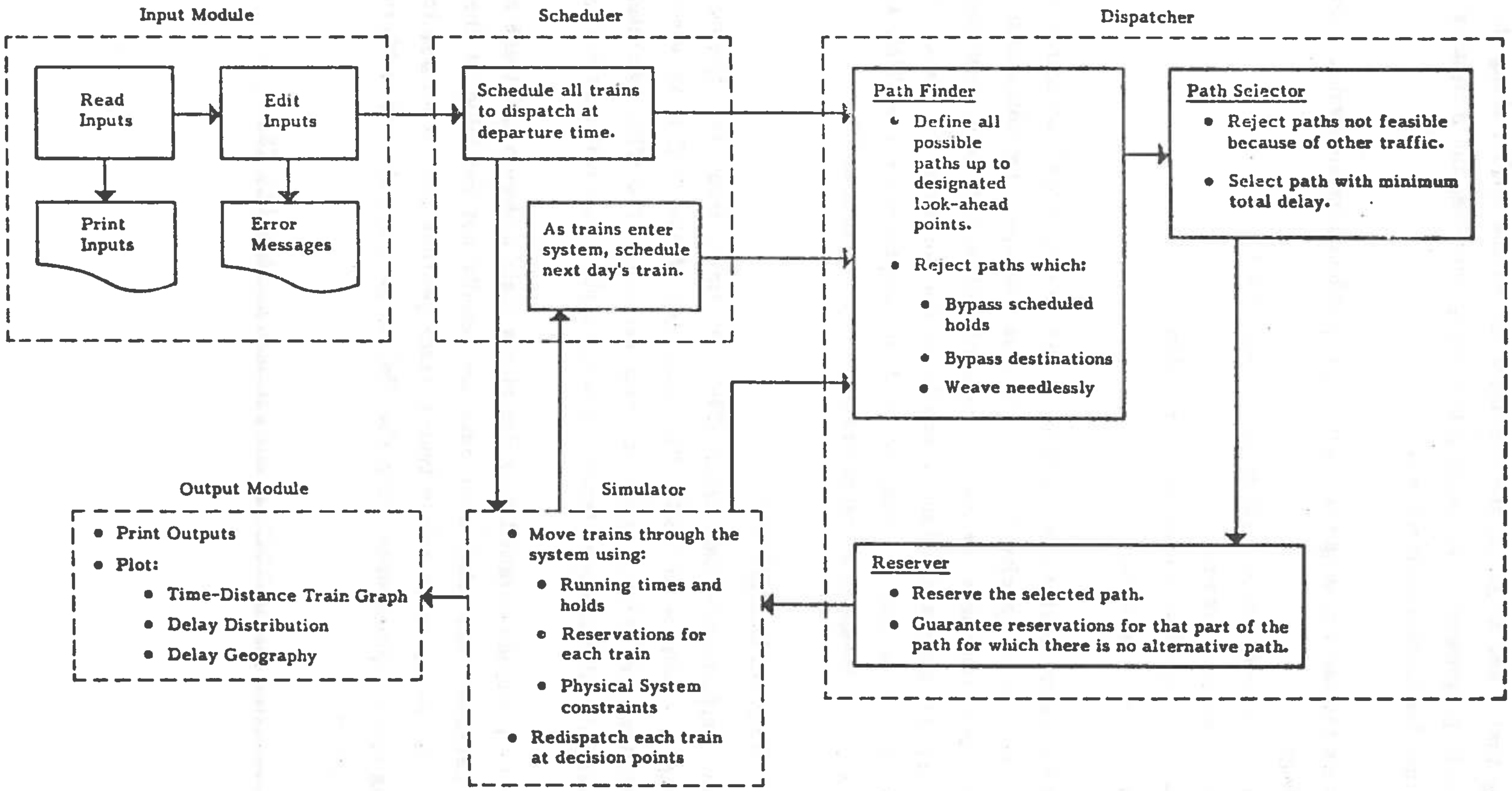


Figure E-1. Structure of the Train Dispatching Simulation Model running times, and so forth, the simulator moves the traffic along the rail line. As traffic progresses to decision points along the line, the simulator calls the dispatcher for further instructions.

Numerous tabular and graphical outputs are produced by the model, including the following:

- time-distance train graph (or stringline)
- train-delay reports
- train-delay frequency distribution
- delay by location

It will normally require several runs of the model, at various traffic levels, to produce an entire capacity function (time vs. tonnage). By judicious selection of the train mix, functions for several types of traffic (unit train, manifest, TOFC, etc.) may be generated simultaneously in one sequence of runs. Functions generated in this way are exactly what are required for the TNM, since they relate commodity-specific travel times to total rail line traffic.

Train Performance Calculator

A train performance calculator (TPC) obtained from the Missouri-Pacific Railroad is available at TSC. The main use of the TPC is to estimate fuel consumption for various types of train service. The TPC can also provide estimates of rail free-speed travel times for input to the rail capacity model.

TPC inputs include detailed data describing train make-up and track geometry. Since detailed track alignment data are usually not available at the network level, it is necessary to define typical track profiles and curvatures for various physiographic regions when using the TPC to generate the network's rail energy functions.

Documentation for the TPC has not yet been published by TSC.

Rail Cost Model

The rail-cost simulator is an adaptation of a rail cost model developed by TSC. The original TSC model is described in (3) and (14). Modifications made by CACI included removal of costing elements related to rail terminals, introduction of travel time and fuel consumption as functions of annual tonnage, and generation of a complete cost vs. tonnage function in a single run of the model. Otherwise, the model formulation and philosophy are the same as in the TSC version.

The model is based upon determination of the cost of rail transportation over a particular rail segment, which is defined as mainline route with no intervening terminals or major junctions. This is precisely the type of cost data needed for the TNM. Also the model's output represents estimated "engineered economic costs," rather than accounting costs such as contained in reports to the ICC. In this approach, the resources required to provide rail transport are determined using engineering relationships, and resource "prices" including both capital and operating expenses determine the costs incurred.

The following six cost elements are presently included in the model:

- linehaul facility
- locomotive
- crew
- fuel
- railcar
- overhead

Costs accrue to segments on the basis of output measures which are logically the most closely related to the cost. For example, railcar-maintenance cost is based on car mileage, while railcar-capital cost is based on time. Fuel costs vary with speed and grade, crew costs with train miles, variable-facility maintenance with traffic volume and average speed, and so on. A full explanation of the allocation procedures used is given in (14).

Some of the key model inputs are as follows:

- traffic volume - annual tonnages for which unit costs are desired
- segment length
- number of tracks
- travel-time function
- fuel-consumption function
- facility investment-and-maintenance costs
- locomotive and railcar data
    - purchase price
    - life
    - weight
    - maintenance cost
    - linehaul utilization
    - load per railcar
- crew wages
- fuel price
- empty backhaul
- average number of cars per train
- discount rate
- overhead cost

The primary model output is a table of unit-rail linehaul cost (mills per net ton-mile) vs. annual tonnage. A breakout of costs by cost element is also provided.

Program documentation for the CDC CYBERNET version of the rail cost model is given in Appendix F. This version is available through CACI or TSC. The original version of the model is also available at TSC.

Train Delay Simulator

The Train Delay Simulator is a simple simulation model which estimates congestion delays for two-way traffic on a single-track rail line with sidings. It is much less detailed than the Rail Capacity Model but is correspondingly less expensive to run. As a result it is practical to make a large number of runs under varying conditions in order to develop transit-time functions.

A small example of a typical rail configuration is illustrated in Figure E-2. At specified intervals the model dispatches trains from A to B and simulates their travel to the opposite end of the line. The principal delays occur when two trains traveling in opposite directions require the use of the same segment of single track. Trains which arrive at such a segment when it is in use must wait at a siding until the competing train has passed. Additional delays may arise from the requirement to maintain a minimum separation between trains traveling in the same direction. The model simulates one day's activity on the line and reports the average and standard deviation of the total delay for traffic in each direction.

- Input

Input data to the model is free format. Values are required only to appear in the correct order, separated by one or more blanks. All values are required; there are no defaults.

The track configuration is described to the model in terms of segments. A segment is defined as a section of single track together with the following siding. As shown in Figure E-2 the division of the line into segments is dependent on the direction of travel. The input data lists the lengths of the segments as seen in both the outbound (A to B) and inbound (B to A) directions of travel. The location and length of sidings is implied by the overlaps between the two sets of segments. Note that once a train is cleared to enter a segment it can travel its full length without additional delay.

Specifically, the track data required consists of (1) the number of segments, (2) a list of segment numbers for the outbound direction, each followed by the corresponding segment length in miles, and (3) a similar segment list for the inbound direction. The first three lines in Figure E-3 show how the example track would be input. Note that segments are numbered from left to right for both directions.

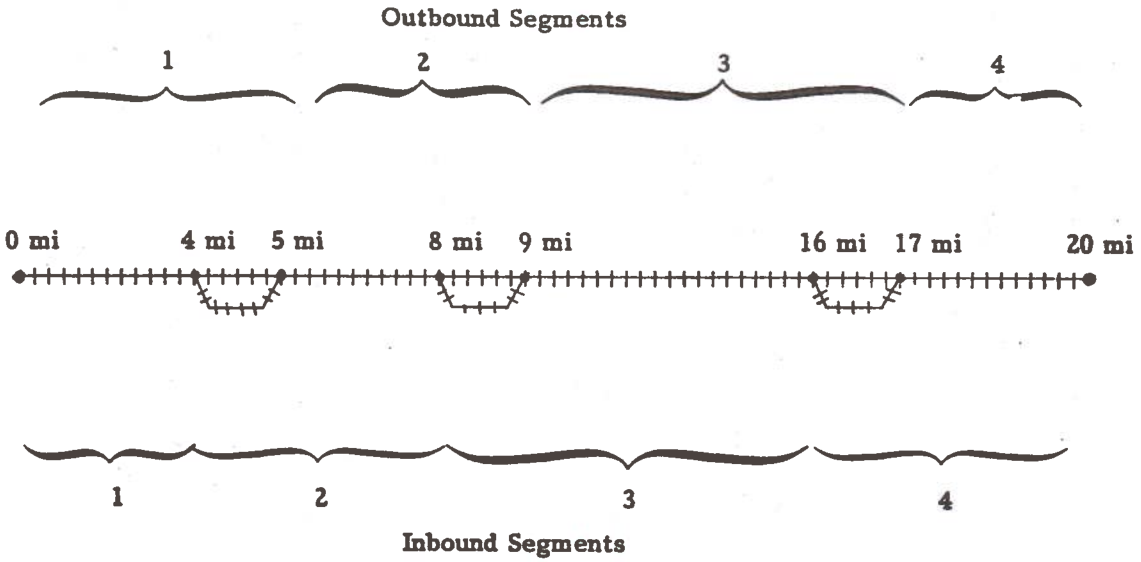


Figure E-2. Example Track Configuration for Train Delay Simulator

```
4
1  5.0   2 4.0  3  8.0   4  3.0
4  4.0   3 8.0  2  4.0   1  4.0
20.0  0.0 20  20 14   .1  .50
```

Figure E-3. Example of Input Data for Train Delay Simulator

The remaining input data describe the train operations. The following values are required:

(1) Average train speed (mph)

(2) Speed variation (mph) - speeds on each segment are randomly drawn from a uniform distribution on the interval (average-variation, average+variation).

(3) Number of outbound trains per day.

(4) Number of inbound trains per day.

(5) Number of operating hours per day. This is used to calculate the average inter-departure time between successive trains. The simulation will continue until all specified trains have completed their trips.

(6) Minimum separation between trains traveling in the same direction (hours).

(7) Spread of inter-departure times, expressed as a fraction of the average inter-departure time obtained by dividing the operating hours per day by the number of trains per day. Actual intervals between departures are drawn randomly from a uniform distribution on the interval (1-spread) x average, [(1+spread) x average], subject to the minimum separation constraint.

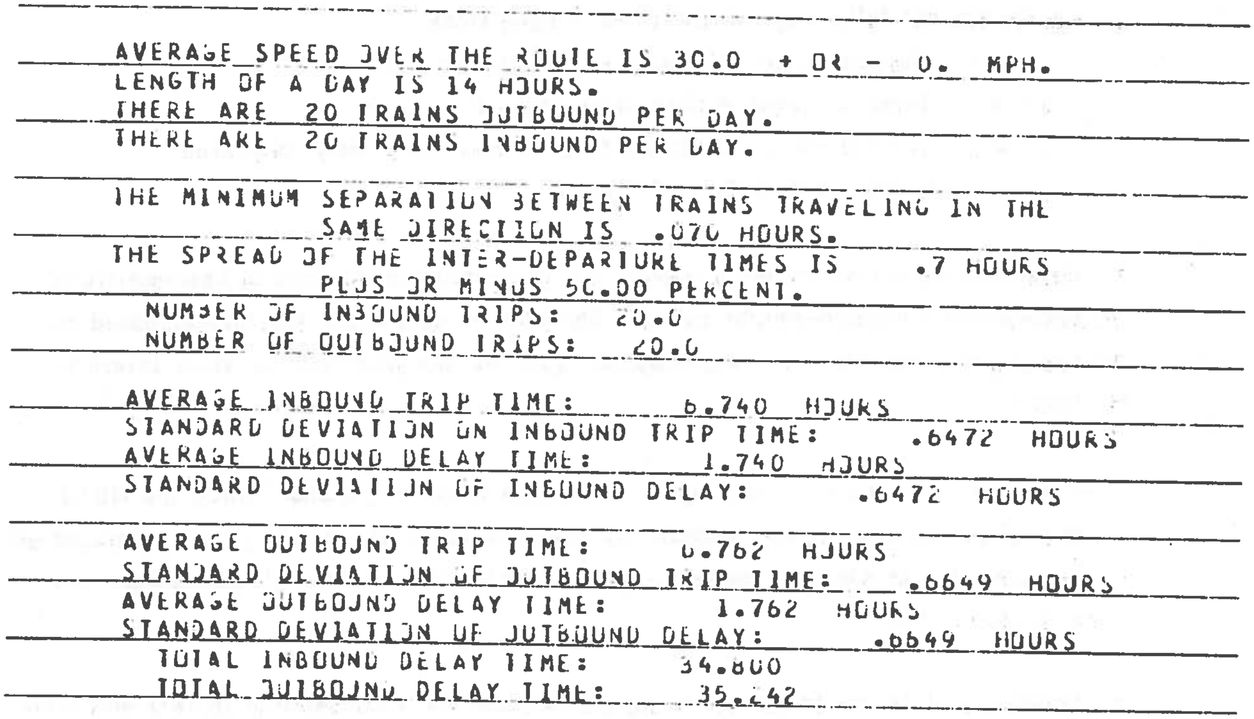
The last line in Figure E-3 illustrates a typical set of train data.

● Output

An example of the model output appears as Figure E-4 and is basically self-explanatory. Note that the first part of the output is a playback of the input data. The reported standard deviations should be used with some caution, as they are not adjusted for correlation between the delays of successive trains.

● Usage

At present this simulator is not a fully supported element of the TSC Freight Energy Model. This version was developed as a simple prototype, and some revisions and extensions are needed to make it generally useful.



```
 AVERAGE SPEED OVER THE ROUTE IS 30.0  + OR - 0.  MPH.
 LENGTH OF A DAY IS 14 HOURS.
 THERE ARE  20 TRAINS OUTBOUND PER DAY.
 THERE ARE  20 TRAINS INBOUND PER DAY.

 THE MINIMUM SEPARATION BETWEEN TRAINS TRAVELING IN THE
                 SAME DIRECTION IS  .070 HOURS.
 THE SPREAD OF THE INTER-DEPARTURE TIMES IS     .7 HOURS
                 PLUS OR MINUS 50.00 PERCENT.
   NUMBER OF INBOUND TRIPS: 20.0
   NUMBER OF OUTBOUND TRIPS:  20.0

   AVERAGE INBOUND TRIP TIME:        6.740  HOURS
   STANDARD DEVIATION ON INBOUND TRIP TIME:      .6472  HOURS
   AVERAGE INBOUND DELAY TIME:        1.740  HOURS
   STANDARD DEVIATION OF INBOUND DELAY:       .6472  HOURS

   AVERAGE OUTBOUND TRIP TIME:       6.762  HOURS
   STANDARD DEVIATION OF OUTBOUND TRIP TIME:    .6649  HOURS
   AVERAGE OUTBOUND DELAY TIME:        1.762  HOURS
   STANDARD DEVIATION OF OUTBOUND DELAY:       .6649  HOURS
     TOTAL INBOUND DELAY TIME:      34.800
     TOTAL OUTBOUND DELAY TIME:      35.242
```

Figure E-4. **Train Delay Simulator Output**

Truck Speed Model

Truck speeds may be calculated using a procedure developed by Oak Ridge National Laboratory (ORNL), which, in turn, uses the data and methodology given in the Highway Capacity Manual (15). The ORNL procedure (16) estimates truck speeds for the following combinations of conditions:

- Highway type - freeway, multilane, two-lane
- Terrain - level, rolling, mountainous
- Service level - relatively free-flowing, relatively congested
- Year - 1950, 1960, 1970, 1980

Embodied in the estimates are past and projected time trends in baseline truck speeds and power-to-weight ratios. The effects of terrain are further based on the assumption that trucks comprise 10% of the vehicles on main intercity highways.

Table E-1 shows some truck speed estimates made by ORNL. Since the ORNL procedure is simple and essentially deterministic, there is no computerized version of the ORNL "model". Instead, complete data and particulars are available in (16).

Additional data on truck operating characteristics are available in (17) and (18). Volume 3 of this report details how these and other data sources may be used to develop highway performance functions for input to the transportation network model.

Table E-1. Estimated Truck Operating Speeds

1970

Terrain	Level of * Service	Freeway	Multilane Highway	Two-lane Highway
Level	B	63.8	58.5	53.2
	D	42.1	36.9	31.9
Rolling	B	54.2	49.7	42.6
	D	35.8	31.3	25.6
Mountainous	B	41.5	38.0	30.3
	D	27.4	23.9	18.2

1980

Terrain	Level of Service	Freeway	Multilane Highway	Two-lane Highway
Level	B	68.0	62.3	56.7
	D	45.6	39.2	34.0
Rolling	B	57.8	53.0	45.4
	D	38.7	33.4	27.2
Mountainous	B	44.2	40.5	32.3
	D	29.6	25.5	19.4

* As defined in the Highway Capacity Manual (15); service level B corresponds to relatively free-flowing conditions, and D to relatively congested conditions.

Source: reference (16).

Truck Cost Model

Intercity trucking costs, including both linehaul and terminal costs, may be estimated for truck load (TL) traffic using a TSC truck cost model based on a previous version developed by the Association of American Railroads (AAR).* This model is similar in many respects to the TSC rail cost model, in that it develops estimates of engineered economic costs. Informal model documentation is available from TSC.

Basic model inputs include travel-time and fuel-consumption estimates, which may be derived as discussed in the preceding sections. Additional inputs include:

- Truck and trailer data
    - purchase cost
    - economic life
    - maintenance costs
    - load capacity (weight and cube)
- Driver wages
- Fuel price
- Tire cost and life
- Oil and lubrication costs
- License and registration fees
- Taxes
- Discount rate
- Cargo density
- Overhead costs
- Vehicle utilization
- Empty backhaul
- Trip length
- Platform charges

The main output of the model is the estimated cost per ton and ton-mile for truck transportation, including a detailed breakout by cost element. This last item is important for it permits separation of costs into linehaul and terminal portions, as required for input to the TNM.

---

* It is perhaps unusual to base trucking costs on a model originally developed by the railroads. However, this is the best truck cost model of general applicability which is currently available, and TSC truck transportation specialists have thoroughly examined the model and determined that it contains no modal bias.

Lock Capacity Function Generator

Much of the travel time on the inland waterways is consumed in transiting navigation locks. The lock capacity function generator (LOKCAP) was developed for TSC by CACI to provide a convenient and inexpensive means of estimating lock transit and delay times. Complete program documentation for and example applications of LOKCAP are given in (13). LOKCAP has been installed on the CDC CYBERNET system, and is available through TSC or CACI.

LOKCAP estimates average lock transit time as a function of annual-traffic volume. Model inputs include:

- Lockage times - mean and variance for each phase of the lockage cycle
- Average tonnage per loaded barge
- Tow-type or lockage-type frequency distributions - for each tow type or lockage type, the following items are required:
    - number and type of barges in tow
    - direction, upstream/downstream
    - percentage of empty barges
    - lockage type
    - relative frequency (sum over all types = 1.0)

LOKCAP is based on an application of queueing theory to lock operations. Specifically, the lock is conceptualized as a single-server with random (Poisson) arrivals and a general service time distribution of known mean and variance (i.e., the M/G/1 queueing model). Service times are adjusted at each traffic level to take into account varying probabilities of turnback lockages occurring. A one-up/one-down service policy is assumed to prevail whenever there is a queue on both sides of the lock. The model determines the average time which a tow spends in queue prior to lockage (delay) and the average transit time through the chamber for each of 13 traffic levels, and also estimates the lock capacity (defined as that theoretical traffic level at which lock utilization is 100% and delays are infinite). The transit time vs. traffic volume pairs describe the capacity function for a lock chamber. For a two-chamber lock, the chamber functions are added horizontally to obtain a function for the lock facility.

The main LOKCAP output is a tabular representation of the time function. Auxiliary outputs include function-coordinate data suitable for input to a plotting program and a report giving detailed lockage statistics at each volume level.

Inland Navigation Simulation Model

Another source of detailed waterway operations data is an inland-navigation simulation model developed by CACI for the Army Corps of Engineers. The model is completely documented in (23), and user instructions are also provided in (5).* The model has been installed on the CDC CYBERNET system, and is available through TSC, the Corps, or CACI.

The navigation simulator is a relatively large and detailed model, providing explicit representations of individual waterway facilities, cargo consignments, and vessels. The model is specifically designed to accommodate systems as large as the entire Mississippi River - Gulf Coast waterway system. Each lockage facility is explicitly represented in the form of two processing-time distributions for each chamber. Linear stretches of docks are combined and abstracted as single ports; port processing is represented by loading and unloading times and by barge pick-up and drop-off times. Commodity movements enter the model in the form of a list of individual shipments. Tow makeup and dispatching are internal to the model, and en route fleeting operations are represented. Empty barge movements needed to accommodate trade imbalances are scheduled internally via decision rules built into the program.

Figure E-5 is a schematic showing the organization of the inland navigation simulator. The figure also summarizes the model's inputs and outputs.

Within the context of the TSC Freight Energy Model, the main uses of the navigation simulator are to verify and calibrate the lock-transit time functions generated with LOKCAP, and to estimate transit times for inland waterway channels and ports.

---

*See Reference Section, Volume III.

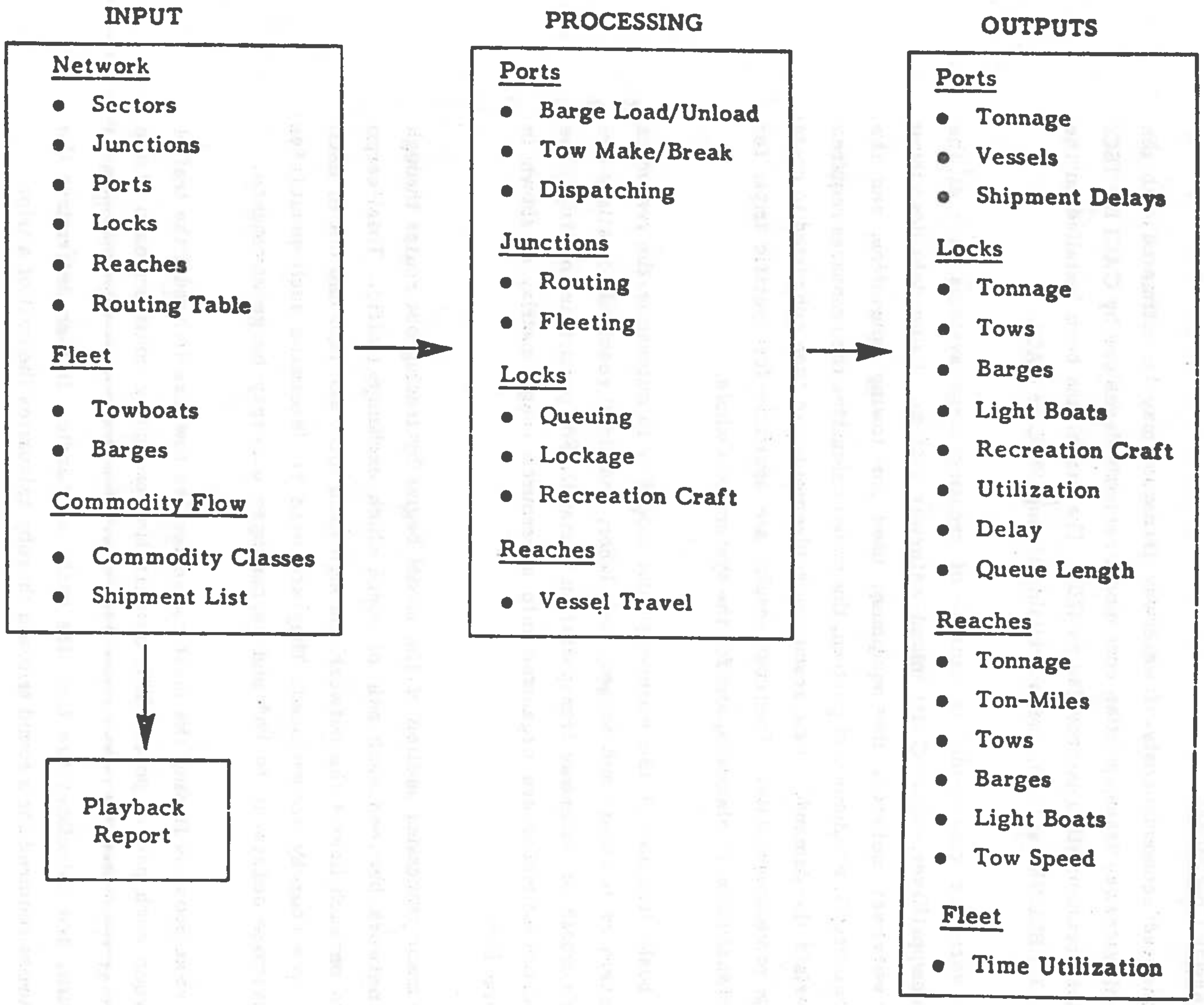


Figure E-5. Elements of the Inland Navigation Simulation Model

Waterway Cost Model

Engineered economic costs of waterway transport may be estimated with the inland waterway transportation cost model recently developed by CACI for TSC. Model documentation is provided in (20). The model has been installed on the CDC CYBERNET system, and is available through TSC or CACI.

The waterway cost model is capable of treating large systems such as the Mississippi River - Gulf Coast inland waterway system. Using data describing the waterway network, the equipment used for towing operations, and the commodity flow volume and pattern, the model calculates the resources required to satisfy the demand. These resource requirements are then converted to costs using price-input data. The cost results are available for specific trips, for individual network elements, and for the system as a whole.

The basic function of the waterway cost model is to determine the resources (numbers of towboats and barges, fuel, labor, and time) required to satisfy one year's worth of waterway transportation demand. For particular tow trips, the resource estimates are organized into a resource usage matrix, as shown in Figure E-6.

The main processing section of the model begins by tracing out routes through the network between each pair of ports which exchange traffic. Total cargo flows on each link of the network, through each lock, and into and out of each port are thereby accumulated. They are used to determine such quantities as average delays at locks* and percentages of empty barge movements.

The next phase is finding the most cost-effective tow size to handle the traffic between each pair of ports. This optimization procedure considers each of the towboat types defined in the input data (e.g., classified by towboat horsepower) in turn, and calculates the tow size each can handle. It then determines the resources required for a round trip and thereby calculates the cost of a trip.

---

* The model is designed to accept as input lock-delay functions generated with LOKCAP.

Resource Operation	Fuel (gal)	Labor (man-hr)	Towboat Time (hr)	Barge Time (hr)	Cargo Time (hr)
1. Loading/ Unloading					
2. Port Delay					
3. Wait for Towboat					
4. Tow Makeup					
5. Link Travel					
6. Lockage					
7. Lock Delay					

Figure E-6. Waterway Cost Model Resource Usage Matrix

The towboat-tow size combination which minimizes the cost per ton is selected as the one which will be used.

Note that the model determines both fuel-consumption and waterway-transport cost. Hence several runs of the model, at various traffic levels, will produce the data needed to prepare the energy and cost function inputs required for the TNM.

Pipeline Model

Cost, time, and energy functions for pipelines may be based on a model and data developed for TSC by J.G. Debanne (21). This model is presently available through TSC.

The pipeline operations elements of the Debanne model consist of standard hydraulic engineering relationships* among pipe diameter, flow rate, flow velocity, fluid viscosity, head loss, and pumping—energy input. These relationships, or the output of the model, may be used to generate capacity and energy functions. Pipeline transmission costs are approximated as a fixed proportion (e.g., 17 to 18 percent) of total pipeline investment. Pipeline investment is computed endogenously (for a pipe of given diameter) as the sum of the delivered cost of steel, construction cost, and investment in pumping capacity. Hence, as with the other modal simulators, estimated pipeline transmission costs are engineered economic costs.

The Debanne model treats a <u>segment</u> of the pipeline system, which may be an aggregation of several individual trunklines, as a single pipe of sufficient size to carry the aggregate flow. In that there are economies of scale in pipeline transport, this tends to underestimate costs. However, basing pipeline tariffs on total investment tends to overstate the current value of older pipeline segments. On balance, these two effects cancel and produce acceptably accurate cost estimates.

In addition to its usefulness as a modal simulator, the Debanne model provides for a comprehensive analysis and forecasting of energy commodity supply, demands, and distribution. Details are given in (21).

---

* This description is oriented to petroleum pipelines. Comparable relationships and data for natural gas pipelines are also included in the model.

APPENDIX F. RAIL COST MODEL: CDC CYBERNET VERSION

Introduction

The purpose of this program is to calculate rail freight costs per ton-mile as a function of net tons shipped, given speed and fuel consumption functions and a set of parameters describing the rail-freight operations and basic costs. The resulting cost function can be input to the transportation network model to estimate linehaul cost for a class of links which have similar operating and cost characteristics.

The relationships used to calculate cost are taken directly from a model developed by John Murphy at TSC (14). This program departs from the TSC model in five ways:

- Backhaul costs, or some fraction of them, can be directly charged to the front haul.
- Speed/delay is an explicit function of net annual freight volume on the route .
- The program includes only the linehaul portion of rail freight costs.
- Fuel consumption, expressed in gallons or other energy units per gross ton-mile, is an explicit function of net annual freight volume on the route.
- The program produces costs in mills/net ton-mile for a set of net annual freight volumes.

All of these differences influence how costs are produced; but for a similar set of assumptions the costs/ton-mile are almost identical. A comparison of the costs produced by the TSC Model and the CACI program is given later.

The next section presents a brief note on some of the new features of this program. A comparison between the program results and those produced by the TSC model follows. This comparison is followed by a section on using the program which is intended as a reference/user's manual. Finally, a program listing is presented.

New Features

Three new features of the program require further explanation and justification. They are the treatment of empty backhaul; the speed/delay function; and the exclusion of terminal costs. In many situations, because of special cars or imbalances in the volume of shipments, a train may be empty or partly empty on a return trip. Since the cost of the empty return trip is directly caused by the shipment of goods on the front haul, the cost of the empty backhaul should be charged to the front haul. Accordingly, the fraction of the empty backhaul cost which is to be charged to the front haul must be specified by the user of the cost model. This fraction is then used to increase the number of locomotives and railcars used, and subsequently to increase the effective gross weight of the train. Specifically:

- TLOCO = FH.LOCO (1. + FEB)

where TLOCO = total number of locomotives
FH.LOCO = locomotives required on the front haul
FEB = fraction of empty backhaul costs to be charged to the front haul

- TRCAR = FH.RCAR (1. + FEB)

where TRCAR = total number of railcars
FH.RCAR = railcars required on the front haul

- GROSS = NET + LOCO.WT (TLOCO) + CAR.WT (TRCAR)

where GROSS = total effective gross weight of the train
NET = net tons transported by the train
LOCO.WT = weight of a locomotive
CAR.WT = tare weight of a railcar

The number of locomotives, the number of railcars and the effective gross weight of the train are then used to calculate cost per net ton-mile. The implicit assumption is that the train speed on the backhaul is the same as it is on the fronthaul. This assumption is good where speed limits or congestion are the primary determinants of train speed rather than the power to weight ratio.

The average speed of the train is specified by the user of the program in a table of hours per mile as a function of net kilotons shipped per year. Train delays caused by congestion are included in the hours per mile figure. So, in general, hours per mile will increase with net-kilotons shipped per year because the congestion delay time increases. However, the actual traveling time will remain relatively constant. Roadway maintenance costs depend on the moving speed of the train, not on the average speed of the train, so the free speed is used in the calculation of roadway–maintenance cost. The free speed is set at the speed corresponding to the lowest annual volume specified in the speed/delay function.

Because the program accounts for only the linehaul portion of rail freight costs, care must be exercised in specifying annual railcar and locomotive utilization, and the fraction of costs to cover overhead. Railcar and locomotive utilization is used to account for idle time and assign it to in-use time. However, it is important to adjust these utilization factors in conjunction with terminal cost components so that full costs are covered and no costs are double counted.* The fraction of costs to cover overhead should likewise be adjusted with factors in other components of total rail freight costs.

---

* For example, the railcar utilization is set at 8760 hours/year or 100% in the comparison with the TSC model because TSC assigned idle railcar time and cost to terminal operations.

Comparison with TSC Costs

TSC costs are taken from Table III-1 of The Calculation of Comparable Modal Shipment Costs for Regional Commodity Flows by David Anderson (3). They are converted to mills per ton mile by dividing by the link length, 403 miles, and multiplying by 1000 to convert dollars to mills. A detailed listing of the assumed operating and cost-input data is found in Figure F-3.

Figure F-1 shows the results of the cost comparison. CACI costs/net ton-mile are somewhat higher than the TSC costs; Table F-1 and Figure F-2 show that the roadway-maintenance and fuel-cost categories account for the bulk of this difference.

Calculating backwards from the TSC fuel cost* reveals that this cost implies 526 net ton-miles/gallon. This is consistent with a net/gross tonnage ratio of .556. This is the ratio for the front haul only. CACI costs include 100% of the empty backhaul fuel costs.

The roadway-maintenance cost differences are more difficult to trace, but they are probably due to a slight difference in how backhaul costs are accounted.

---

* Assuming 946 gross ton-miles/gallon and 30¢/gallon fuel cost.

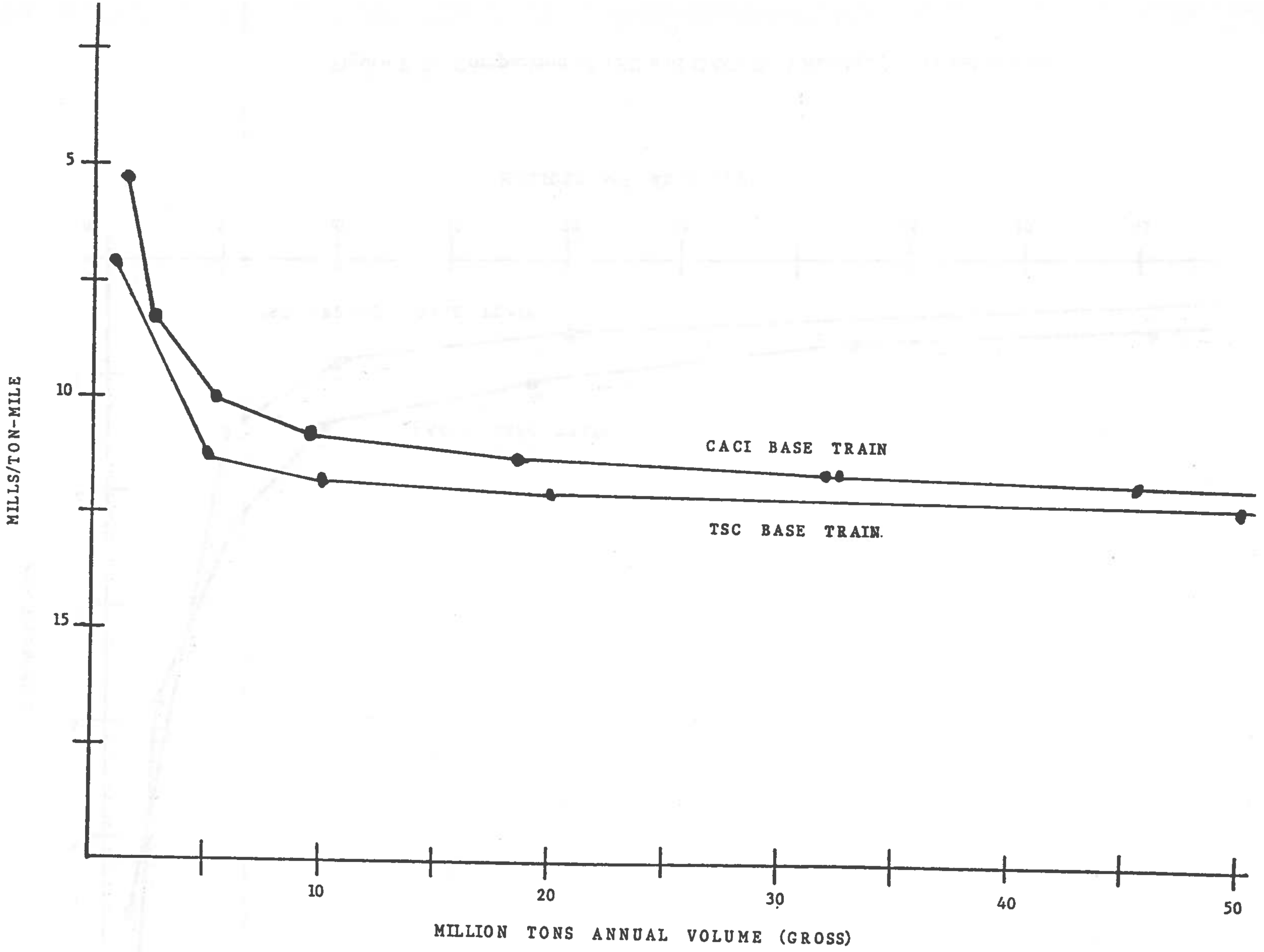


Figure F-1. Comparison of TSC and CACI Rail Cost Estimates

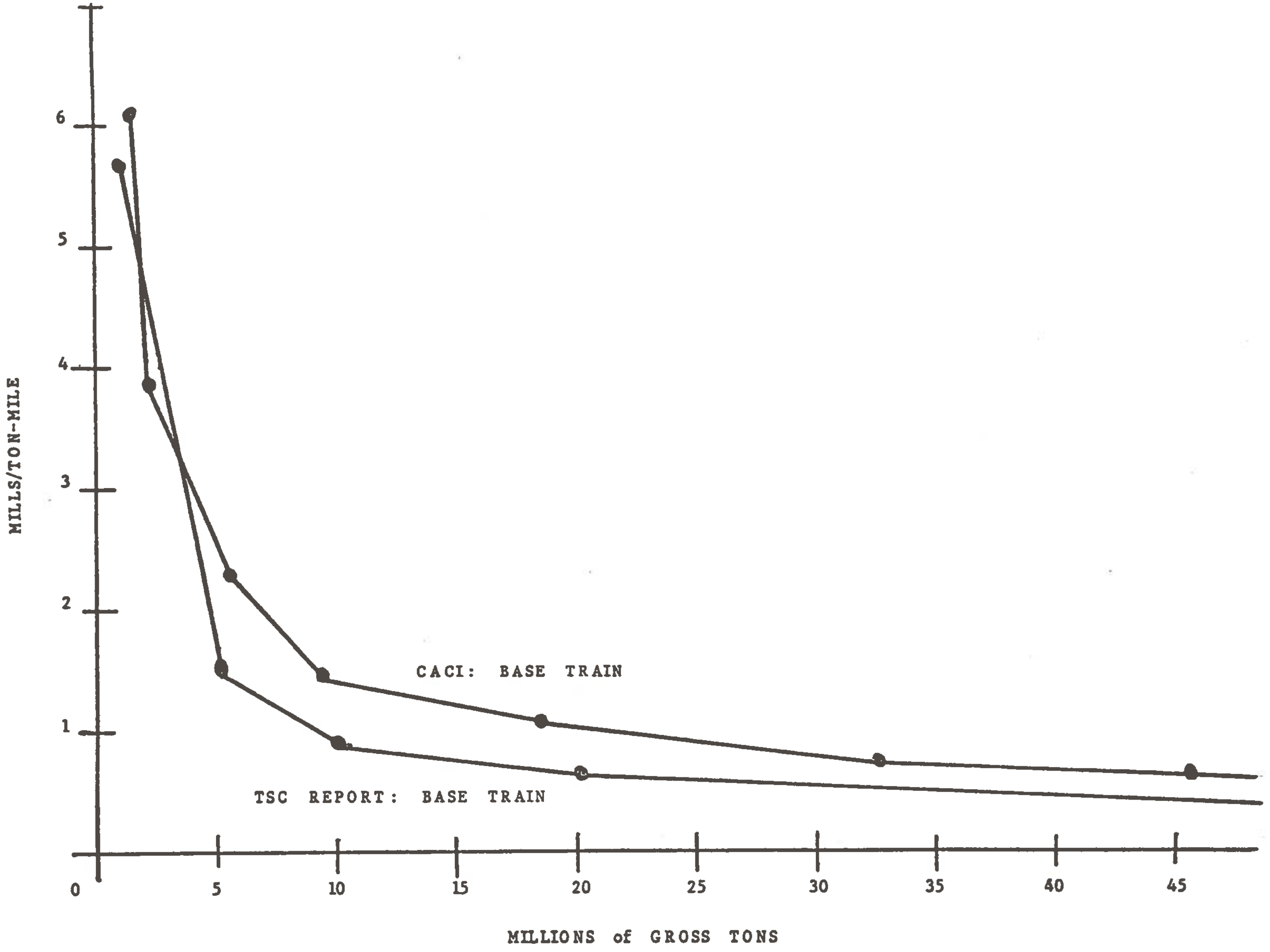


Figure F-2. Comparison of TSC and CACI Rail Roadway Cost Estimates

Table F-1. Costs for Base Train (in Mills/Ton-Mile)

Cost Category	CACI	TSC	Difference
Locomotive			
Maintenance	1.49	1.49	———
Capital	1.44	1.43	.01
Railcar			
Maintenance	1.46	1.46	———
Capital	0.56	0.57	- .01
Fuel	0.85	0.57	.28
Crew	1.88	1.89	- .01
			.27

Using the Program

- Output

  Figure F-3 presents the output of the program. The input-data playback is followed by the program results: cost/net ton-mile by cost category for a set of net annual volumes. This sample output shows locomotive capital, railcar capital and fuel costs not varying with annual volume because the input speed and fuel functions are constant at all volumes. The effective gross tons, which includes empty backhaul as described earlier, is used in the calculation of the net-ton/gross-ton ratio which is shown in the program output.

- Input Data

  Table F-2 presents the five groups of data required by the program, the card formats for each card in each group, and a description of each data item. Further explanation of some of the data items follows Table F-2. A sample listing of data cards directly follows the program listings.

```
                 BASE TRN              1 1.0000000
                    SPEED              2        1
                      0. 0.0450000
                  50000. 0.0450000
                     FUEL              2 0.0
                      0.        0.00
                  54500.        0.00
****************************************************
                 I-N-P-U-T  D-A-T-A
****************************************************

               HORSEPOWER/TRAILING TON                        1.90000
               NUMBER OF LOADED CARS                         66.50000
               NUMBER OF EMPTY CARS                           0.0
               FRACTION EMPTY BACKHAUL                        1.00000
               INTEREST RATE                                  0.10000
ROADWAY               1  TRACKS
               WELDED(1) OR JOINTED(2)                        2.00000
               K1-INSPECTION                                  1.00000
               K2-RAILS                                       1.00000
               K3-TIES                                        1.00000
               K4-SURFACING                                   1.00000
               INVESTMENT/MILE ($)                            0.0
               INVESTMENT LIFE (YEARS)                       25.00000
LOCOMOTIVE
               MAINTENANCE/MILE ($)                           0.66300
               HORSEPOWER/LOCOMOTIVE                       3000.00000
               LOCOMOTIVE WEIGHT (TONS)                     250.00000
               VALUE/LOCOMOTIVE ($)                      380000.00000
               % SALVAGE                                      0.10000
               LOCOMOTIVE LIFE (YEARS)                       15.00000
               ANNUAL HOURS UTILIZATION                    3300.00000
RAILCAR
               TARE WEIGHT (TONS)                            30.00000
               MAINTENANCE/MILE ($)                           0.03900
               VALUE/CAR ($)                              25000.00000
               % SALVAGE                                      0.10000
               RAILCAR LIFE (YEARS)                          20.00000
               ANNUAL HOURS UTILIZATION                    6760.00000
               NET TONS/LOADED CAR                           53.50000
MISCELANEOUS
               CREW COST/MILE ($)                             3.35000
               FUEL COST/GALLON ($)                           0.30000
               HELPER LOCOMOTIVE MILES/TON-MILE               0.0
               INFLATOR/DEFLATOR FROM 1974                    1.00000
               FACTOR TO CONVERT TO GALLONS                   1.00000
               FRACTION OF COSTS FOR OVERHEAD                 0.0
```

Figure F-3. Output of the Rail Cost Model

```
**************************************************
           P-R-O-G-R-A-M  R-E-S-U-L-T-S
**************************************************

                 COST FUNCTION  BASE TRN

COSTS CONSTANT AT ALL VOLUMES(IN MILLS):
        CREW COST/TON-MILE                 1.88321
        LOCOMOTIVE MAINT./TON-MILE         1.49083
        RAILCAR MAINT./TON-MILE            1.45794
        HELPER LOCO.COST/TON-MILE          0.0

        NET TONS / GROSS TONS              0.37263

   NET KTONS/YEAR MILLS/TON-MILE          LOC.CAPIT. RCAR CAPITAL  FUEL   ROAD MAIN ROADINV.
 BAS. TRN         500.    14.772           1.49525   0.55553   0.85106   7.03808   0.0
                 1000.    11.662           1.49525   0.55553   0.85106   3.92827   0.0
                 2000.    10.015           1.49525   0.55553   0.85106   2.28103   0.0
                 5000.     8.984           1.49525   0.55553   0.85106   1.25035   0.0
                10000.     8.553           1.49525   0.55553   0.85106   0.81885   0.0
                20000.     8.308           1.49525   0.55553   0.85106   0.57390   0.0
                30000.     8.215           1.49525   0.55553   0.85106   0.48132   0.0
                40000.     8.165           1.49525   0.55553   0.85106   0.43079   0.0
                50000.     8.132           1.49525   0.55553   0.85106   0.39829   0.0
```

Figure F-3. Continued

Table F-2. Input Data Formats for the Rail Cost Model

Group	Card	Format	Description
1	1	(12X, 2A4, 5X, I5, F10.7)	Cost Function Name Input Data Print Switch Inflator/deflator from 1974
2	1	(12X, 2A4, 5X, I5, 5X, I5)	Speed function Name Number of Points in the function Number of tracks
	2-last	(10X, F10.0, F10.7)	Net ktons Hours per mile
3	1	(12X, 2A4, 5X, I5, F10.7)	Fuel function name Number of points in the function Conversion factor to gallons
	2-last	(10X, F10.0, F10.2)	Net ktons Energy units/ton-mile
4	1	(4F10.3)	Horsepower/gross trailing ton Loaded cars Empty cars Interest rate (annual, decimal) Fraction empty backhaul (decimal)
	2	(7F10.3)	Jointed/welded rails K1-inspection cost adjustor K2-rail cost adjustor K3-tie cost adjustor K4-surfacing cost adjustor Investment ($/mile) Facility life (yrs.)
	3	(7F10.3)	Locomotive maintenance cost ($/mile) Horsepower per locomotive Locomotive weight Value per locomotive ($) Fraction salvage value (decimal) Locomotive life (yrs.) Annual utilization (hrs.)
	4	(7F10.3)	Railcar tare weight (tons) Railcar maintenance cost ($/mile) Value of each railcar ($) Fraction salvage value (decimal) Railcar life (yrs.) Annual Utilization (hrs.) Load in tons/loaded car (tons)
	5	(4F10.3)	Crew cost ($/mile) Fuel cost ($/gallon) Helper locomotive cost (mills/ton-mile) Fraction of cost to cover overhead (decimal)
5	1-last	(F10.3)	Net annual volume at which costs are to be calculated.
	Last	/*	

Group 1 Card 1	Input data print switch - print if non-zero.
Group 1 Card 1	Inflator/deflator from 1974 - The equation used to estimate railway costs is based on 1974 dollars. To produce a cost function in some other-year dollars, two procedures can be followed: 1) Specify an inflator/deflator to transform 1974 dollars to the year required and specify all input costs in 1974 dollars or 2) Specity all input costs in the year dollars desired and multiply the four K factors (Group 4 Card 2) on roadway cost by the inflator/deflator required to convert from 1974 dollars. Note - default value of deflator is 1.0.
Group 2 Card 1	Number of Points in the Speed Function - At least two points must be specified and no more than 18 points may be.
Group 2 Card 2-last	These are the data cards for the speed function. They must be arranged in order of increasing net annual volume.
Group 3 Card 1	Number of Points in the Fuel Function - At least two points must be specified and no more than 18 points may be.
Group 3 Card 1	Conversion Factor to Gallons - Factor which when multiplied by the energy units of the fuel function produces gallons for pricing. Default value is 1.0.
Group 3 Card 2-last	These are the data cards for the speed function. They must be arranged in order of increasing net annual volume.
Group 4 Card 1	Fraction Empty backhaul - Fraction of empty backhaul costs assigned to front haul. Assumes same speed both directions.
Group 4 Card 2	Jointed/welded = 2 for jointed rails = 1 for welded rails
Group 4 Card 2	K1-K4 - Roadway-cost adjustment factors. The model accounts for cost variations attributable to gross annual volume and speed. These factors are used to account for other variations in roadway costs. For example, use of very large (e.g.,120 ton) railcars has been found to cause higher rail wear; so if this situation is modeled, K2 should be increased above 1.0.

Group 5 Card 1

Net Tons Annual Volume - If the first volume is negative the model will produce cost estimates at each volume specified in the speed function. Annual volumes of less than one train load will be converted to one train load. A message will be printed if a volume specified is larger than the largest specified in either the fuel or the speed function. The values of these functions will be extrapolated based on the last two points provided.

Program Listing

A listing of the rail cost program and sample input-data cards appears on the following pages.

```
//D6RRCST  JOB (0106,KIST),HCXIE,CLASS=E,TIME=1,PRTY=10
/*NCSETUP
// EXEC FORTGCLG,REGION.GC=150K,TIME.GC=5
//FORT.SYSIN DD *
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C              THIS PROGRAM CALCULATES COST AS A                   C
C              FUNCTION OF VOLUME WHEN GIVEN A DELAY               C
C              FUNCTION, A FUEL CONSUMPTION FUNCTION               C
C              AND PARAMETERS ON RAIL OPERATIONS                   C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IMPLICIT REAL (A-Z)
      DIMENSION DNAM(2),FNAM(2),CNAM(2),DVOL(18),FVOL(18,,HPM(18),
     X          TMPG(18)
      INTEGER  SWT,DPTS,FPTS,I,J,NLOCO,N,M,NT,EPRT
      DATA  SWT/0/,DVOL/18*0.0/,FVOL/18*0.0/,HPM/18*0.0/,TMPG/18*0.0/
C..READ IN COST FUNCTION NAME,AND ECHO PRINT SWITCH (NON 0=PRINT)
      READ(5,100) CNAM,EPRT,FLATR
      IF(FLATR.LE.0.0) FLATR=1.
      IF(EPRT.NE.0) WRITE(6,100) CNAM,EPRT,FLATR
C..READ DELAY FUNCTION NAME AND NUMBER OF POINTS AND NUMBER OF TRACKS
      READ(5,110) DNAM,DPTS,NT
      IF(EPRT.NE.0) WRITE(6,110) DNAM,DPTS,NT
C
C..READ HOURS PER MILE AS A FUNCTION OF NET ANNUAL KTONS, AND SAVE 1ST
      DO 10 I=1,DPTS
      READ(5,120) DVOL(I),HPM(I)
      IF(EPRT.NE.0) WRITE(6,120) DVOL(I),HPM(I)
   10 CONTINUE
      FRESPD= 1.0/HPM(1)
C
C..READ FUEL FUNCTION NAME, NUMBER OF POINTS,AND CONVERSION FACTOR TO GALLONS
      READ(5,130) FNAM,FPTS,CFACT
      IF(EPRT.NE.0) WRITE(6,130) FNAM,FPTS,CFACT
      IF(CFACT.LE.0.0) CFACT=1.0
C
C..READ  ENERGY UNITS PER TON-MILE AS A FUNCTION OF NET ANNUAL KTONS.
      DO 20 I=1,FPTS
      READ(5,140) FVOL(I),TMPG(I)
      IF(EPRT.NE.0) WRITE(6,140) FVOL(I),TMPG(I)
   20 CONTINUE
C
C..READ TRAIN CHARACTERISTICS:  HP/TRAILING TON, LOADED CARS, EMPTY CARS,
C        FRACTION EMPTY BACKHAUL, INTEREST RATE
      READ(5,150) HPPTT,LC,EC,FEBH,IN
      IF(EPRT.NE.0) WRITE(6,151)
      IF(EPRT.NE.0) WRITE(6,152) HPPTT,LC,EC,FEBH,IN
C
C..READ ROADWAY DATA JOINTED(2)/WELDED(1),K1..4,INVEST./MILE,LIFE
      READ(5,150) RJW,RK1,RK2,RK3,RK4,RINV,RL
      IF(EPRT.NE.0) WRITE(6,153) NT,RJW,RK1,RK2,RK3,RK4,RINV,RL
C
C...READ LOCOMTV. DATA  MAINT./MI.,HP/LOCO.,WT,VALUE/LOCO.,% SALV.,LIFE,UTIL.
      READ(5,150) LMAINT,LHP,LWT,LVAL,LSALV,LL,LUTIL
      IF(EPRT.NE.0) WRITE(6,154) LMAINT,LHP,LWT,LVAL,LSALV,LL,LUTIL
C
C..READ RAILCAR DATA TARE WT.,MAINT/MI,VALUE,%SALV.,LIFE,UTILIZA.,LOAD/LOADEDCAR
      READ(5,150) CTARE,CMAINT,CVAL,CSALV,CL,CUTIL,CLOAD
      IF(EPRT.NE.0) WRITE(6,155) CTARE,CMAINT,CVAL,CSALV,CL,CUTIL,CLOAD
C
C..READ  CREW COST PER MI., FUEL COST PER GAL, HELPER LOCO CENTS PER TON.MILE
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C                           AND FRACTION OVERHEAD
            READ(5,150) CREW,FUEL,HELPER,OVER
            IF(EPRT.NE.0) WRITE(6,156) CREW,FUEL,HELPER,FLATR,CFACT,OVER
            FLATR=FLATR*1000.
      C
      C
      C...READ FIRST KTON VOLUME OR SET SWITCH TO USE TIME FUNCTION VOLUMES.
            READ(5,150) FIRST
            IF(EPRT.NE.0) WRITE(6,157)
            IF(FIRST.LT.0.0) SWT=1
      C
      C
      C...START CALCULATIONS
      C
      C...CAPITAL RECOVERY FACTORS
            N1=(1.+IN)**RL
            RCRF=IN*N1/(N1-1.)
            N2=(1.+IN)**LL
            LCRF=IN*N2/(N2-1.)
            N3=(1.+IN)**CL
            CCRF=IN*N3/(N3-1.)
      C...NET TONS PER TRAIN, GROSS TRAILING TONS, GROSS TONS PER TRAIN
            NTPT = LC*CLOAD
            GTT = NTPT+((EC+LC)*CTARE)
            NLOCO=(GTT*HPPTT/LHP)+.999
            XLOCO=NLOCO
      C...ADJUSTMENTS FOR EMPTY BACKHAUL
            EC=EC+(LC*FEBH)
            XLOCO=XLOCO*(1.+FEBH)
            GTT=GTT+(LC*FEBH*CTARE)
            GTPT =(LWT*XLOCO)+GTT
      C...LOCOM. COST PER HOUR ,  RAILCAR COST PER HOUR
            LCPH=(LVAL*LCRF*(1.-LSALV)+(LVAL*LSALV*IN))/LUTIL
            CCPD=  (CVAL*CCRF*(1.-CSALV)+(CVAL*CSALV*IN))/CUTIL
      C...CREW COST PER TON MILE
            CREWC=(CREW/NTPT)*(1.+FEBH)*FLATR
      C...MAINT.COSTS PERT TON.MILE LOCOMOTIVE, RAILCAR.
            LMC=FLATR*LMAINT*XLOCO/NTPT
            CMC=FLATR*CMAINT*(EC+LC)/NTPT
      C....WRITE HEADING AND THE UNCHANGING COST CATEGORIES
            NETGRS= NTPT/GTPT
            WRITE(6,200)CNAM,CREWC,LMC,CMC,HELPER,NETGRS
            I=1
      C
      C...START LOOP ON VOLUME  (KTONS)
      C
   90       CONTINUE
            TOTAL=0.0
            IF(SWT.EQ.1) VOL=DVOL(I)
            IF(SWT.EQ.0) VOL=FIRST
            IF(VOL.LT.NTPT/1000.) VOL=NTPT/1000.
      C...GET TIME PER MILE, CALCULATE SPEED
            DO 30 J=2,DPTS
            IF(VOL.LE.DVOL(J)) GO TO 40
   30       CONTINUE
            WRITE(6,210) VOL
   40       N=J
            M=J-1
            THPM=HPM(M)+(((HPM(N)-HPM(M))/(DVOL(N)-DVOL(M)))*(VOL-DVOL(M)))
            SPD= 1./THPM
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C...GET GAL PER TON-MILE AND CONVERT TO TON-MILE PER GAL
      DO 50  J=2,FPTS
      IF(VOL.LE.FVOL(J)) GO TO 60
   50 CONTINUE
      WRITE(6,220)VOL
   60 N=J
      M=J-1
      GAL=TMPG(M)+(((TMPG(N)-TMPG(M))/(FVOL(N)-FVOL(M)))*(VOL-FVOL(M)))
      MPG=1.0/GAL
C
C..CALCULATE ROADWAY COST, NUMBER OF TRAINS, ANNUAL GROSS TONS.
      ATRN= VOL*1000./NTPT
      AGT = ATRN*GTPT/1000000.
      Y=1.0
      IF(AGT.GT.10.) Y=1.2
      RVCST=0.0
      RFCST= Y*(536. +(670.*NT))*RK1
      RVCST=((268.+(536.*SQRT(AGT))+(43.*AGT))*RK2*NT)
     X           + ((804.+(121.*SQRT(AGT)))*RK3*NT)
     X       + (386.+ (39.*RJW*AGT*((FRESPD/E3.)+((FRESPD**2.)/6250.)))
     X                *RK4*NT)
      RCOST=(RFCST+RVCST)*GTPT/(AGT*1000000.)
      RCCST= FLATR*RCOST/NTPT
      RCI=(PINV*RCRF/(AGT*1000000.))*GTPT
      RCI=FLATR*RCI/NTPT
C
C...CALCULATE  LOCO  COSTS, RAILCAR COSTS,FUEL
      LCOST= THEM*LCPH*XLOCO
      CCOST= THEM*CCPD*(EC+LC)
      LCCST=FLATR*LCOST/NTPT
      CCCST=FLATR*CCOST/NTPT
      FCOST=(CFACT*FUEL/MPG)*(GTPT/NTPT)*FLATR
C...SUM COSTS
      TOTAL= CREWC+LMC+CMC+RCCST+LCCST+CCCST+FCOST+HELPER+RCI
      TOTAL=TOTAL*(1.0+OVER)
      IF(I.GT.1) WRITE(6,240) VOL,TOTAL,LCCST,CCCST,FCOST,RCCST,RCI
      IF(I.EQ.1)WRITE(6,230)CNAM,VOL,TOTAL,LCCST,CCCST,FCOST,RCCST,RCI
      IF(SWT.EQ.0) READ(5,150,END=999) FIRST
      IF((SWT.EQ.1).AND.(I.GE.CFIS)) GO TO 999
      I=I+1
      GO TO  90
C
C...END LOOP
  999 CONTINUE
  100 FORMAT(12X,2A4,5X,I5,F10.7)
  110 FORMAT(12X,2A4,5X,I5,5X,I5)
  120 FORMAT(10X,F10.0,F10.7)
  130 FORMAT(12X,2A4,5X,I5,F10.7)
  140 FORMAT(10X,F10.0,F10.6)
  150 FORMAT(7F10.3)
  151 FORMAT(5('*******'),/,20X,'I-N-P-U-T  D-A-T-A',/,9('*******'),/)
  152 FORMAT(10X,'HORSEPOWER/TRAILING TON',12X,F10.5,/,10X,
     X 'NUMBER OF LOADED CARS',14X,F10.5,/,10X,
     X'NUMBER OF EMPTY CARS',15X,F10.5,/,10X,
     X'FRACTION EMPTY BACKHAUL',12X,F10.5,/,10X,
     X 'INTEREST RATE',22X,F10.5)
  153 FORMAT(' ROADWAY',I10,'  TRACKS',/,10X,
     X 'WELDED(1) OR JOINTED(2)',12X,F10.5,/,10X,
     X 'K1-INSPECTION',22X,F10.5,/,10X,
     X 'K2-RAILS',27X,F10.5,/,10X,
     X 'K3-TIES',28X,F10.5,/,10X,
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      X 'K4-SLRFACING',23X,F10.5,/,10X,
      X 'INVESTMMENT/MILE ($)',15X,F1C.5,/,1CX,
      X 'INVESTMENT LIFE (YEARS)',12X,F1C.5)
  154 FCRMAT(' LOCOMOTIVE',/,1CX,
      X 'MAINTENANCE/MILE ($)',15X,F10.5,/,1CX,
      X 'HCRSEPOWER/LCCCMOTIVE',14X,F1C.5,/,1CX,
      X 'LOCCMCTIVE WEIGHT (TCNS)',11X,F1C.5,/,1CX,
      X 'VALLE/LOCOMOTIVE ($)',12X,F13.5,/,1CX,
      X '% SALVAGE',26X,F1C.5,/,1CX,
      X 'LCCCMITIVE LIFE (YEARS)',12X,F1C.5,/,1CX,
      X 'ANNLAL HCURS UTILIZATICN',10X,F11.5)
  155 FCRMAT(' RAILCAR',/,10X,
      X 'TARE WEIGHT (TCNS)',17X,F10.5,/,1CX,
      X 'MAITENANCE/MILE ($)',16X,F1C.5,/,1CX,
      X 'VALLE/CAR ($)',20X,F12.5,/,1CX,
      X '% SALVACE',26X,F10.5,/,1CX,
      X 'RAILCAR LIFE (YEARS)',15X,F1C.5,/,1CX,
      X 'ANNUAL HCURS UTILIZATICN',1CX,F11.5,/,10X,
      X 'NET TCNS/LOACED CAR',16X,F10.5)
  156 FCRMAT(' MISCELANECUS',/,1CX,
      X 'CREW COST/MILE ($)',17X,F1C.5,/,1CX,
      X 'FUEL CCST/GALLCN ($)',15X,F1C.5,/,10X,
      X 'HELPER LOCCMOTIVE MILLS/TCN-MILE',2X,F1C.5,/,10X,
      X 'INFLATOR/UELFATCR FRCM 1974',8X,F1C.5,/.1CX,
      X 'FACTCR TO CCNVERT TC GALLCNS',7X,F1C.5,/,1CX,
      X 'FRACTICN OF COSTS FOR CVERHEAC',5X,F1C.5)
  157 FCRMAT(1H1)
  20C FCRMAT(9('******'),/,14X,'P-R-C-G-R-A-M  R-E-S-U-L-T-S',/,
      X 9('******'),//,20X,'CCST FUNCTICN',2X,2A4,//,' COSTS CCNSTANT',
      X' AT ALL VCLUMES(IN MILLS):',/,10X,'CREW CCST/TCN-MILE',1CX,F10.5,
      X/,10X,'LCCCMOTIVE MAINT./TCN-MILE',2X,F1C.5,/,
      X 1CX,'RAILCAR MAINT./TCN-MILE',5X,F1C.5,/,
      X 10X,'HELPER LOCO.COST/TCN-MILE',3X,F1C.5,///,
      X1CX,'NET TCNS / GROSS TCNS',7X,F1C.5,////,4X,'NET KTCNS/YEAR MIL',
      X'LS/TCN-MILE',5X,'LOC.CAPIT. RCAR CAPIAL  FLEL  RCAD MAIN RCAC',
      X 'INV.')
  210 FCRMAT(' VOLUME',F10.0,' IS BEYCND LARGEST VCLUME IN THE CELAY FUN
      XCTICN')
  220 FCRMAT(' VOLUME',F10.0,' IS BEYCNC LARGEST VCLUME IN THE FUEL FUNC
      XTICN')
  230 FCRMAT(2X,2A4,F10.C,F10.3,10X,5F1C.5)
  24C FCRMAT(10X,F10.0,F10.3,10X,5F1C.5)
      STCP
      END
//GC.SYSIN CC *
                  BASE TRN          1       0.00
                     SPEEC          2          1
                       0.0      0.045
                   50000.0      0.045
                      FUEL          2
                       0.0   .0010571
                   54500.C   .0010571
           1.9        66.5        CC.       1.CC       C.1
            2.          1.         1.         1.        1.        0.0        25.
         0.663       3000.       250.   38CCCC.C       C.1        15.      3300.
          30.0       0.039     25CCC.        0.1       20.      8760.       53.5
          3.35        0.30         0.
         500.0
        1C00.0
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239.      10000.0
240.      2CCC0.0
241.      3CCC0.0
242.      4CC00.0
243.      5CC00.0
244.   /*
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