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SYSTEM DESCRIPTION
EUROPEAN THEATER NETWORK ANALYSIS MODEL
(ETNAM)

VOLUME I

USER'S MANUAL
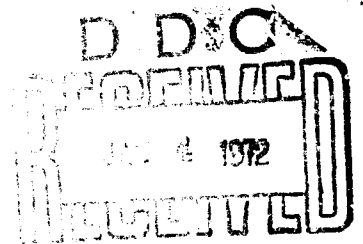
JANUARY 1971

PREPARED FOR LOGISTICS DIRECTORATE (J-4)

36

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FOR THE

LOGISTICS DIRECTORATE (J-4), JOINT STAFF

ABSTRACT:

1. This document provides a basic, non-technical introduction to the European Theater Network Analysis Model (ETNAM). It is intended to serve the analyst as a basic introduction and guide to the application of the ETNAM model to problems in strategic mobility. The kinds of information that can be obtained from the model are described in some detail as are both the capabilities limitations of the solution method. The types of input data necessary, the level of accuracy required and some possible sources of the data are discussed.

2. This document supersedes the Research Analysis Corporation's publication, "System Description, Part I - User's Manual," dated October 1969.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
inter theater mobility						
linear programming						
mathematical programming						
model, transportation network						
multicommodity						
network analysis						
problems, theater mobility						
strategic mobility						
theater mobility						
transportation network model						

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CHAPTER 1. INTRODUCTION

1. <u>General Introduction</u>. The System Description (SD) for the European Theater Network Analysis Model (ETNAM) has been prepared for the Defense Communications Agency (DCA) under contract DCA 100-70-C-0039, Modification #GO1, dated January 22, 1970. Submission of the System Description is in partial fulfillment of paragraph 3.2 of that modification.

a. <u>Division of System Description</u>. The System Description consists of four related parts, published in four volumes. Volume I is the User's Manual and is intended primarily for User Action Officers. Volume II is the Operator's Manual and is intended for the use by those responsible for running the model on either the CDC 6400 or IBM 360/65 computer. Volume III is the Analytical Manual and is intended for the use of analysts and programmers. Volume IV is the Data Base and is intended for those gathering and structuring data for the model.

b. <u>Supporting Material</u>. While it is intended that these manuals be capable of use independently, it should be noted that the Operational Capability Description (OCD) and the Capability Design Specifications (CDS) for ETNAM contain much additional information of value to both action officers and analysts. The OCD contains a detailed statement of the types of applications for which the ETNAM model has been designed. The Analytical Manual (particularly Enclosures 1, 2, 3 and 4) contains a detailed and rigorous mathematical statement of the algorithms used in the ETNAM model. This information is not repeated in the User's Manual.

c. <u>Organization</u>. The organization of this User's Manual is in accordance with the "Documentation Standards" (DCA Instruction 210-175-3) for this document. The order of the major headings and the information selected for inclusion have been based upon this Instruction.

d. <u>Intended Use</u>. This User's Manual is intended to provide a basic, non-technical introduction to the ETNAM model. It is intended to serve the analyst as a basic introduction and guide to the application of the ETNAM model to problems in strategic mobility. The kinds of information that can be obtained from the model are described in some detail as are both the capabilities and limitations of the solution method. The types of input data necessary, the level of accuracy required and some possible sources of the data are discussed. A potential user should be able to use this information to determine if the model can assist him in the analysis of specific problems.

e. <u>Limitations</u>. It should be noted at the outset, however, that this User's Manual will not be adequate in itself to prepare the user for the operation of the ETNAM model. The formulation of strategic mobility problems for ETNAM requires some basic familiarity with network terms and methods. Understanding of the solution algorithm of the model requires an understanding of some sophisticated mathematical techniques. It has been found in applications of the model to date that analysts can learn

the basic network terms and methods quickly and easily. Most users seem
to prefer to leave the actual operation of the computer programs to
specialists.

(1) The basic formulation of the problem to be solved and the
interpretation of the results should be carefully controlled by the user
himself. In the applications of the ETNAM model completed to date, those
with full user participation have been significantly more successful than
those conducted entirely by the model developers.

f. <u>Understanding ETNAM</u>. For many users the quickest and most suc-
cessful way to learn the uses of the ETNAM model is to study the formula-
tion and results of previous applications. A number of these test and
production cases are now available at the Research Analysis Corporation,
McLean, Virginia and at the Logistics Directorate (J-4), Office of Joint
Chiefs of Staff, The Pentagon, Washington, D. C. Five successful veri-
fication tests have been completed and a review of these tests will be
of considerable assistance to the potential user. A draft of the
"Verification Test Plan Results, ETNAM I," prepared by MAJ James R. Carnes,
(J-4), JCS, is available at the Research Analysis Corporation.

CHAPTER 2. OBJECTIVES

1. <u>Basic Objective</u>. The ETNAM model is a generalized model for the analysis of transportation networks. While it was designed specifically to handle the European Theater, it can be used to analyze the networks of any current theater of operation. Its basic objective is to determine the feasibility of movement plans and to determine the mobility resources required to fulfill such plans. There is also a wide variety of other analytical purposes that may be accomplished using the model.

   a. Intratheater strategic mobility analysis is concerned with both capacities and capabilities. Capacity is defined as the upper limit of throughput which is determined by the permanent or semi-permanent facilities of the transportation network. For example, a dock or wharf in a harbor has a certain rated capacity which means that, given the necessary resources of labor and equipment, a certain maximum amount of cargo can be unloaded in a given period of time. Thus a port has a rated capacity which is determined by the upper limits of all the various facilities which are necessary to the operation of the port.

   b. These capacities assume the availability of resources to operate the facilities. That is, capacity is not convertible to capability until the labor, equipment, and other resources are made available and allocated to the facilities. Similarly, capability must be in terms of specific commodities and cargo handling equipment. Both ammunition and bulk cargo may be unloaded through a particular port facility, but the capability to do so is dependent on the types of equipment available. The capability of a facility can be estimated accurately only in terms of specific commodities and cargo handling resources.

   c. Based on the definitions above, capability is the throughput that can be achieved subject to the constraints of both capacity and resource availability. Intratheater analysis must determine the capability of the theater transportation system based on the following basic inputs:

     (1) network capacities
     (2) resource availabilities
     (3) movement (delivery) requirements

In addition to these basic inputs, relative values (system costs) of the resources to be employed are required if the user wants to determine the least cost set of resources required to meet the requirements.

   d. Thus the basic objective of the ETNAM model is to determine the movement capability of a theater transportation system if the available resources are fixed; or, alternatively, to determine the resources required to achieve a particular capability if the delivery requirements are known. In addition to these basic types of information, the ETNAM model provides a number of analytical indicators of the characteristics of a theater transportation network.

CHAPTER 3. SYSTEMS SUMMARY

1. **Capabilities.** The ETNAM model consisted of four modules: Input,
RACAT, Output and POP (Post Optimal Package). The Resource Allocation
and Chain Analysis Technique (RACAT) is a mathematical algorithm devel-
oped by the Research Analysis Corporation for the ETNAM model. It is
the basic solution procedure for the system. The model can be run
using the maximum-flow, minimum-cost, minimum-time, or mixed minimiza-
tion of cost and time operating objectives.

   a. In general terms, the model will accept data on the road, rail,
waterway, pipeline, and air networks (including intermodal transfer
points); capacities of particular nodes in the network (if desired);
data on the productivity, inventory, resource prices, and (if des . .1)
restrictions on the use of mobility support forces; and the commodity
movement requirements of the plan being analyzed. Based on these inputs
the model will select routes and allocate resources to the network so as
to maximize flow, minimize cost, or minimize time in accordance with the
objectives of the user. The following outputs are available:

      (1) Routes selected from origins to destinations, the resources
allocated to these routes by commodity, and transit time for each route.

      (2) Summary of commodity flow and resources allocated to each
link used in the solution.

      (3) Summary of ton-mile flow by mode (if link capacities are
expressed in STONS).

      (4) Total flow over the network by commodity.

      (5) Total resources required to achieve the flow.

      (6) Workloads by commodity at specified nodes not to exceed 50.

      (7) Intermodal transfer points used in the solution, flow by
commodity, and resources allocated.

      (8) Shadow prices of links, nodes and resources which are used
to capacity. [The shadow price of a link, node or resource is the
additional flow (or the decrease in cost or time) which would result if
one additional unit of measure was available to the corresponding link
capacity, node capacity or resource inventory.]

   b. When the POP (Post Optimal Package) Module is used, an addi-
tional report shows the range of selected right-hand-side constraints
(taken one at a time while the others are held fixed at their given
value) within which the solution holds.

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c. Before examining each of the various operating objectives, certain features of the model which apply to all objectives shall be discussed. The basic purpose of the model is the selection of routes and the assignment of vehicles and other resources to these routes so as to optimize some measure of effectiveness. That is, the model is able to select a feasible set of paths connecting origins and destinations and assign the vehicles and other resources to these paths so that a quantitative measure of effectiveness is optimized. For example, cost or time may be minimized or flow maximized. Since the number of different resources which may be assigned is theoretically unlimited, there is a practical upper limit of fifty imposed by the size of the model.

2. **Maximum Flow.** The simplest operating objective is max-flow. When using this objective the model maximizes the flow which can be achieved through the network given the capacity limitations of the network and the capability of the resources. Requirements for each commodity at each destination are frequently set as limitations so that the program will not attempt to deliver more than the quantity required.

    a. It should be noted that while there is a maximum quantity which can be delivered, given the constraints, there is often a large set of alternative routes and vehicle assignments which will achieve this maximum flow. The program, run with the max-flow objective, must not have prices assigned to the resources.

3. **Minimum Cost.** If the resources to be allocated can be assigned relative prices, the program can find the set of routes and the allocation of resources which will minimize total cost. The available inventory of each type of resource may be set at a limit. Delivery requirements are set for each commodity and the program determines the allocation which will meet these requirements at minimum cost.

    a. When using this objective there is generally a single optimum solution. It is rare that there are alternative min-cost solutions. It should be noted that the min-cost solution is not independent of time. Since the quantity of a given resource used is a function of travel time, time is minimized for that resource.

4. **Minimum Time.** A variation of the min-cost objective is the min-time objective. Using the min-time objective, routes are selected and resources assigned so as to meet delivery requirements within minimum total ton-hours. Resource prices must not be assigned when the min-time objective is used. It should be pointed out that when the network constraints are given in equivalent units such as short tons, each commodity will have equivalent weight in the objective function. But when the constraints are in vehicles-per-time-period, the weights may vary considerably. In this case the flows are expressed in the natural units of the commodities and the objective function is the sum of the products of (commodity flow) x (travel time) over a route (e.g., Objective function = PAX · hours + barrel · hours + ton · hours + container · hours ...).

This objective function gives priority to the commodity with the smallest unit, that is the smallest in terms of the link capacity used.

5. **Mixed Minimization of Cost and Time.** The mixed minimization of cost and time objective is not a separate operating objective as far as ETNAM is concerned, but rather a problem formulation option that the analyst may use under the min-cost operating objective. Briefly, the method assigns time as a resource to be minimized along with the other applicable costs. For each commodity - transportation mode pair a time "productivity" is given. This is the amount of time it takes to move one unit of the specified commodity one mile on the specified transportation mode. A price is attached to the resource time. In a min-cost run, time is minimized to the extent that the total cost is minimized which depends on the prices of the other resources. It is not necessary to follow this procedure for all commodities. It is frequently the case that some commodities should be given time-priorities while others should be shipped via the least cost routes. For example, PAX and Unit Equipment might have elapsed time included as one of the resources used (and priced) while other commodities are handled in the usual min-time way. This approach would have the effect of placing PAX and Unit Equipment shipments on the most expeditious routes while the other commodities (e.g., POL) would be sent via the least cost routes without the time minimization consideration.

6. **Optional Features of the Model.** In addition to the standard features of the model (e.g., multi-commodity, resource allocation), the model has a number of special features that are available at the user's option. These optional features include: node constraints, vehicles-per-time-period link and node capacities, the Post Optimal Package (POP) and the substitution of resources.

    a. **Node Constraints.** In the "normal" use of the model, constraints are set on the links of the network. These constraints limit the traffic that may be assigned to a specific highway, rail, waterway, airway, transfer or pipeline link. It is sometimes desirable, however, to limit the traffic that passes through a node. For example, an analyst might wish to limit the traffic that passes through an intersection on the grounds that the intersection is vulnerable to enemy air attack. The ability to include up to fifty node constraints is built into the ETNAM system.

    b. **Vehicles-Per-Time-Period Capacity Constraints.** Link and node capacities are normally expressed in terms of tons-per-time-period. This method is used most often because the input data is most often available in that form and the use of tons-per-time-period capacities greatly reduces the calculations required. An alternative method of expressing capacities is by vehicles-per-time-period. The use of vehicles-per-time-period has the advantage of permitting the shipment of commodities in their natural units. For example, routes would be selected to ship actual people instead of equivalent tons of people. This would provide a more accurate and realistic description of the commodity movements.

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c. Post Optimal Package. The Post Optimal Package (POP) is a separate module which is run at the user's option to determine the range of values of link, node, resource and requirement right-hand-sides for which the optimal solution remains optimal. The only relationship between POP and the other three modules is the input file to POP, TAPE14, which is composed of selected data from the Input and RACAT Modules. POP is described in detail in the Analytical Manual.

d. Substitution of Resources. The substitution feature permits more than one combination of resources for a given arc-commodity pair. Examples of substitution situations are: dry cargo to be hauled by military truck or by commercial truck; POL to be hauled by tank truck or by stake and platform truck with POL containers; and air cargo to be flown via one of two different types of aircraft. When using the substitution option the program will select the routes and resource allocations which will optimize the objective functions. The substitution feature permits a more realistic allocation of resources. It is rare that the mix of existing resources precisely matches the requirements of a particular scenario. Specialized equipment for the handling of a commodity (e.g., tank trucks) should be allocated so as to maximize flow (or minimize cost) with the residual delivery requirements handled by other means.

7. Assumptions. The ETNAM model is based upon a special form of linear programming. It is a generalized, multi-commodity, static equilibrium network analysis model with resource constraints. While it is a generalized model (that is, it can "solve" any network problem of the proper form), there are a number of assumptions that are implied by the solution method. These assumptions are described below.

a. Linearity. The model assumes complete linearity in the use of resources, the capacity of links and nodes, and in the value of deliveries. For example, it is assumed that the resources required are precisely proportional to the quantity moved. If one truck company can move 483 tons of bulk cargo over a particular route in one day, it is assumed that precisely 1/483 truck companies are required to move one ton and 100/483 truck companies to move 100 tons over the same route. The solution procedure depends upon this assumption of linearity.

b. Static Equilibrium. The model is a static equilibrium model and does not directly account for the dynamic properties of a transportation system. Briefly, this means that the model deals with steady-state "pipeline" flows of goods over the routes and does not concern itself with the scheduling of individual vehicles or with changes in the composition of delivery requirements. Thus the model deals with a "snapshot" of the network in a single time-period. The resources allocated to a particular route are based on the number required to sustain a flow. Thus resources returning empty, in maintenance,

or awaiting unloading, must be included in the total number of resources required to sustain a flow over a route.

8. **Limitations and Restrictions.** Certain limits on variables have been established for purposes of ETNAM. In general, these limits and restrictions have been determined by the core storage available in the computers used and by the desire to create a model that is economical in its use of computer time. There is no theoretical limit to the number of variables allowed. For example, it is theoretically possible to build a model of this type that would handle 1000 origin-destination pairs. Computer programs do require precise dimensions, however, and an effort was made to set the limits at such levels that most practical problems can be accommodated. These limitations are as follows.

a. **Network Links.** The system will accommodate up to 700 links. These links may be of any mode; i.e., rail, highway, airway, transfer, etc.

b. **Nodes.** The user may set an upper limit on the flow through particular nodes. The maximum number of nodes which can be constrained is 50.

c. **Resource Types.** Up to 50 resource types are permitted. A resource type is defined as a mobile asset (e.g., a truck) required to accomplish flow over two or more links of the network.

d. **Substitution Groups.** Up to three alternative combinations of resources are permitted for each link-mode pairing.

e. **Movement Requirements.** Movements required by commodity, by origin-destination pair, may be specified up to 150 rows. These requirements may represent "fixed" demands between origin and destination or, alternatively, delivery requirements for certain commodities where the model will select the origins (the sources) of the commodity from a set of possible origins.

f. **Commodities.** A commodity is defined as a category of flow (people or material) that requires specialized transportation resources or has a special productivity rate. A limit of 20 different types of commodities (e.g., POL, PAX, dry cargo, etc.) has been established.

g. **Modes.** Transportation modes such as rail, highway, airway, transfer, pipeline, etc., may be specified in up to 20 types.

9. **System Hardware and Software.** The ETNAM system is currently programmed in FORTRAN IV for the Control Data 6400 computer installed at the Research Analysis Corporation and for the IBM 360/65 computer installed at the National Military Command System Support Center (NMCSSC) at the Pentagon.

a. Control Data 6400. The Control Data 6400 version of ETNAM
requires 150K (Octal) core storage (plus system requirements) and four
tape drives (plus system requirements). It uses the Input/Output
routine "LTRIO" and three small assembly language subroutines.

b. IBM 360/65. The IBM 360/65 version is completely disk oriented
and will operate on any 360/50 or 360/65 with "I" level core or larger.
The IBM 360 version uses no special routines or assembly language
subroutines.

10. System Interface. ETNAM is a model designed to provide a produc-
tion capability using the RACAT algorithm. The ETNAM model has been
converted for NMCSSC hardware. Although there is no automated inter-
face with other NMCSSC systems, there are a number of manual interfaces
with related systems (manual and mechanized).

a. The ETNAM system is generalized and hence it is possible to
obtain input data from whatever sources the user may prefer. In the
paragraphs that follow, the data sources used in the runs of the ETNAM
model to date are listed. This listing is intended as a guide only.

b. The network data used in ETNAM runs to date have come primarily
from the European Theater Transportation Study (ETTS), done by the
Research Analysis Corporation for J-4, the Mobility System Support Re-
sources (MSSR) Study runs done by J-4, DIA documents, and from previous
studies of RAC's Network Analysis Model (NAM). While NAM has been
superseded by ETNAM for muliticommodity runs, the technical paper "Simu-
lation and Gaming Methods for Analysis of Logistics (SIGMALOG): Network
Analysis Model", RAC TP-353, May, 1969 provides a detailed explanation
of the construction of a network.

c. Resource availability and productivity have also come from the
ETTS report. Additional data on the productivity of standard units
have been obtained from appropriate field and technical manuals.

d. Resource prices have been derived from ten-year systems cost
data developed by the Mobility Systems Support Resources (MSSR) Study
group. Additional information on resource productivities is also
available. Delivery requirements have generally been provided directly
by the user based upon Deployment Plan (DEPLAN) data. This data require-
ment would seem to be a potential area for automatic interface with
current data systems of the NMCSSC. The payoff in such a system would
be limited, since at most 150 data items are involved. In addition,
it has been found in the past that the users of the ETNAM system have
usually evaluated these data manually prior to entering it into the
ETNAM runs. In fact, it is of paramount importance that the user care-
fully check the input reports before proceeding to the RACAT Module.

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e.   Volume IV of the System Description, Data Base, provides the permanent and semi-permanent environmental data for the analysis of military mobility problems in selected theaters of the world. The user of the ETNAM model must develop his own problem-oriented data such as movement requirements, origins, and destinations. The Data Base should prove to be of invaluable assistance to the user provided that the manual is kept current. Table 1 lists the various data base elements and their sources.

11. <u>Macro Flow Chart</u>. Figure 1 is a General Flow Chart of the solution process for an ETNAM problem. A complete list of available output reports is included in Chapter 6 and shown in Enclosure 1.

a.   Figure 2 is a System Flow Schematic showing the four modules of the ETNAM system and their relationship. The files shown in this figure are described in the Analytical Manual.

b.   Figure 3 shows the deck arrangement for the ETNAM model. In problems run to date all input data have been entered on cards and the total deck has included less than one thousand cards.

TABLE 1. DATA ELEMENTS AND TYPICAL SOURCES

Data Element	Typical Sources
Link Distance*	Data Base - Maps
Link Capacity*	Data Base - DIA Documents
Link Condition*	Data Base - Generated by Analyst
Link Prices - Tolls	Generated by Analyst for Special Effects
Node Capacity	Generated by Planner
Mode Speed*	Data Base or as Function of Distance-Condition
Master Resource Vectors*	Data Base or Based on Theater Collected Data
Resource Inventories*	Data Base or From Theater Sources
Resource Prices	Study of Economic Data Necessary - Study Dependent
Movement Requirements*	Input from DEPLAN - GFE - POSTURE or From Theater
Origin-Destination Pairs*	DEPLAN or User Determined
Conversion Factors/Payload Factors	Generated by Analyst

*Items available in SD, Volume IV, Data Base
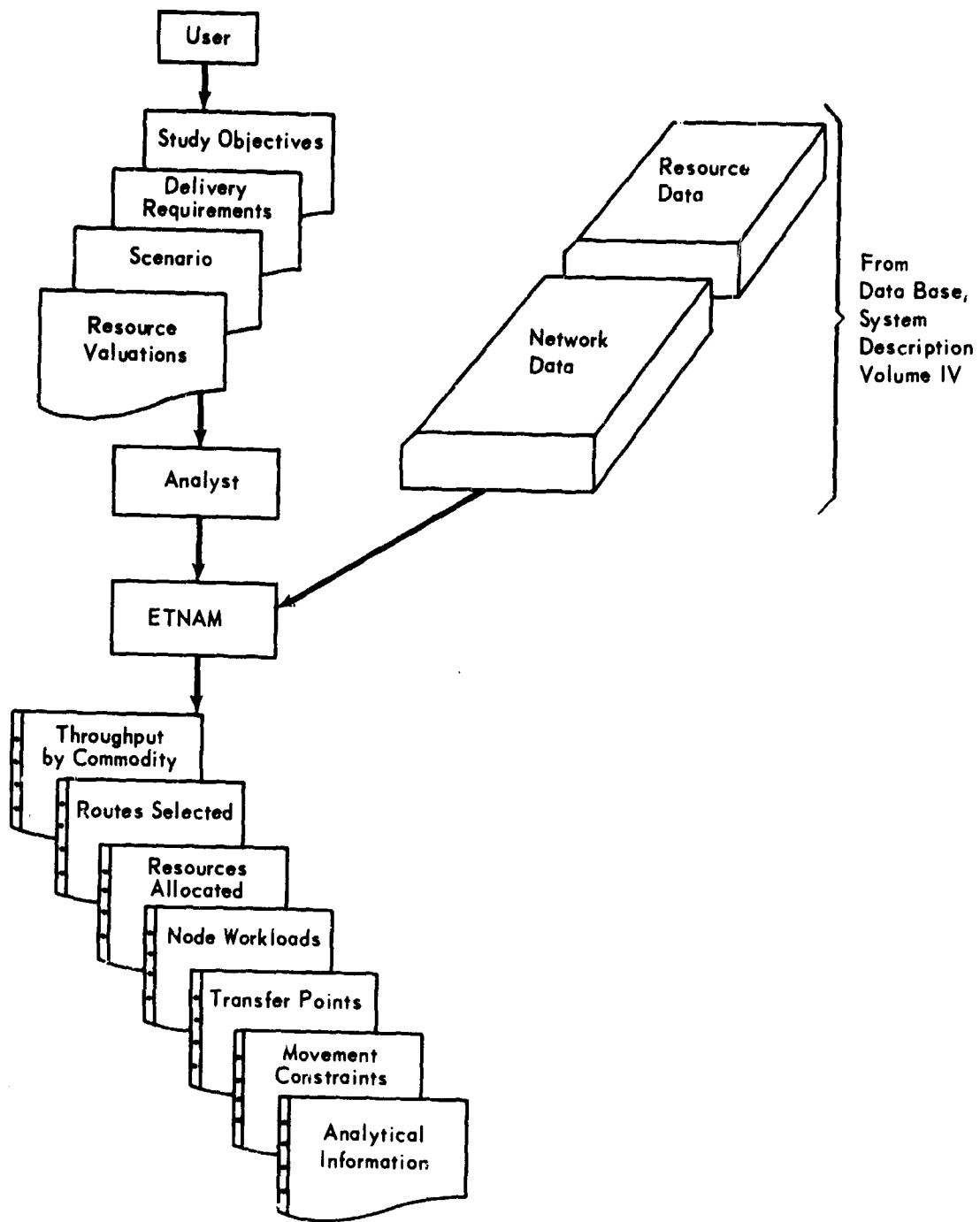
FIGURE 1. GENERAL FLOW OF THE SOLUTION PROCESS

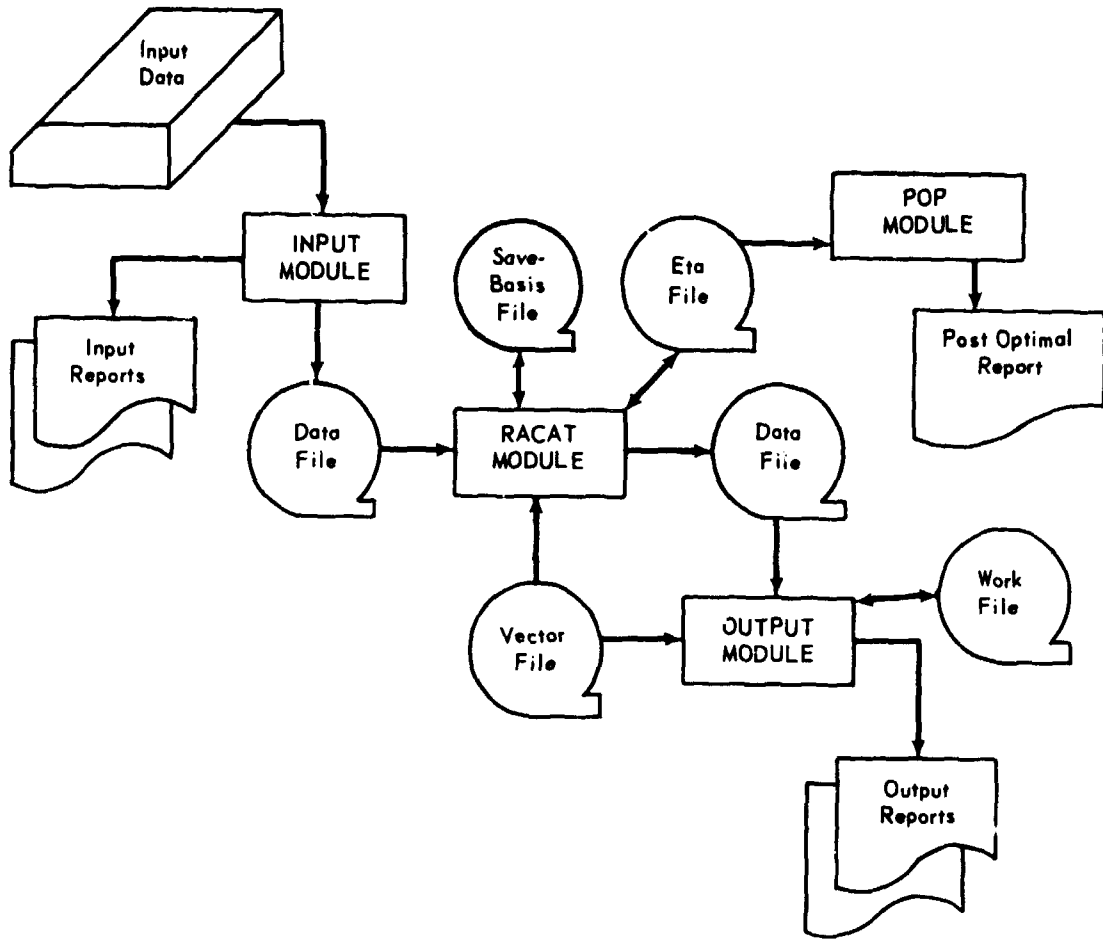FIGURE 2. ETNAM SYSTEM FLOW SCHEMATIC

END

Data Cards

POP MODULE
Programs

Data Card

OUTPUT
MODULE
Programs

Data Card

RACAT
MODULE
Programs

Input
Data

INPUT
MODULE
Programs

Systems Cards

Job Card
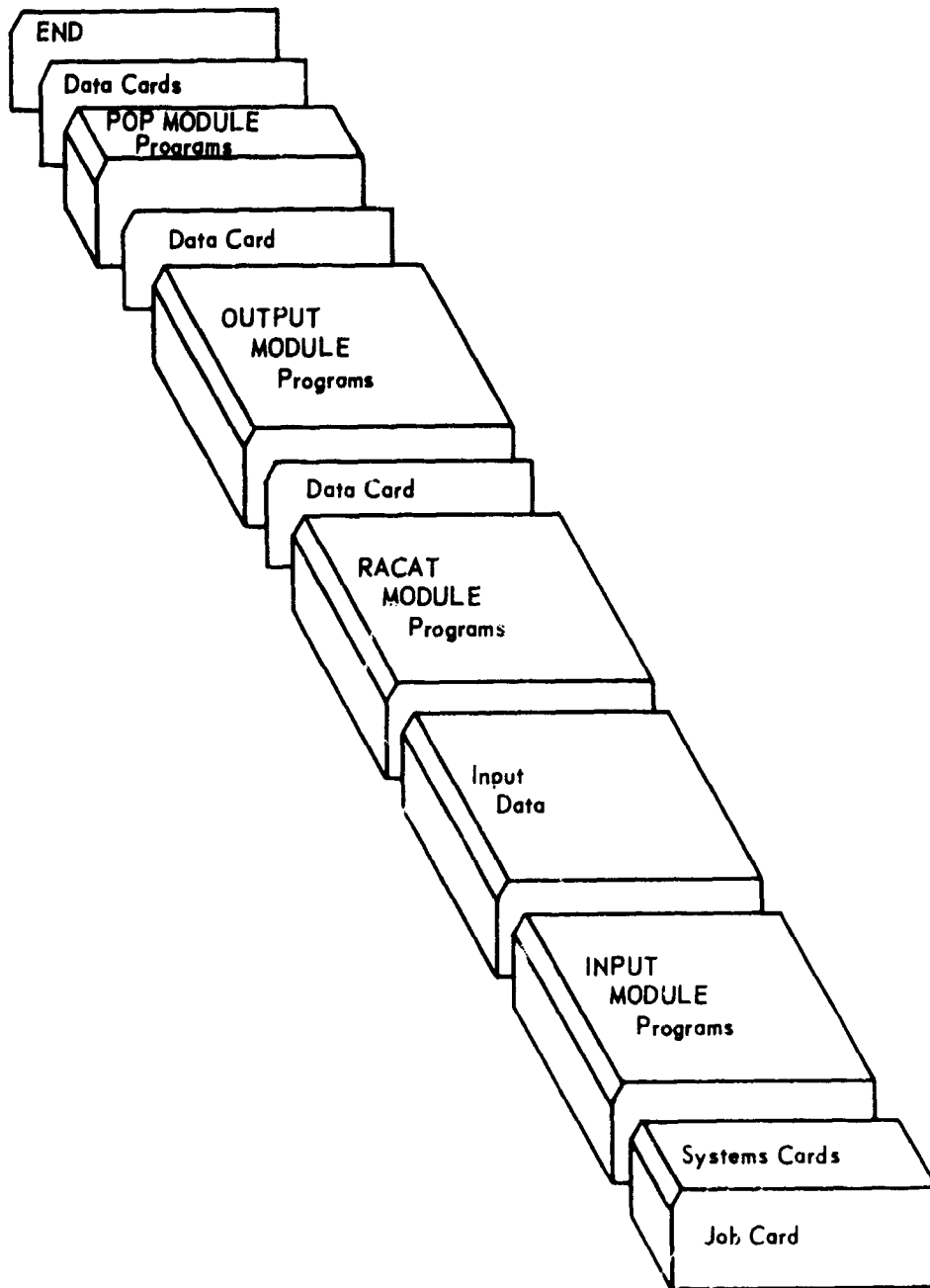
FIGURE 3. DECK ARRANGEMENT FOR ETNAM SYSTEM

CHAPTER 4. DATA FILES

1. <u>Purpose</u>. There are five data files created and used by the ETNAM system. These are as follows:

a. <u>Data File</u>. This binary file (TAPE1) is created by the Input Module and contains the input data, edited and formatted for use by the RACAT Module. It is a relatively small file in terms of volume and is created from scratch for each run of the ETNAM system.

b. <u>Vector File</u>. This file (TAPE2) is created by the RACAT Module. Each record is a binary representation of the routes and the resources assigned that are generated by the shortest chain algorithm and tested for use by the RACAT algorithm during the solution procedure. Not all such routes will be included in the final solution. This file is used by the Output Module to generate the output reports and by the RACAT Module when that module is restarted.

c. <u>Save-Basis File</u>. This file (TAPE9) is created by the RACAT Module and contains the record of the vectors in the basis and their location within the basis. While it is not necessary to generate this file, it is advisable to produce the Save-Basis File for ease of restarting the RACAT Module in the event that the optimal solution is not reached.

d. <u>Work File</u>. This file is created and used by the Output Module. It is solely a data processing file used when the solution data created by the RACAT Module are too voluminous to be handled by the available core storage in the Output Module.

e. <u>Eta File</u>. This file (TAPE14) contains a binary representation of the basis inverse for use in the linear programming solution procedure. The RACAT Module employs a mathematical procedure known as the "product form of the inverse" and the Eta File -- named for the Greek letter -- contains this data in binary form. The file is continuously updated throughout the operation of the algorithm.

f. <u>Post Optimal File</u>. This binary file (TAPE14) is the Eta File created by the RACAT Module with selected data from the Data File. This file is only used when it is desired to run the Post Optimal Package after obtaining the optimal solution.

g. <u>Temporary Files</u>. The Vector File, the Save-Basis File, and the Eta File are temporary work files for use during the solution of a single problem. None of them is updated or modified except automatically by the program in the course of a particular run. These files are described in detail in the Analytical Manual. The remainder of this chapter will therefore be concerned only with the Data File.

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2. <u>Data Element Definitions</u>. This section contains the definition of
the data elements required for the ETNAM system. The paragraph "System
Interface" in Chapter 3 described the sources of data used in the past
and currently available for ETNAM runs. Card formats and detailed des-
criptions of the method of preparing the data are given in the Analyti-
cal Manual. Table 2 lists the data elements by major heading and
indicates the requirements for these data by type of run. A discussion
of each data element follows.

    a. <u>Link Distance</u>. The distance between nodes in a network is
naturally defined for most highway, pipeline, waterway, airway, and
rail links as the physical distance to be traveled between nodes.
Transfer links between modes present a different problem in that the
actual physical distance may be quite small, but the time, effort, and
resources required to traverse the link may be large. In general the
distance traversed in the transfer link is set equal to 1. The time,
effort, and resources required to accomplish the transfer may be
represented by the condition data element described below.

    b. <u>Link Capacity</u>. The capacity of a link is defined to be the
maximum flow of all commodities or the maximum number of vehicles that
can be moved across a link in the given period of time. Capacities can
be given for a "sustained" rate and for a "surge" rate. The basic idea
behind this concept is that over a short period of time roads, rail
lines, etc., may be used to a greater extent than for a normal sustained
period of time. Eventually, however, the requirement for maintenance
will force the user to reduce flow down to the "sustained" rate.
Either rate may be used in the ETNAM System. It would seem logical to
use the sustained rate for the majority of analytical purposes. The
same comments apply to seasonal rates which are available in DIA reports.

    (1) Since most links are used for several commodities, it is
necessary to use a unit measure of capacity which can reflect all
commodities. In most network analyses, this unit has been short tons.
That is, the capacity of each link is expressed in short tons for a
period of time. This is accomplished through the use of commodity
conversion factors. It is sometimes confusing to speak of short tons
of passengers, but this is really simply a means to obtain a common
unit for comparison with capacity limits. Both passengers and cargo
are ultimately related to capacity in terms of the number of vehicles
required.

    (2) Another method of expressing link capacity is by vehicles-
per-time-period. This means that a link with a capacity of 200 can
accommodate a flow of 200 vehicles in a given period of time. By
using vehicles-per-time-period as a measure of link capacity it is
possible to express commodities in their natural units (i.e., numbers
of passengers, barrels of gasoline, tons of coal, etc.).

Table 2.

DATA ELEMENTS REQUIRED BY SOLUTION OBJECTIVE

Data element	Max-flow	Max-flow w/requirements	Min-cost	Substitution	Min-time	Mixed minimization
Link Distance	R	R	R	R	R	R
Link Capacity	R	R	R	R	R	R
Link Condition	R	R	R	R	R	R
Link Prices-Tolls	O	O	O	O	O	O
Mode Speed	O	O	O	O	R	O
Master Resource Vectors	R	R	R	R	R	R
Resource Inventories	R	R	O	O	R	R
Resource Prices		R	R	R		R
Movement Requirements		R	R	R	R	R
Origin-Destination Pairs	R	R	R	R	R	R
Conversion/Payload Factors	Conversion factors are required when using tons-per-time-period. Payload factors are required when using the vehicles-per-time-period.					
Node Capacities	(Optional for all solution objectives.)					

R - Required
O - Optional

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(3) If the unit of capacity is in terms of vehicles-per-time-period instead of short tons, then the commodity conversion factors are replaced by payload factors. The commodity conversion factors convert the requirements from natural units to short tons while the payload factors convert natural units to vehicles.

c. <u>Commodity Conversion Factors</u>. If the capacity of the links of the network is expressed in tons, commodity conversion factors are required to convert the commodity movement requirements into tons. For example, a barrel of POL is sometimes converted to tons by multiplying by 0.13. Note that some commodities, like ammunition, do not require conversion since they are usually expressed in tons.

d. <u>Payload Factors</u>. If the capacity of the links of the network is expressed in vehicles-per-time-period, payload factors are required to convert the commodity movement requirements into vehicle loads. If the substitution option is not used, payload factors are needed for every commodity-mode combination. For example, if the mode is highway and the commodity is ammunition we might find that the average payload per truck is fourteen tons when heavy (18 ton rated) tractor trailers are used. If the substitution option is used, we must provide a payload factor for every commodity, mode, and substitution group combination. If different vehicles are used in the substitution groups, then the payload factors must reflect this difference.

e. <u>Link Condition</u>. The link condition coefficient is used to express the difference between the quality of various links of the same mode and therefore the difference in resource requirements. The use of the link condition coefficient is perhaps best indicated by example.

(1) Two highways may connect city A and city B. One highway may be a four-lane, limited access, first quality road, while the other is a two-lane, secondary highway with poor surface condition. If both roads are of equal distance, it is clear that less resources will be required to sustain a given flow over the super highway than over the secondary road even though they are of equal length.

(2) The condition factor is provided to express this differing requirement for resources. Some experience will be required to determine the best method of assigning the condition coefficient. As a first approximation, however, the condition coefficient is proportional to the inverse of the average speed over the link. This is equivalent to making the use of resources proportional to the traversal time of the link. An example of this method was given in a previously published paper.[1]

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[1]See "An Evaluation of Various Extensions to the Resource Allocation and Chain Analysis Technique (RACAT) for the ETNAM", Research Analysis Corporation, 30 Aug 1968.

(3) It may be determined by some analysts that the condition coefficients should be set equal to unity for all links. This is equivalent to the assumption that resource costs are only a function of distance traveled and quantities delivered and are independent of condition. This would correspond to the common procedure in which a single average "miles in the hour" rate is used for all routes.

f. Link Tolls. The link toll is the price for the use of a link. It is anticipated that link tolls will not often be used to reflect actual costs of link use, but rather will be used for special analytical purposes.

(1) For example, consider a case where certain routes have already been established in a previous time period. The analyst may wish to place a penalty on the establishment of new routes. In such a case, he could assign tolls to the links not already established. The analyst may also wish to penalize certain links because of vulnerability or other reasons. He could assign a toll to these links and hence keep them out of the solution unless they were essential to the meeting of delivery requirements.

(2) It is anticipated that link tolls will be reserved for the use of the analyst and hence will not be collected as data.

g. Mode Speed. The average speed by mode is used in the ETNAM system to calculate link traversal times and the cumulative travel time for each of the routes selected. Mode speed is required for the minimum time objective and is optional for the other objectives. Since mode speed is used to calculate the elapsed travel time over an entire route which may take several days, mode speed should be calculated based on a twenty-four hour day. That is, mode speed (or miles-in-the-hour) should be calculated as the total distance covered in a twenty-four hour period including rest stops, refueling, etc., divided by twenty-four.

h. Node Capacity. The capacity of a node is defined to be the maximum flow of all commodities or the maximum number of vehicles that can be moved through a node in a given period of time. Frequently there are nodes which are points of intersection of three or more links. Since the nodes of intersection will be subjected to all the flows from their radial links, it might be necessary to impose an upper limit on the flow through the nodes of intersection. This might be required because of the physical limitations of the nodes or because of the vulnerability of the nodes and the desire to restrict the flow through them.

i. Master Resource Vectors. Link resource requirements are assigned by mode-commodity pair; i.e., a single master resource vector is established for each mobility mode and commodity. For example, if POL is a commodity there must be a POL/highway master vector which

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expresses the mobility resources required to sustain a unit flow of POL over a unit distance by highway. Obtaining master resource vector data is an important task, essential to the operation of the ETNAM system. Three alternative methods are suggested.

(1) One approach is to use the Field Manual and/or Technical Manual planning factors of the appropriate service to establish resource vectors. This method will simplify data gathering and would have the advantage that the planning factors would be consistent with official data.

(2) A second approach is to gather data in the theater (the ETTS Report will provide examples of some of these data) and prepare resource vectors based on the observed productivity rates.

(3) A third approach is to consult Volume IV, the Data Base, for the resource capabilities. This will be a good source of data provided that it has been kept current.

(4) It may be that a combination of these three alternatives will prove to be best.

j. Resource Inventories. The quantity available of each allocatable resource is a necessary data element. This may be the actual or planned inventory of these resources or may be some other figure established by the user as the upper limit of resources to be allocated. Using the max-flow objective, the quantity of resources available will often be the limiting factor. With the min-cost objective, it may be desirable for some analytical purposes to set available resources at high levels so as to permit the system to select the best set of resources regardless of current inventory levels. Thus the quantities to be input as resource inventories will vary widely depending on the analyst's purpose.

k. Resource Prices. Resource prices, as used in the ETNAM system, reflect the relative value of the allocatable resources. These prices are not necessarily procurement costs, but are the economic costs of obtaining and operating the resources in the theater. These prices must not be used to operate the model with its max-flow or min-time objective but are essential when using the min-cost objective.

(1) Prices are necessary simply because the various resources are not of equal value. If barges and trucks are priced equally, barges with their large capacity will be used to the limit of their ability, consistent with the constraints of the network. The vehicle with the greatest capacity would appear to be the best choice in every case. With a relative price assigned to each resource type, the allocation will be based on economic advantages.

l. __Origin-Destination Pairs__. Origin-destination pairs are essential to the operation of the ETNAM system for any of its objectives. Origin-destination pairs generally consist of a port (sea or air) and a destination. These pairs can be input as specific requirements, or origins may be linked together so that the system selects the best combination of origins to supply one or more destinations. The ETNAM system has the capability to select optimum routes for multiple origin-destination pairs. This feature should be used, therefore, whenever such routes are of value to the analyst.

m. __Movement Requirements__. Movement requirements are required by commodity and by destination for a minimization run. The level of detail (i.e., the number and types of these) of course, depends on the user's study objectives.

CHAPTER 5. SYSTEM UPDATE PROCEDURES

1. <u>Updating the System</u>. The ETNAM model has no files that are regularly updated in the usual sense. Each problem is set up and operated as an independent entity. Network and resource productivity data are relatively unchanging and hence these data are used with only minor changes from run to run within the same theater. These data are not voluminous, however. The typical problem has less than one thousand cards containing network and productivity data. The updating system for these data is, therefore, manual and there are currently no plans for the development of an automated system.

CHAPTER 6. JOB PREPARATION PROCEDURES

1. **Authorization Procedures.** The ETNAM model was developed for DCA/
J-4 and its use is coordinated through those organizations. Agencies
wishing to use the ETNAM model should first contact the Defense Communi-
cations Agency, National Military Command System Technical Support
(DCA/NMCSTS) Directorate to determine the procedure for obtaining
authorization for the use of the model.

2. **Operation of the Model.** The ETNAM model is currently programmed
in FORTRAN IV for the Control Data 6400 located at the Research Analysis
Corporation, McLean, Virginia and for the IBM 360/65 located at the
National Military Command System Support Center.

3. **Preparation of Input Data.** It is suggested that the following steps
be followed in the preparation of input data for the ETNAM model.

   a. **Network Data.** The first step in the preparation of input data
is the selection or the development of a network. Networks for several
theaters are available and can be found in Part Two of the Data Base.
These networks can be reviewed and can be adjusted to meet individual
requirements where desired. If a user desires to develop his own net-
work it is suggested that he refer to "Simulation and Gaming Methods
for Analysis of Logistics (SIGMALOG): Network Analysis Model", RAC-TP-
353, May, 1969. Chapters 2 and 3 of this paper describe the general
procedures for the development of transportation network data.

   b. **Resource Data.** The next step in the development of input data
is the collection of resource data. These data include resource pro-
ductivities, inventories, and systems costs. Part One of the Data Base
has data of this type that may be used as is or that may be modified for
use in future studies. In general, the user should plan to develop and/
or evaluate most of these data himself as the results are very sensitive
to them.

   c. **Conversion/Payload Factors.** Conversion factors for each commo-
dity must be determined by the user if the capacity of the links and
nodes are expressed in short tons. On the other hand payload factors
for each commodity-mode combination must be determined if the capacity
is expressed in vehicles-per-time-period.

   d. **Requirements.** The last major step is the development of delivery
requirements and origin-destination pairs. In general these data are
dependent upon the scenario of the problem to be studied and should be
carefully prepared.

   e. **Parameters and Controls.** The remaining data to be prepared
consist primarily of run parameters and analytical controls. These
inputs are best prepared in consultation with a technical analyst
familiar with the model. The Analytical Manual and the CDS contain
detailed technical descriptions of the inputs required.

f. _Input Formats._ Table 3 lists the Input Data Reports and Enclosure 1 contains the reports generated by the Input Module. These reports are simply the input data organized and formatted for easy checking and reference by the user. The Input Module can be operated independently of the other three modules of the system. It is recommended that these input reports be obtained and checked carefully by the user prior to the first operational run of the RACAT and Output Modules. Errors in the data are more easily seen in this more systematic form.

<div align="center">

TABLE 3. INPUT REPORTS

</div>

1. Run Summary
2. Rates of Speed by Mode
3. Commodity Identification
4. Network Listing
5. Table of Unique Nodes
6. Node Constraints*
7. Resource Prices and Inventories
8. Resource Productivities
9. Trip Payload**
10. Origin-Destination Data

*User specifies the nodes to be constrained.
**Shown if link capacities are expressed in vehicles-per-time-period.

CHAPTER 7. OUTPUT OPTIONS

1. <u>Output Reports</u>. The ten r⸺orts prepared by the Output Module are shown in Table 4. Those reports that are optional are so indicated. Enclosure 1 shows the formats for these reports. A brief explanation of the ten reports is given below.

TABLE 4. OUTPUT REPORT OPTIONS

1. Run Parameters
2. Summary of Network Flow, Ton-Mile Flow by Mode*
3. Summary of Mode X Flow - Optional
4. Movement Constraint Report - Optional
5. Route Report
6. Origin Workload Report - Optional
7. Destination Workload Report - Optional
8. Node Workload Report - Optional**
9. Summary of Commodity Flow - Optional
10. Summary of Resources Used - Optional

*Report generated only when link capacities are expressed in short tons.

**User specifies the nodes for which data is accumulated.

a. <u>The Run Parameter Report</u>. The Run Parameter Report is a brief summary of the most basic parameters used in the run and the value of the objective function at solution. The study objective, the number of substitutions, the number of modes, the number of commodities, the number of resources. the number of node constraints, and the type of capacity are shown. The number of iterations used by the RACAT Module in solving the problem and the value of the objective function are also shown. The value of the objective function is the total flow achieved, the total cost required, or the total ton-hours required depending on the study objectives -- max-flow, min-cost or mixed minimization, or min-time respectively. In addition, the report options requested by the user are presented.

b. <u>Summary of Network Flow and Ton-Mile Flow by Mode</u>. The Summary of Network Flow Report shows the total flow over each of the links in the network by commodity. Thus for any given link in the network the user can find the total flow by commodity over that link that results from all chains using it. The total flow, the capacity, and the residual are shown. The flow by commodity is also detailed. Only those commodities that are active are shown in the section of the report labeled, "Flow by Commodity...". Those links with zero flow, that is those links that were not used in the solution, are listed separately.

(1) Two potential areas of misunderstanding should be noted. Users have the option of making any of the links in the network "directed" or "undirected." That is, the user may specify whether flow is to

be permitted in only the indicated direction or in both directions.
If the link is designated as an "undirected" link the RACAT Module
may assign flow to move from the TO node to the FROM node. Further,
it is possible that a single link may have flow in one direction for
one commodity and in the opposite direction for another. This is quite
normal, particularly when distinct origin-destination pairs are used.
Thus it is not always possible to give precise meaning to the FROM and
TO nodes of a link. The actual direction of any flow is easily deter-
mined from the routes shown in the route report.

(2) A second area of possible misunderstanding is related to
the unit of the commodities moving on a link. When capacities are
expressed in short tons each commodity flow is shown in its specified
unit. For example, the commodity POL may be shown in barrels while
resupply is shown in short tons. The total flow in each case is shown
in equivalent short tons. Therefore, the total flow may not be the
sum of the flow by commodity. When capacities are expressed in vehicles-
per-time-period each commodity flow is shown in its specified unit.
However the total flow, the capacity, and the residual are shown in
vehicles-per-time-period.

c. Summary of Mode X Flow. This report is exactly like the Summary
of Network Flow Report except that it shows only those links of the
mode designated by the user. The basic idea behind this report is
that the user may be especially interested in the flows over links of
a particular mode. For example, analysts are often especially inter-
ested in the activity on transfer links. This report gives the user
the ability to obtain a special report detailing a particular mode.

d. Movement Constraint Report. This report shows the factors that
constrain the solution as found by the RACAT Module. For example,
using the max-flow objective certain links, nodes, and resources may
be the limiting factors on the total flow achieved. The Movement Con-
straint Report will list those constraining links, nodes, and resources
and will show the exact amount that the objective function could be
increased if the present limit on one factor was raised by one unit
while all other factors remained constant.

e. The Route Report. The Route Report is a detailed listing of
all the chains used in the solution, together with the flow assigned
to that route and the resources used to accomplish it. This report is
the most basic report of the series and may often be the most useful.
The report shows how the optimum flow meeting the requirements is
achieved through the actual selection of routes and the assignment of
resources to that route. The route number is assigned sequentially
simply for identification. Routes are listed in order by commodity.
The route flow, cumulative flow, and travel time for the route are
shown. The route nodes in order of their occurrence are then shown.
This, of course, permits the user to trace the exact route used. The

resources assigned to the route are shown for each route and for each commodity in total.

    f. <u>Origin Workload Report</u>. The Origin-Workload Report shows the flow by commodity out of each origin. Each node designated as an origin by the user in the input data is printed with its corresponding flow. If a node is both an origin and an intermediate node (on separate chains) only the originating flow will be reported.

    g. <u>Destination Workload Report</u>. The Destination Workload Report is identical to the Origin Workload Report except that the terminating nodes of chains are reported.

    h. <u>Node Workload Report</u>. The Node Workload Report is identical in format to the Origin Workload Report and the Destination Workload Report. The user may request that up to fifty nodes be included in the list. In certain studies, particularly vulnerability studies, it may be useful to know the flow by commodity passing through a particular node.

    i. <u>Summary of Commodity Flow</u>. The Summary of Commodity Flow Report summarizes the flow over the network by commodity. In min-cost, mixed minimization, and min-time runs these flows will correspond to the movement requirements. In max-flow runs these flows will be the maximum flow achieved, given the constraints of the network and the available resources.

    j. <u>Summary of Resources Used</u>. The Summary of Resources Used Report shows the total resources assigned to the network in order to accomplish the flow, the residual (unassigned) resources, and the routes to which these resources are assigned.

2. <u>Post Optimal Report</u>. When the Post Optimal Package (POP) is used a report is printed which shows the range of each right-hand-side value for which the solution is valid. Essentially a solution is a set of routes and the flows over those routes which will achieve the desired flow. The POP report shows how much the constraints can be varied (increased or decreased) without the necessity for changing the routes used.

CHAPTER 8. CODING AND DECODING TABLES

1. <u>Use of Tables</u>. Coding and decoding tables are not used in the ETNAM model.

SAMPLE REPORTS OF TEST PROBLEM

1. **Data for Sample Run.** The reports contained in this Enclosure represent the solution to a sample problem developed by the ETNAM study group for test purposes. Figure 4 is the network schematic used to generate the network data for the run. It is not drawn to scale. Specific parameters are listed below.

    a. **Modes.** Four modes are represented - highway, rail, transfer, and port discharge.

    b. **Commodities.** Two commodities are moved - dry and passengers.

    c. **Resources.** Five resource types are considered - stake/platform truck, bus, freight car, passenger car, terminal services company.

    d. **Node Constraints.** Two rail nodes are constrained.

    e. **Capacities.** The capacities of the links are expressed in vehicles-per-time-period.

2. **Run Reports.** The reports are for a minimum cost run with no tolls imposed on the links of the network. The various reports are listed in the following order: Input, Output, and Post Optimal Package reports. This sample problem is for illustrative purpose only and should not be used as a specific statement of the system capabilities.

Enclosure 1

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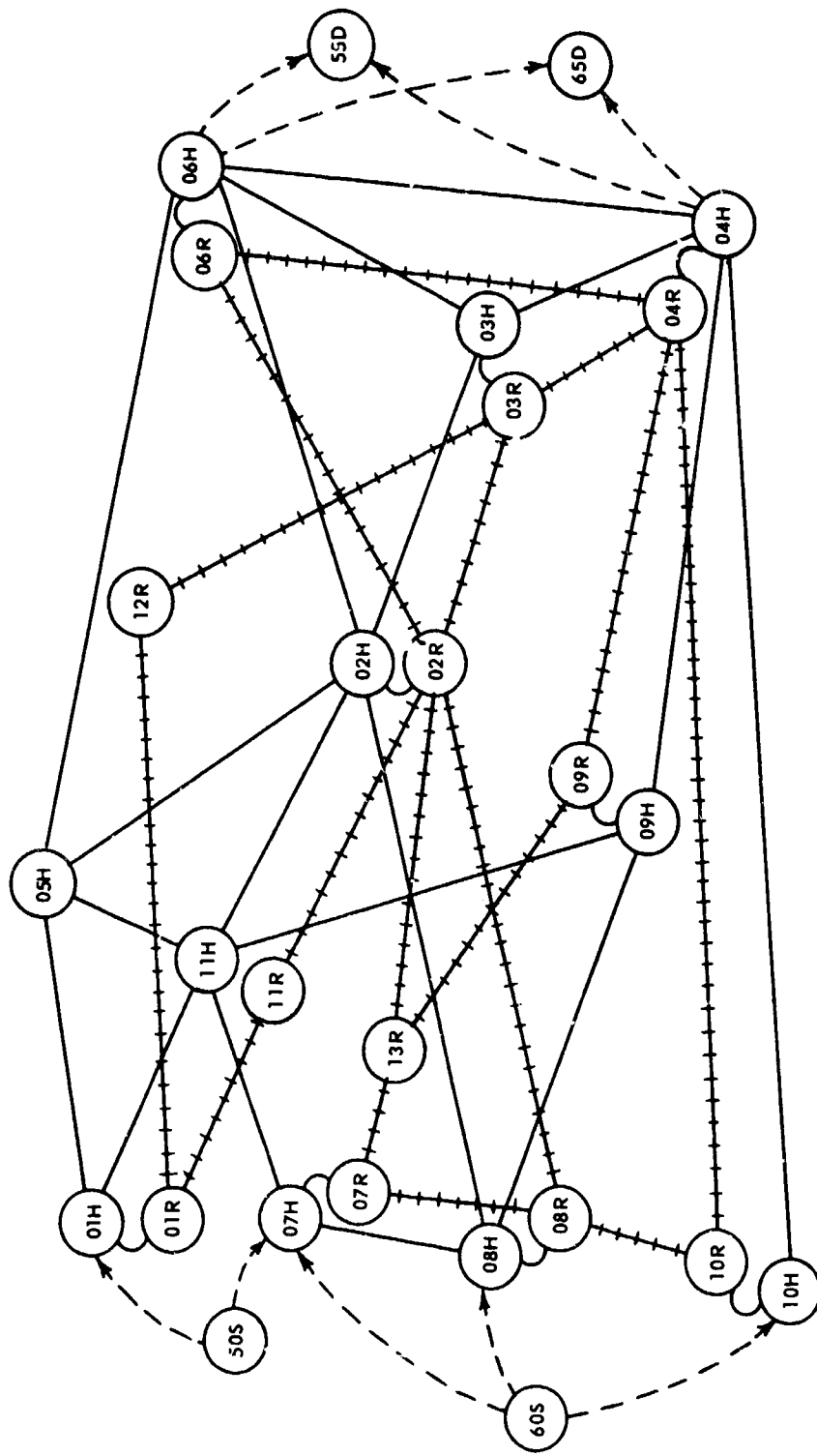
FIGURE 4. TEST NETWORK SCHEMATIC

MODE	LINK
Hiwy	————
Rail	+++++
Tran	⌒
Tran (port and depot)	— — —

ORIGINS	DESTINATIONS
50S	55D
60S	65D

...ETNAM I SAMPLE PROBLEM ... SEPTEMBER 1970

R U N   S U M M A R Y   R E P O R T

RUN PARAMETERS...

RUN MODE	NO. OF SUBSTITUTIONS	NO. OF MODES	NO. OF COMMODITIES	NO. OF RESOURCES	NO. OF NODE CONSTRAINTS	TRIPS	INVERSION COUNT	MAXIMUM ITERATIONS	NO. OF ROWS
MIN COST	1	4	2	5	2	YES	75	150	61

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...ETNAM I SAMPLE PROBLEM ... SEPTEMBER 1970

RATES OF SPEED BY MODE   MIN COST

MODE NO.	MODE NAME	SPEED
1	HIWY	15.00
2	RAIL	12.00
3	TRAN	.10
4	PORT	.20

...ETNAM I SAMPLE PROBLEM ... SEPTEMBER 1970   MIN COST

C O M M O D I T Y   I D E N T I F I C A T I O N   R E P O R T

COMMODITY NUMBER	COMMODITY NAME	CONVERSION FACTOR
1	DPY	NONE
2	PAX	NONE

NETWORK LISTING

LINK	FROM	TO	MODE	COND	DISTANCE	TOLL	CAPACITY	SYM AND COMMODITIES
1	01H	05H	HIWY	1.0	125.00	0.00	700.0	0000007
2	01H	11H	HIWY	1.0	90.00	0.38	700.0	0000003
3	01H	01P	TRAN	1.0	1.00	0.02	1.0	0000003
4	01R	11R	RAIL	1.0	95.00	0.00	700.0	0000003
5	01R	12R	RAIL	1.0	220.00	0.00	700.0	0000003
6	02H	06H	HIWY	1.0	190.00	0.00	200.0	0000003
7	02H	03H	HIWY	1.0	120.00	0.00	900.0	0000003
8	02H	02P	TRAN	1.0	1.00	0.00	1.0	0000003
9	02P	05R	RAIL	1.0	215.00	0.00	30.0	0000003
10	02P	03R	RAIL	1.0	135.00	0.00	700.0	0000003
11	03H	06H	HIWY	1.0	90.00	0.00	800.0	0000003
12	03H	03R	HIWY	1.0	140.00	0.00	700.0	0000003
13	03H	04R	TRAN	1.0	1.00	0.00	1.0	0000003
14	03R	04R	RAIL	1.0	95.00	0.00	700.0	0000003
15	04H	06H	HIWY	1.0	190.00	0.00	700.0	0000003
16	04H	55D	TRAN	1.0	1.00	0.00	1.0	4000001
17	04H	04P	TRAN	1.0	1.00	0.00	1.0	0000003
18	04P	06P	RAIL	1.0	215.00	0.00	700.0	0000003
19	04P	06H	HIWY	1.0	250.00	0.00	300.0	0000003
20	05H	11H	HIWY	1.0	105.00	0.00	400.0	0000003
21	05H	02H	TRAN	1.0	160.00	0.00	400.0	0000003
22	05H	05R	TRAN	1.0	1.00	0.00	1.0	0000003
23	06H	55D	TRAN	1.0	1.00	0.00	1.0	4000001
24	06H	07R	TRAN	1.0	1.00	0.00	1.0	4000003
25	07H	04H	HIWY	1.0	60.00	0.00	700.0	0000003
26	07H	11H	HIWY	1.0	85.00	0.00	700.0	0000003
27	07R	06R	RAIL	1.0	65.00	0.00	700.0	0000003
28	07R	13P	RAIL	1.0	70.00	0.00	1.0	0000003
29	08H	08R	TRAN	1.0	1.00	0.00	1.0	0000003
30	08H	02H	HIWY	1.0	190.00	0.00	400.0	0000003
31	08H	09H	HIWY	1.0	165.00	0.00	400.0	0000003
32	08P	02R	RAIL	1.0	200.00	0.00	700.0	0000003
33	08R	10R	RAIL	1.0	110.00	0.00	700.0	0000003
34	09H	09P	TRAN	1.0	1.00	0.00	1.0	0000003
35	09H	04H	HIWY	1.0	220.00	0.00	400.0	0000003
36	09P	04R	HIWY	1.0	250.00	0.00	50.0	0000003
37	10H	04H	HIWY	1.0	375.00	0.00	1.0	0000003
38	10H	10P	TRAN	1.0	1.00	0.00	1.0	0000003
39	10P	04P	RAIL	1.0	410.00	0.00	500.0	0000003
40	11H	09H	HIWY	1.0	150.00	0.00	500.0	0000003
41	11H	02H	HIWY	1.0	125.00	0.00	400.0	0000003
42	11R	02R	RAIL	1.0	140.00	0.00	700.0	0000003
43	12R	03P	RAIL	1.0	170.00	0.00	700.0	0000003
44	13P	09P	RAIL	1.0	115.00	0.00	500.0	0000003
45	13R	02P	RAIL	1.0	140.00	0.00	1.0	0000003
46	50S	01H	PORT	1.0	1.00	0.00	1.0	4000001
47	50S	07H	PORT	1.0	1.00	0.00	1.0	4000001
48	60S	07H	PORT	1.0	1.00	0.00	1.0	4000007

...ETNAM I SAMPLE PROBLEM ... SEPTEMBER 1978

MIN COST

N E T W O R K   L I S T I N G

LINK	FROM	TO	MODE	COND	DISTANCE	TOLL	CAPACITY	SYM AND COMMODITIES
51	60S	8AH	PORT	1.0	1.00	0.00	1.0	4000002
52	60S	10H	PORT	1.0	1.00	0.00	1.0	4000002

TOTAL NO. OF UNIQUE NODES   27

TABLE OF UNIQUE NODES

MIN COST

1	01H	2	01P	3	02H	4	02R	5	03H	6	03R	7	04H	8	04R
9	05H	10	06H	11	07H	12	07R	13	08H	14	08R	15	09H	16	09P
17	10H	18	10R	19	11H	20	11R	21	12R	22	13R	23	50S	24	60S
25	06R	26	55D	27	65D										

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...ETNAM I SAMPLE PROBLEM ... SEPTEMBER 1970

N O D E C O N S T R A I N T R E P O R T   MIN COST

NODE   MODE   CONSTRAINT

03R   RAIL   500.0
11R   RAIL   100.0

El-9

...E XAM I SAMPLE PROBLEM ... SEPTEMBER 1970

RESOURCE PRICES AND INVENTORIES BY TYPE

MIN COST

RESOURCE NO.	RESOURCE NAME	ACTUAL PRICE	NORMALIZED PRICE	INVENTORY
1	S/PL	7.00	7.00	100000.00
2	BUS	7.00	7.00	100000.00
3	FRTC	1.00	1.00	100000.00
4	PAXC	1.00	1.00	100000.00
5	TSC	2.00	2.00	100000.00

...ETNAM I SAMPLE PROBLEM ... SEPTEMBER 1970

MIN COST

R E S O U R C E   P R O D U C T I V I T I E S

COMMODITY IS DRY

TPRO = TOTAL PRODUCTIVITY BY MODE
TCOS = TOTAL COST OF RESOURCES BY MODE
(EXPRESSED IN INPUT UNITS)

MODE = HIWY
RES PROD -   S/PL=   .00100000   TPRO=   .00100000
RES COST -   S/PL=   .007000   TCOS=   .007000

MODE = RAIL
RES PROD -   FRTC=   .00104030   TPRO=   .00104000
RES COST -   FRTC=   .001048   TCOS=   .001048

MODE = TRAN
RES PROD -   TSC =   .0000300A   TPRO=   .00003000
RES COST -   TSC =   .000060   TCOS=   .000060

MODE = PORT
RES PROD -   TSC =   .00139000   TPRO=   .00139000
RES COST -   TSC =   .002780   TCOS=   .002780

E1-11

RESOURCE PRODUCTIVITIES

SUBSTITUTION GROUP NO. 1   COMMODITY IS PAX   TPRO = TOTAL PRODUCTIVITY BY MODE
TCOS = TOTAL COST OF RESOURCES BY MODE
(EXPRESSED IN INPUT UNITS)

MODE = HIWY
RES PROD - BUS = .0075960   TPRO= .0025000
RES COST - BUS = .001750   TCOS= .001750

MODE = RAIL
RES PROD - PAXC= .00008286   TPRO= .00008286
RES COST - PAXC= .000083   TCOS= .000083

MODE = PORT
RES PROD - TSC = .00000143   TPRO= .00000143
RES COST - TSC = .000083   TCOS= .000083

TOTAL NO. OF PRODUCTIVITIES = 7

...ETNAM I SAMPLE PROBLEM ... SEPTEMBER 1970

T R I P   P A Y L O A D   R E P O R T

MIN COST

SUBSTITUTION GROUP NO. 1

	HIWY	RAIL	TRAN	PORT
DRY	10.0	10.0	7000.0	10000.0
PAX	50.0	50.0	35000.0	5000. ɔ

ORIGIN - DESTINATION DATA REPORT

ORIGIN/DESTINATION PAIRS BY COMMODITY WITH DELIVERY REQUIREMENTS...

COMMODITY	DELIVERY REQUIREMENTS	ORIGIN	DEST.	REQUIRES	ORIGIN	DEST.	REQUIRES	ORIGIN	DEST.	REQUIRES	ORIGIN	DEST.	REQUIRES	ORIGIN	DEST.	REQUIRES
DRY	9080	1 505	550	9080												
PAX	13475	2 605	650	13475												

TOTAL NO. O/D PAIRS   2

NORDES ON TAPE FOR RACAT

1   23   26   60
2   24   27   61

E1-14

*** E T N A M   M O D E L ***

O U T P U T   R E P O R T S

...ETNAM I SAMPLE PROBLEM ... SEPTEMBER 1970

RUN PARAMETERS =

RUN MODE	NO. OF SUBSTITUTIONS	NO. OF MODES	NO. OF COMMODITIES	NO. OF RESOURCES	NO. OF NODE CONSTRAINTS	TRIPS
MIN COST	1	4	2	5	2	YES

SOLUTION REACHED IN   21 ITERATIONS

VALUE OF OBJECTIVE FUNCTION =   6170.708

REPORT OPTIONS SPECIFIED ARE...
0 0 0 0 0 0 0 0 0

** SUMMARY OF NETWORK FLOW **

/...TOTAL FLOW, CAPACITY, AND RESIDUAL ARE IN EQUIVALENT TONS OR TRIPS-FLOW BY COMMODITY HAS DIMENSIONS OF INPUT DATA.../

LINK NO.	NODES FROM 10	MODE	TOTAL FLOW	CAPACITY	RESIDUAL	FLOW BY COMMODITY....	
3 01H	01R	TRAN	.30	1.00	.78	DRY = 2079	
4 01R	11R	RAIL	148.00	700.00	520.00	DRY = 1800	
5 01R	12R	RAIL	28.00	700.00	672.00	DRY = 279	
6 02H	06H	HWY	97.50	200.00	182.50	DRY = 974	
8 02H	02R	TRAN	.14	1.00	.86	DRY = 974	
9 02R	06R	RAIL	70.00	30.00	.00	DRY = 380	
10 02R	03R	RAIL	472.00	700.00	226.00	DRY = 2525	PAX = 10974
14 03R	04R	RAIL	500.00	700.00	200.00	DRY = 2084	PAX = 10974
16 04H	55D	TRAN	1.00	1.00	.00	DRY = 6999	
18 04H	04R	TRAN	1.00	1.00	.00	DRY = 6999	
19 04R	06R	RAIL	350.00	700.00	350.00	DRY - 805	PAX = 13474
23 06H	06R	TRAN	.54	1.00	.46	DRY = 1105	PAX = 13474
24 06H	55D	TRAN	.30	1.00	.70	DRY = 2079	
25 06H	85D	TRAN	.38	1.00	.62	PAX = 13474	
26 07H	07R	TRAN	1.00	1.00	.00	DRY = 6999	
30 07R	13R	RAIL	700.00	700.00	.00	DRY = 6999	
31 08H	08R	TRAN	.31	1.00	.69	PAX = 10974	
34 08R	02R	RAIL	219.50	700.00	480.50	PAX = 10974	
38 09R	04R	RAIL	500.00	700.00	200.00	DRY = 4999	
48 10H	10R	TRAN	.07	1.00	.93	PAX = 2500	
41 10R	04R	RAIL	50.00	50.00	.00	PAX = 2500	
44 11R	02R	RAIL	148.00	700.00	520.00	DRY = 1800	
45 12R	03R	RAIL	28.00	700.00	672.00	DRY = 279	
46 13R	09R	RAIL	500.00	500.00	.00	DRY = 4999	
47 13R	02	RAIL	200.00	500.00	300.00	DRY = 1999	

** S U M M A R Y   O F   N E T W O R K   F L O W **

/...TOTAL FLOW, CAPACITY, AND RESIDUAL ARE IN
EQUIVALENT TONS OR TRIPS-FLOW BY COMMODITY
HAS DIMENSIONS OF INPUT DATA.../

LINK NO.	MODES FROM TO	MODE	TOTAL FLOW..	CAPACITY	RESIDUAL	FLOW BY COMMODITY....	
48	50S 01H	PORT	.21	1.00	.79	DRY =	2879
49	50S 07H	PORT	.70	1.00	.30	DRY =	6999
51	60S 08H	PORT	.22	1.00	.78	PAX =	10974
52	60S 16H	PORT	.05	1.00	.95	PAX =	2500

...ETNAM I SAMPLE PROBLEM ... SEPTEMBER 1970

MIN COST

** S U M M A R Y   O F   N E T W O R K   F L O W **

LINKS WITH ZERO FLOW

LINK NO.	NODES FROM	TO	LINK NO.	NODES FROM	TO	LINK NO.	NODES FROM	TO	LINK NO.	NODES FROM	TO	LINK NO.	NODES FROM	TO	LINK NO.	NODES FROM	TO	LINK NO.	NODES FROM	TO
1	01H	05H	2	01H	11H	7	02H	03H	11	03H	04H	12	03H	06H	13	03H	03R	15	04H	05H
17	04H	65D	28	05H	06H	21	05H	11H	22	05H	02H	27	07H	04H	23	07H	11H	29	07R	68R
32	08H	82H	33	08H	09H	35	08R	10R	36	09H	09R	37	09H	04H	39	10H	04H	42	11H	03H
43	11H	82H	50	60S	07H															

** S U M M A R Y   O F   T R A N   M O D E   F L O W **

/...TOTAL FLOW, CAPACITY, AND RESIDUAL ARE IN EQUIVALENT TONS OR TRIPS-FLOW BY COMMODITY HAS DIMENSIONS OF INPUT DATA.../

LINK NO.	MODES FROM	TO	TOTAL FLOW..	CAPACITY	RESIDUAL	FLOW BY COMMODITY....
3	01M	01R	.30	1.00	.70	DRY = 2079
8	02M	02R	.14	1.08	.86	DRY = 974
16	04M	550	1.00	1.00	.00	DRY = 6999
18	04M	04R	1.00	1.00	.00	DRY = 6999
23	06M	06R	.54	1.00	.46	DRY = 1105 PAX = 13676
24	06M	550	.30	1.00	.70	DRY = 2079
25	06M	650	.38	1.00	.62	PAX = 13676
26	07M	07R	1.00	1.00	.00	DRY = 6999
71	08M	08R	.31	1.00	.69	PAX = 10974
40	10M	10R	.07	1.00	.93	PAX = 2508

M O V E M E N T   C O N S T R A I N T   R E P O R T

ROW NO.		ROW TYPE		RIGHT-HAND SIDE	VALUE OF INCREASE (SHADOW PRICE)
9	02R	06R	RAIL	30.000	-11.064800
18	04H	04R	TRAN	1.000	-1565.200000
30	07R	13P	RAIL	700.000	-.468000
41	10R	04R	RAIL	54.000	-8.754860
46	13R	09R	RAIL	500.000	-8.724000
58		03P		500.000	-8.672000
59		11R		180.000	-.208000
60		DRY		9040.000	1.598160
61		PAX		13475.000	.226883

...ETNAM I SAMPLE PROBLEM ... SEPTEMBER 1970

R O U T E   R E P O R T

MIN COST

COMMODITY = DRY

$ = MOVEMENT CONSTRAINT ON LINK
- = NO MOVEMENT CONSTRAINT ON LINK

ROUTE NO. 1   LABEL= 1-125   ROUTE FLOW= 4195.00   CUM FLOW= 4195.0   TRAVEL TIME= 71.2
ROUTE NODES 50S   - PORT - 07H   - TRAN - 07R $ RAIL $ 13R $ RAIL $ 09R   - RAIL - 04R $ TRAN $
             04H   - TRAN - 55D
RESOURCES ASSIGNED FRTC 1897.82 TSC   6.21

ROUTE NO. 2   LABEL= 1-119   ROUTE FLOW= 1025.00   CUM FLOW= 5220.0   TRAVEL TIME= 71.7
ROUTE NODES 50S   - PORT - 07H   - TRAN - 07R $ RAIL $ 13R   - RAIL - 02R   - RAIL - 03R   - RAIL -
             04R $ TRAN $ 04H   - TRAN - 55D
CONSTRAINED NODES WHOSE CAPACITIES ARE SATURATED -- 03R
RESOURCES ASSIGNED FRTC 469.04 TSC   1.52

ROUTE NO. 3   LABEL= 1-111   ROUTE FLOW= 300.00   CUM FLOW= 5520.0   TRAVEL TIME= 72.5
ROUTE NODES 50S   - PORT - 01H   - TRAN - 01R   - RAIL - 11R   - RAIL - 02R $ RAIL $ 06R   - TRAN -
             06H   - TRAN - 55D
CONSTRAINED NODES WHOSE CAPACITIES ARE SATURATED -- 11R
RESOURCES ASSIGNED FRTC 140.40 TSC   .44

ROUTE NO. 4   LABEL= 1- 97   ROUTE FLOW= 1500.00   CUM FLOW= 7020.0   TRAVEL TIME= 73.7
ROUTE NODES 50S   - PORT - 01H   - TRAN - 01R   - RAIL - 11R   - RAIL - 02R   - RAIL - 03R   - RAIL -
             04R $ TRAN $ 04H   - TRAN - 55D
CONSTRAINED NODES WHOSE CAPACITIES ARE SATURATED -- 03R   11R
RESOURCES ASSIGNED FRTC 725.40 TSC   2.22

COMMODITY = DRY

$ = MOVEMENT CONSTRAINT ON LINK
- = NO MOVEMENT CONSTRAINT ON LINK

ROUTE NO. 5   LABEL= 1-153   ROUTE FLOW= 805.00   CUM FLOW= 7825.0   TRAVEL TIME= 39.2
ROUTE NODES 50S   - PORT - 07H   - TRAN - 07R $ RAIL $ 13R $ RAIL $ 09P   - RAIL - 04R   - RAIL -
             05R   - TRAN - 06H   - TRAN - 55D

RESOURCES ASSIGNED FRTC 544.18 TSC   1.19

ROUTE NO. 6   LABEL= 1- 94   ROUTE FLOW= 280.00   CUM FLOW= 8105.0   TRAVEL TIME= 75.4
ROUTE NODES 50S   - PORT - 01H   - TRAN - 01R   - Rail - 12P   - RAIL - 03R   - RAIL - 04R $ TRAN $
             04H   - TRAN - 55D

CONSTRAINED NODES WHOSE CAPACITIES ARE SATURATED -- 03R
RESOURCES ASSIGNED FRTC 141.23 TSC   .41

ROUTE NO. 7   LABEL= 1-111   ROUTE FLOW= 975.00   CUM FLOW= 9080.0   TRAVEL TIME= 65.2
ROUTE NODES 50S   - PORT - 07H   - TRAN - 07R $ RAIL $ 13R   - RAIL - 02R   - TRAN - 02H   - HWY -
             06H   - TRAN - 55D

RESOURCES ASSIGNED S/PL 185.25 FRTC 212.94 TSC   1.44

TOTALS FOR DRY COMMODITY ROUTES

TOTAL FLOW IS EQUAL TO   9080.0   USES   7 ROUTES
TOTAL RESOURCES ASSIGNED   S/PL   185.4   FRTC   4131.01 TSC   13.44

E1-22

...ETMAM I SAMPLE PROBLEM ... SEPTEMBER 1970

MIN COST

R O U T E   R E P O R T

COMMODITY = PAX

$ = MOVEMENT CONSTRAINT ON LINK
- = NO MOVEMENT CONSTRAINT ON LINK

ROUTE NO. 5   LABEL= 2-129   ROUTE FLOW= 2500.00   CUM FLOW= 2500.0   TRAVEL TIME= 87.1

ROUTE NODES 60S   - PORT - 10M   - TRAN - 10R $ RAIL $ 04R   - RAIL - 06R   - TRAN - 06H   - TRAN -
             65C

RESOURCES ASSIGNED PAXC 129.47 TSC   .00

ROUTE NO. 9   LABEL= 2-131   ROUTE FLOW= 10975.00   CUM FLOW= 13475.0   TRAVEL TIME= 8.7

ROUTE NODES 60S   - PORT - 08M   - TRAN - 08R   - RAIL - 02R   - RAIL - 03R   - RAIL - 04R   - RAIL -
             86R   - TRAN - 06H   - TRAN - 65D

CONSTRAINED MODES WHOSE CAPACITIES ARE SATURATED -- 03R

RESOURCES ASSIGNED PAXC 586.56 TSC   .02

TOTALS FOR PAX COMMODITY ROUTES

    TOTAL FLOW IS EQUAL TO 13475.0   USES   2 ROUTES

    TOTAL RESOURCES ASSIGNED   PAXC   716.02   TSC   .02

E1-23

...ETNAM I SAMPLE PROBLEM ... SEPTEMBER 1970

MIN COST

O R I G I N   W O R K L O A D   R E P O R T

ORIGIN FLOW BY COMMODITY...

50S   DRY = 9088

6CS   PAX = 13475

...ETNAM I SAMPLE PROBLEM ... SEPTEMBER 1976   MIN COST

D E S T I N A T I O N   W O R K L O A D   R E P O R T

DEST. FLOW BY COMMODITY...

550   DRY = 9088

650   PAX = 13475

El-25

...ETMAN I SAMPLE PROBLEM ... SEPTEMBER 1970   MIN COST

NODE   WORKLOAD   REPORT

NODE   FLOW BY COMMODITY...

13R   DRY = 7000

02R   DRY = 3800 PAX = 10975

03R   DRY = 2005 PAX = 10975

05H   NONE

E1-26

MIN COST

S U M M A R Y   O F   C O M M O D I T Y   F L O W

COMMODITY NO.	NAME	NUMBER OF ROUTES		TOTAL FLOW
1	DRY	1 -	7	9080.0
2	PAX	8 -	9	13475.0

F1-27

S U M M A R Y   O F   R E S O U R C E S   U S E D

RESOURCE	ASSIGNED	RESIDUAL	ROUTES								
S/PL	105.25	99814.75	7								
FRTC	4131.01	95868.99	1	2	3	4	5	6	7		
DAXC	716.92	99283.98	5	9	4	4	5	6	7	8	9
TSC	13.46	99986.54	1	2	3	3	5	6	7	8	9

...ETHAM I SAMPLE PROBLEM ... SEPTEMBER 1970

TYPE OF CONSTRAINT	RHS INTERVAL
ARCS	1 - 52
RESOURCES	53 - 57
NODE CONSTRAINTS	58 - 59
REQUIREMENTS	60 - 61

ROW NO.	RHS VALUE	TOTAL FLOW OR RES USED	LOWER BOUND VALUE	UPPER BOUND VALUE
1	700.000	.000	-.000	99999999.000
3	1.000	.297	.297	99999999.000
5	700.000	28.000	28.000	99999999.000
7	900.000	30.000	-.000	99999999.000
9	30.000	30.000	-.000	127.500
11	800.000	.000	-.000	99999999.000
13	1.000	0.000	-0.000	99999999.000
15	700.000	0.000	-0.000	99999999.000
17	1.000	.000	-.000	99999999.000
19	700.000	950.000	950.000	99999999.000
21	400.000	.000	-0.000	99999999.000
23	1.000	.543	.543	99999999.000
25	1.000	.395	.395	99999999.000
27	700.000	0.000	-0.000	99999999.000
29	700.000	0.000	-0.000	99999999.000
31	1.000	.314	.314	99999999.000
33	400.000	0.000	-0.000	99999999.000
35	700.000	0.000	-0.000	99999999.000
37	400.000	.000	-0.000	99999999.000
39	50.000	.000	-0.000	99999999.000
41	50.000	50.000	-.000	147.500
43	400.000	.000	-0.000	99999999.000
45	700.000	28.000	28.000	99999999.000
47	500.000	200.000	200.000	99999999.000
49	1.000	.700	.700	99999999.000
51	1.000	.229	.219	99999999.000
53	100000.000	185.250	185.250	99999999.000
55	100000.000	4131.010	4131.010	99999999.000
57	100000.000	13.458	13.458	99999999.000
59	180.000	150.000	30.000	203.000
61	13475.000	13475.000	8600.000	17500.000

ROW NO.	RHS VALUE	TOTAL FLOW OR RES USED	LOWER BOUND VALUE	UPPER BOUND VALUE
2	700.000	0.000	-0.000	99999999.000
4	720.000	180.000	180.000	99999999.000
6	200.000	97.500	97.500	99999999.000
8	1.000	.139	.139	99999999.000
10	700.000	472.000	472.000	99999999.000
12	700.900	0.000	-0.000	99999999.000
14	700.000	500.000	500.000	99999999.000
16	1.000	1.000	1.000	99999999.000
18	1.000	1.000	.543	1.000
20	300.000	0.000	-.000	99999999.000
22	400.000	0.000	-0.800	99999999.000
24	1.000	.297	.297	99999999.000
26	1.000	1.000	1.000	99999999.000
28	700.000	.000	-.000	99999999.000
30	700.000	700.000	597.500	700.000
32	400.000	0.000	-0.000	99999999.000
34	700.000	219.500	219.500	99999999.000
36	1.000	0.000	-0.000	99999999.000
38	700.000	500.000	500.000	99999999.000
40	1.000	.071	.071	99999999.000
42	500.000	0.000	-0.000	99999999.000
44	700.000	180.000	180.000	99999999.000
46	500.000	500.000	419.500	597.500
48	1.000	.208	.208	99999999.000
50	1.000	0.000	-0.000	99999999.000
52	1.000	.050	.050	99999999.000
54	100000.000	.000	-.000	99999999.000
56	100000.000	716.024	716.024	99999999.000
58	580.000	500.000	419.500	597.500
60	9080.000	9080.000	8800.000	10105.000
0	0.000	0.000	0.000	0.000

GLOSSARY

algorithm - A precise procedure, such as a computer program or routine, that will process certain well-defined inputs to obtain a solution or a particular result.

capability - The capability of a facility or process is defined as that portion of its capacity that is converted to throughput by the resources assigned to it. Capability is that throughput which can be achieved subject to the constraints of capacity and the availability of resources.

capacity - Capacity is defined as the upper limit of throughput for a fixed facility assuming that all necessary resources are available. For example, a wharf may have a rated capacity for loading and unloading which assumes the availability of the necessary resources.

chain - A series of links which, formed sequentially, define a feasible route from an origin to a destination. Normally, a chain is defined by node numbers. Synonym, path.

directed/undirected - Characteristics of an arc or link in a network where flow is allowed either one-way (directed) or two-way (undirected).

dynamic - Marked by continuous change which significantly affects the equilibrium of the process. A classic definition of a dynamic model states that every variable in the model must be dated.

edge - see link

graph - see network

link - A link is a component of a network which connects two nodes. Links are typically assigned capacity and distance values. Links can be used to represent a fixed transportation facility such as a road, rail line or air route. Links may also be used to represent a process such as unloading or manufacture. Synonym, arc, edge.

multi-commodity - In the context of this SD, this term describes the problem of moving many different types of goods (and troops) over a network between distinct origin-destination pairs. Each commodity may require distinct types of resources and must be clearly identified as it moves through the network.

network - A network is a set of nodes or points in space together with some subset of all possible links connecting the nodes to each other. Typically, a network will consist of a set of nodes with links between nearby nodes. A road map is an example of a network. Synonym, graph.

node - A node is one of the components of a network. A node is a
point in space, the intersection of one or more links. Typically
nodes in a network represent cities, road junctions, origins, des-
tinations or points on a link where the capacity or the resources
required changes. Synonym, vertex.

optimum - The best solution within some stated evaluation criteria.
Optimal solutions are obtained via optimization techniques such
as mathematical programming or methods of the calculus.

shadow prices - A feature of linear programming which provides infor-
mation as to the value of change in the objective function due to
an additional unit of a row constraint restricting the solution.
For example, a shadow price of a restricting link capacity would
indicate the increased flow possible (in a maximization problem)
given an additional unit of capacity on that particular link.
Synonym, simplex multiplier.

simplex multipliers - see shadow prices

static - Characterized by the equilibrium state. In terms of modeling
problems the important point is the stability of the equilibrium.
If the equilibrium is not easily upset by changes or if the system
moves directly to a new equilibrium state following a change, static
models are generally relied upon.

vector - In this SD a vector is defined simply as a series or list of
numbers, each one corresponding to a particular type of data. A
resource requirements vector, for example, would be a series of
numbers (some might be zero) indicating the quantity of each type
of resource required.

vertex - see node